PROGRESS IN CARDIOVASCULAR DISEASES 57 (2014) 19–31

Available online at www.sciencedirect.com

ScienceDirect

www.onlinepcd.com

Clinical Application of Three-Dimensional Echocardiography

Caroline Morbach[a,b], *Ben A. Lin*[a], *Lissa Sugeng*[a,*]

[a]*Yale University, New Haven, CT, USA*
[b]*Department of Internal Medicine I and Comprehensive Heart Failure Center, University of Würzburg, Würzburg, Germany*

ARTICLE INFO

Keywords:
Three-dimensional echocardiography
Valvular heart disease
Left ventricular function and right ventricular function

ABSTRACT

Echocardiography is one of the most valuable diagnostic tools in cardiology. Technological advances in ultrasound, computer and electronics enables three-dimensional (3-D) imaging to be a clinically viable modality which has significant impact on diagnosis, management and interventional procedures.
Since the inception of 3D fully-sampled matrix transthoracic and transesophageal technology it has enabled easier acquisition, immediate on-line display, and availability of on-line analysis for the left ventricle, right ventricle and mitral valve. The use of 3D TTE has mainly focused on mitral valve disease, left and right ventricular volume and functional analysis. As structural heart disease procedures become more prevalent, 3D TEE has become a requirement for preparation of the procedure, intra-procedural guidance as well as monitoring for complications and device function. We anticipate that there will be further software development, improvement in image quality and workflow.

Three-dimensional echocardiography (3DE) is a clinically viable tool used in transthoracic imaging to determine left and right ventricular (LV and RV) size and function. With the dawn of three-dimensional transesophageal echocardiography (3D TEE), this technology plays an integral role in interventional structural procedures due to the demands of imaging required for device placement. This review will provide a basic understanding of 3DE and its current clinical applications in cardiology.

Current technology

Equipment

In the early 1990s, 3DE was initially created as a series of two-dimensional (2D) images sequentially acquired from one window or non-sequentially obtained from multiple acoustic windows gated to ECG and respiration to reconstruct one 3D (three-dimensional) volume.[1–6] It necessitated a computer and specialized software in addition to an ultrasound machine. Initial work by Olaf von Ramm and colleagues using a sparse matrix array probe was one of the first steps to "real-time" 3D imaging.[7] Although many investigators used this technology, 3DE was primarily a research tool.

The introduction of a fully-sampled matrix array transducer was pivotal in establishing 3DE as an innovative technology used in our clinical routine today to improve diagnosis, provide accurate measurements and guide interventional procedures.[8]

To date, most ultrasound companies have ultrasound transducers that are capable of performing 2D, Doppler and 3D imaging due to improved manufacturing of crystals,

Statement of Conflict of Interest: none.

* Address reprint requests to Lissa Sugeng, MD, MPH, Associate Professor of Medicine, Yale School of Medicine, Section Cardiovascular Medicine, P.O Box 208017, New Haven, CT 06511.
E-mail address: Lissa.Sugeng@yale.edu (L. Sugeng).

http://dx.doi.org/10.1016/j.pcad.2014.05.005
0033-0620/© 2014 Published by Elsevier Inc.

Abbreviations and Acronyms

3D = three-dimensional

3DE = three-dimensional echocardiography

3D TEE = three-dimensional transesophageal echocardiography

2D = two-dimensional

LV = Left ventricle or ventricular

RV = right ventricle or ventricular

LA = left atrium or atrial

RA = right atrium or atrial

ECG = electrocardiographic

MPR = multiplanar reconstruction

MRI = magnetic resonance imaging

AVA = aortic valve area

LVOT = LV outflow tract

TAVR = transcutaneous aortic valve replacement

CT = computerized tomography

PISA = proximal isovelocity surface area

VC = vena contracta

MV = mitral valve

VHD = valvular heart disease

MVD = mitral valve disease

AV = aortic valve

TV = tricuspid valve

PV = pulmonic valve

MR = mitral regurgitation

MS = mitral stenosis

BMV = balloon mitral valvuloplasty

EROA = effective regurgitant orifice area

EF = ejection fraction

ERNA = equilibrium radionuclide angiocardiography

ICE = intracardiac echocardiography

efficient electronics and enhanced computer technology. These 3D imaging probes have more than 2500 elements arranged in a matrix and more efficient electronics, which enable simultaneous 2D imaging and immediate one-beat 3D volumetric imaging on-line.

Image acquisition

A decade after the first fully-sampled matrix probe was introduced, there are more vendors with 3D imaging technology. Hence, in general we will describe image acquisition broadly (Table 1). Electrocardiographic (ECG) gating is not necessary but certainly preferred. Acquisition of a 3D volume can be divided into a (1) single beat or (2) multi-beat acquisition. The volume that is acquired can be a partial volume focused on a defined region of interest such as a valve. To encompass a cardiac chamber such as the left or right ventricle, a wide-angled volume (90–110°) is preferable.

At the present time, all modes of acquisition in most systems can be a one beat acquisition. The sector size, depth, acquisition beats and zoom imaging influence temporal and spatial resolution. As one increases sector size and increases depth to allow a larger field of view, temporal and spatial resolution decrease. The zoom function, or narrowing the sector (lateral and elevational) width, will increase spatial and temporal resolution. To increase temporal resolution at the same sector size, a multi-beat acquisition should be acquired to achieve a higher volume rate (Fig 1).

Imaging of regurgitant jets or flow has been challenging but a one beat color flow Doppler solution is currently available. It provides the ability to view grayscale and color simultaneously. This imaging mode is limited by sector size. For example, to include the entire mitral valve and display a regurgitant jet, the user must choose a multi-beat (rather than one beat) acquisition due to a low volume rate.

The selection of the number of acquisition beats and mode of acquisition (volume) depends on the purpose of the study. Certainly, the highest volume rate with a sector width that includes the region of interest is always preferred. To determine LV function and volumes, a wide-angled sector is chosen to accommodate the LV. If the patient has atrial fibrillation, a single beat acquisition is best to avoid stitching artifacts that can occur with a multi-beat acquisition. When the object of interest is a valvular structure (the aortic or mitral valve), then a one beat acquisition and an appropriate sector width are chosen to optimize volume rate. A multi-beat acquisition is usually selected to achieve a high volume rate and high spatial resolution when breathing can be controlled by either a voluntary breath hold or transiently stopping the ventilator.

Acquiring good quality 3D images depends on good quality 2D imaging. Optimization of the 2D image is essential. Most settings such as overall gain, compress (opacification), brightness, colorization, and smoothing are all post-processing functions. However, the time gain controls (TGCs) should be optimized prior to acquisition since it is not available as a post-processing function. Placing the region of interest in the middle of the sector, strategic placement of focus and maximizing spatial and temporal resolution are key to obtaining an excellent 3D image.

Data processing

Once a volume data set is acquired, display and analysis of the data are required. In general there are 4 types of display: (1) wireframe, (2) surface-rendered image, (3) volume-rendered image, and (4) multiplanar images (2D slices within the volume). Wireframe reconstructions are derived from contours of ventricular or valvular tissue borders (Fig 2). Typically, there is no structural information but volumes, area, perimeter and distance measurements that can be derived from this. Surface-rendered images can be generated from wireframe reconstructions (Fig 2). This type of reconstruction enables us to appreciate structural shape and superimpose information on the surface such as timing of contraction or height of the surface. Volume-rendered images provide anatomic information and can be displayed in a standard orientation but also allow visualization from any view or angle to facilitate appreciation of specific structures. En-face views of an atrial septal defect, ventricular septal defect, or valve orifice are unique to 3D imaging. However, to fully appreciate 3D color flow multiple views are necessary. Multiplanar slices are used to measure distance, area, angle and perimeter. For instance, in the case of aortic stenosis, an aortic annular diameter is measured using multiplanar reconstruction (MPR) views. Futuristically, if MPR