Three-Dimensional Echocardiographic En Face Views of Ventricular Septal Defects: Feasibility, Accuracy, Imaging Protocols and Reference Image Collection

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Background: Ventricular septal defect (VSD) is the most common congenital cardiac anomaly. Accurate assessment is critical for planning treatment. Recent advances in three-dimensional (3D) echocardiography have improved image quality and ease of use.

Methods: The feasibility and accuracy of three specific 3D echocardiographic protocols to demonstrate en face views of VSDs were analyzed in a retrospective review of 100 consecutive patients. Sixty-four patients underwent transthoracic echocardiography and 36 transesophageal echocardiography. Types of VSDs included 34 muscular, 32 perimembranous, 18 malaligned, 11 inlet, four outlet, and one acquired. Ages ranged from 1 day to 77 years, and body weights from 3 to 92 kg. Three-dimensional echocardiographic full-volume mode with standard XYZ and adjustable plane cropping, 3D full-volume mode with iCrop, and narrow-sector live 3D protocols were compared for feasibility and accuracy to obtain a diagnostic-quality en face view of a VSD.

Results: The success rate for obtaining a high-quality en face image for the three protocols was 100% for full-volume mode with iCrop, 97% for full-volume standard mode, and 94% for narrow-sector live 3D mode. The ability of both full-volume mode with iCrop and full-volume standard mode to demonstrate a VSD was slightly better than that of narrow-sector live 3D mode ($P < .001$ for both vs narrow-sector live 3D mode). In all patients, the type, size, and location of the VSD were demonstrated accurately by two or more of the protocols.

Conclusions: Three-dimensional echocardiography of VSDs is feasible and accurate in most patients using defined protocols. The protocols are described and illustrated in detail, and a reference 3D image collection is presented. (J Am Soc Echocardiogr 2015;■:■-■.)

Keywords: Three-dimensional echocardiography, Ventricular septal defect

Isolated ventricular septal defect (VSD) is the most common congenital cardiac anomaly, with an incidence of approximately 3.5 per 1,000 live births.[1] VSDs are also commonly associated with other complex cardiac anomalies. There are six major types of VSD: perimembranous, muscular, inlet, malaligned, outlet, and acquired. Although many small perimembranous and muscular VSDs can be asymptomatic, larger defects and those associated with other cardiac anomalies often require surgical intervention.[2] Accurate assessment of these defects and the surrounding anatomy is critical for appropriate treatment planning.

Two–dimensional (2D) transthoracic echocardiography (TTE) and transesophageal echocardiography (TEE) are well established as reliable methods for initial diagnosis and intraoperative assessment of VSDs.[3-7] Initial reports of three-dimensional (3D) TTE and TEE have demonstrated their usefulness in evaluating the complex structure of VSDs.[8-32] These reports have shown novel views of VSDs and the surrounding structures that are not possible using 2D echocardiography.

Specific image acquisition and cropping protocols for en face views of VSDs have not yet been reported, compared, or widely applied in the clinical setting. The development of such protocols, analogous to those developed for 2D echocardiography, may facilitate the more widespread application of 3D echocardiography (3DE) for VSDs. We used 3D TTE and 3D TEE to evaluate 100 consecutive patients with VSDs in order to (1) determine feasibility and accuracy, (2) describe 3D echocardiographic protocols that reliably demonstrate en face views of VSDs, and (3) provide a collection of 3D echocardiographic reference images of the various types of VSDs.

METHODS

We studied 100 consecutive patients over a 6-month period who presented to our center with VSDs as isolated lesions or as part of more complex diagnoses. All echocardiographic studies were ordered

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Abbreviations

FViCrop = Large-sector full-volume 3D echocardiography plus iCrop mode

FVstd = Large-sector full-volume 3D echocardiography plus standard cropping mode

L3D = Live narrow-sector 3D mode

TEE = Transesophageal echocardiography

3D = Three-dimensional

3DE = Three-dimensional echocardiography

TTE = Transthoracic echocardiography

2D = Two-dimensional

VSD = Ventricular septal defect

for clinical indications, and complete 2D echocardiographic examinations were performed. Any patient with a VSD who underwent 2D TTE during the study period also underwent 3D TTE. Any patient with a VSD and body weight > 20 kg who underwent 2D TEE during the study period also underwent 3D TEE. All transesophageal echocardiographic studies were performed during either catheterization or surgical procedures. We considered 20-kg body weight to be a safe lower limit for the use of the 3D-capable transesophageal transducer. Three-dimensional TEE was not available for patients weighing <20 kg.

In addition to the standard clinical 2D echocardiographic protocol, 3DE was performed using a Phillips iE33 system and the appropriate 3D transthoracic (X5-1 and X7-2) or transesophageal (X7-2t) transducer (Philips Medical Systems, Andover, MA). Right- and left-side en face views of VSDs were obtained using three specific 3D echocardiographic protocols applied in an apical transthoracic or a midesophageal four-chamber view. Images were acquired using the iE33 system and acquisition processing and cropping software. Sixty-four patients underwent TTE and 36 TEE. None were excluded. Three-dimensional echocardiographic images were reviewed retrospectively with the reader blinded to the 2D echocardiographic, intraoperative inspection, cardiac catheterization hemodynamic and angiographic, cardiac magnetic resonance imaging (MRI) or magnetic resonance angiographic, and cardiac computed tomographic angiographic results of patients in whom those studies had been performed.

Description of 3D Echocardiographic Modalities

For anatomic assessment of VSDs, we used three different 3D echocardiographic methods: (1) large-sector full-volume 3DE plus standard cropping mode (FVstd), (2) large-sector full-volume 3DE plus iCrop mode (FViCrop), and (3) live narrow-sector 3D mode (L3D) with no additional cropping. All three methods are available for both TTE and TEE. Detailed descriptions of these techniques are as follows.

Three-dimensional full-volume mode consists of a large-sector 3D data set acquired using one to six heartbeats. A one-beat acquisition is an actual live 3D image, whereas the 3D data set in multiple-beat acquisitions is rapidly and automatically constructed in almost real time over two to six heartbeats. Individual live 3D segments are rapidly and automatically stitched together sequentially into a single large pyramid-shaped 3D sample volume.[33] Acquisition of the individual sectors is triggered by electrocardiography. It is very rapid reconstruction, not actual real-time imaging. This allows the acquisition of a large 3D sample volume that includes most cardiac structures in a single volume. It is stored as a full-volume sample and is immediately available on the echocardiographic machine for extensive postacquisition cropping. Unfortunately, the electrocardiographically triggered rapid sequential reconstruction is prone to motion artifacts whereby the individual samples are stitched together because of respiratory motion or rapid heart rate. This problem can be mitigated using specific methods. After an initial learning curve, a 3D data set can be consistently acquired in <1 min. For analysis of a VSD, a four-beat full-volume acquisition usually provides the best balance between volume rate, resolution, and stitch artifact. The 3D full-volume data set is then cropped using standard cropping or iCrop to demonstrate the important information.

Standard cropping is a method in which the 3D echocardiographic data set is positioned within a cube. Any or all six sides of the cube (X, Y or Z planes) can be positioned to remove extraneous 3D echocardiographic data to reveal the important 3D echocardiographic information. These crop planes have their orientations fixed in the X, Y, and Z planes. If required, an additional cropping tool called adjustable plane cropping can be added. This tool provides for the placement of one or more oblique crop planes. Together, XYZ and adjustable plane cropping constitute what we refer to as standard cropping.

The iCrop mode, a more recently developed method of cropping, allows the placement of an adjustable crop box within the 3D data set. The data within the crop box are included, and the data outside the box are cropped away. The operator adjusts the size, position, and rotation of the box and selects from which of the six sides of the box to view the 3D data set. Although this method is rapid and easy to apply, the sonographer must be cognizant of the fact that the resolution is dependent on the viewing direction because of the inherent different resolutions with axial > lateral > elevation plane spatial resolution.

Narrow-sector live 3D mode, like full-volume 3DE, is an acquisition mode. When using the default one-beat acquisition setting, it provides live actual real-time imaging, with no reconstruction required. A narrow wedge-shaped 3D sector of adjustable size, position, and view aspect is manipulated to demonstrate the important information. The sector size and position are adjusted using lateral and elevation plane controls for width and position. The view aspect is controlled using the 3D rotation tool. When done properly, little or no cropping is required for L3D images. L3D usually provides the highest volume rate and overall resolution of the 3D acquisition modalities. However, it has a relatively small sector volume and must be adjusted by the sonographer to include the structure of interest entirely within the 3D sample volume.

Both of the 3D acquisition modes (full-volume 3D and L3D) and the cropping modes (standard and iCrop) are selected and controlled with typical echocardiographic machine touchpad, dial, and trackball controls. Multiple echocardiographic parameter adjustments can be made at the time of acquisition and during postacquisition processing, including gain, contrast, smoothing, image algorithms, color adjustments, color depth shading adjustments, and rotation throughout 360° in all planes. Image manipulation, cropping, and quantification can be performed on the iE33 ultrasound platform or on the digital storage and review station using dedicated software (Philips Medical Systems).

Three-Dimensional Echocardiographic VSD Protocols

Transthoracic 3D images were obtained from the standard apical four-chamber view. Transesophageal 3D images were obtained from the four-chamber midesophageal view.