Aortic Root Geometry in Patients with Aortic Stenosis Assessed by Real-Time Three-Dimensional Transesophageal Echocardiography

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Background: The authors hypothesized that aortic root geometry is different between bicuspid and tricuspid aortic stenosis (AS) that can be assessed using real-time three-dimensional (3D) transesophageal echocardiography. The aims of this study were (1) to validate the accuracy of 3D transesophageal echocardiographic measurements of the aortic root against multidetector computed tomography as a reference, (2) to determine the difference of aortic root geometry between patients with tricuspid and bicuspid AS, and (3) to assess its impact on pressure recovery.

Methods: In protocol 1, 3D transesophageal echocardiography and contrast-enhanced multidetector computed tomography were performed in 40 patients. Multiplanar reconstruction was used to measure the aortic annulus, the sinus of Valsalva, and the sinotubular junction area, as well as the distance and volume from the aortic annulus to the sinotubular junction. In protocol 2, the same 3D transesophageal echocardiographic measurements were performed in patients with tricuspid AS (n = 57) and bicuspid AS (n = 26) and in patients without AS (n = 32). The energy loss coefficient was also measured in patients with AS.

Results: In protocol 1, excellent correlations of aortic root geometric parameters were noted between the two modalities. In protocol 2, compared with patients without AS, those with tricuspid AS had smaller both sinotubular junction areas and longitudinal distances, resulting in a 23% reduction of aortic root volume. In contrast, patients with bicuspid AS had larger transverse areas and longitudinal distances, resulting in a 30% increase in aortic root volume. The energy loss coefficient revealed more frequent reclassification from severe AS to moderate AS in patients with tricuspid AS (17%) compared with those with bicuspid AS (10%).

Conclusions: Three-dimensional transesophageal echocardiography successfully revealed different aortic root morphologies between tricuspid and bicuspid AS, which have different impacts on pressure recovery. (J Am Soc Echocardiogr 2014;27:32-41.)

Keywords: Three-dimensional echocardiography, Aortic root geometry, Bicuspid aortic stenosis, Tricuspid aortic stenosis, Transcatheter aortic valve replacement

With growing aging populations in industrialized nations, symptomatic patients with severe calcific tricuspid aortic stenosis (AS) with high surgical risk are more likely to be referred for transcatheter aortic valve replacement (TAVR).[1,2] The accurate determination of aortic root geometry before TAVR is related to the rate of successful procedures without complications.[3]

Multidetector computed tomography (MDCT) has been the preferred method for the evaluation of aortic root geometry in patients with tricuspid AS who are candidates for TAVR.[4-6] However, controversy exists regarding aortic root remodeling in tricuspid AS using MDCT.[7,8] Because of the concern of radiation exposure, risk for contrast-induced nephropathy, relative contraindication of atrial fibrillation, and contraindication of hypersensitivity to iodine contrast agents, three-dimensional (3D) transesophageal echocardiography (TEE) has emerged and been demonstrated reliably to evaluate aortic root geometry as an alternative or complement to MDCT.[9,10]

Although the severity of AS is usually determined by aortic valve area (AVA) using the continuity equation,[11] there is a risk for overestimation if correction for pressure recovery is not performed, especially in patients with small aortas.[12-14]

We hypothesized that aortic root geometry is different between tricuspid AS and bicuspid AS, which could have a significant impact on pressure recovery and appropriate strategies for TAVR procedures.

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Abbreviations

AS = Aortic stenosis

AVA = Aortic valve area

AVA_{2DCE} = Two-dimensional aortic valve area by the continuity equation

ELCo = Energy loss coefficient

MDCT = Multidetector computed tomography

STJ = Sinotubular junction

TAVR = Transcatheter aortic valve replacement

TEE = Transesophageal echocardiography

3D = Three-dimensional

2D = Two-dimensional

Accordingly, the aims of this study were (1) to validate the accuracy of 3D transesophageal echocardiographic measurements of aortic root geometry against MDCT as a reference, (2) to compare aortic root geometry between patients with tricuspid and bicuspid AS, and (3) to assess how different changes in aortic root geometry can affect pressure recovery phenomena between the two groups.

METHODS

Study Subjects

In protocol 1, we retrospectively enrolled 40 patients who underwent both coronary MDCT and 3D TEE within 1 month. All patients had received coronary MDCT to diagnose coronary artery stenosis. Patients had also undergone 3D TEE for various indications. Patients who were allergic to iodine contrast agents and those at high risk for contrast nephropathy were excluded. In protocol 2, 57 patients with tricuspid AS and 26 with bicuspid AS who underwent clinically indicated 3D TEE were consecutively enrolled from April 2008 to May 2012. Because it was impossible to enroll strictly normal subjects for 3D TEE as a control group, 32 patients undergoing 3D TEE to determine the source of embolisms (n = 28) or to evaluate cardiac masses in the right heart chamber (n = 4) during the same time window who were subsequently diagnosed to have normally functioning aortic valves were selected as a non-AS group for the comparison of aortic root geometry. The study was approved by the ethics committee at the University of Occupational and Environmental Health hospital, and written informed consent was obtained from all patients at the time of 3D TEE.

MDCT

The multidetector computed tomographic examinations were performed using a 64–detector row scanner (Aquilion 64; Toshiba Medical Systems, Tokyo, Japan). A nonionic iodinated contrast agent (Iopamiro 300; Bayer Healthcare, Osaka, Japan) at 1 mL/kg (4 mL/sec) was injected into the antecubital vein, followed by a 30-mL saline bolus. Image acquisition was triggered by the appearance of contrast in the aortic root. Imaging parameters included a gantry rotation time of 350 msec with 5 mm per rotation, tube voltage of 120 kV, and tube current of 500 mA. Scan data were then reconstructed at a slice thickness of 0.5 mm with 0.5-mm slice resolution using retrospective electrocardiographic gating from end-diastole (0% of the RR interval) to late diastole (90% of the RR interval) at 10% steps. All patients had taken an oral β-blocker (atenolol 25 mg) in the morning of the day of MDCT.

3D TEE

Three-dimensional TEE was performed using a commercially available ultrasound imaging system (iE33; Philips Medical Systems, Andover, MA) with a 3D matrix-array transesophageal transducer (X7-2t; Philips Medical Systems). After induction of topical pharyngeal anesthesia and intravenous sedation, the transesophageal echocardiographic probe was advanced into the esophagus. From the midesophageal position, a long-axis two-dimensional (2D) view (135°) of the aortic valve was obtained. The 3D zoom mode, which displays a smaller magnified pyramidal volume, was subsequently activated to image the aortic root. Using a biplane image, the size of the pyramidal box was adjusted to ensure that the entire aortic root from the aortic annulus to the sinotubular junction (STJ) were included in the scan volume. Gain and compression, as well as time gain compensation, were optimized. Three-dimensional zoom data sets with one-beat acquisition during two consecutive cardiac cycles were stored digitally.

2D Transthoracic Echocardiography

Because the highest jet velocity across the aortic valve in patients with AS is not usually obtained using TEE, we obtained continuous-wave Doppler–derived peak velocity across the aortic valve and pulsed-wave Doppler velocity at the left ventricular outflow tract on 2D transthoracic echocardiography performed as close in time as possible to 3D TEE (median examination time interval, 7 days; range, 0–68 days). To measure peak velocity, multiple locations of continuous-wave flow velocity measurements were performed to acquire the highest velocity across the aortic valve.

MDCT Measurements of the Aortic Root

Measurements of the aortic root parameters were performed in the coronal, single-oblique sagittal, and double-oblique transverse views extracted from 3D multidetector computed tomographic data sets, as previously described.[9] For measurements of AVA, the frame showing maximal opening of the aortic valve was selected (usually the frame at 20% or 30% of the RR interval), and AVA was manually traced in the double-oblique transverse view. For measurements of the aortic annulus, sinus of Valsalva, and STJ, the double-oblique transverse view was realigned to be perpendicular to the long axis of the aortic root at the desired level, and its boundaries were manually traced (Figures 1A–1C). For the measurement of aortic root volume, 14 equidistant cutting planes orthogonal to the long-axis view were applied from the aortic annulus to the STJ in two long-axis views of the aortic root. The aortic root volume was calculated using a summation of slice area times slice width. The distance from the annulus to the coronary orifice was measured at the end-diastolic frame (0% or 90% of the RR interval) because of easy visualization of the relationship between the two structures. The left coronary artery ostium was identified in the oblique coronal reformation views oriented orthogonally to the plane of the aortic annulus. The right coronary artery ostium was identified on oblique sagittal reformation views. Measurements were performed from the lower part of each ostium to the aortic annulus, perpendicular to the annulus (Figures 1D and 1E). These measurements were performed using commercial software (zioTerm2009; Ziosoft Inc, Tokyo, Japan).

3D TEE Measurements of the Aortic Root

From the zoomed 3D data sets, two orthogonal long-axis views of the aortic root (anterior-posterior and medial-lateral projections) were extracted using the multiplanar reconstruction mode (Figure 2-1). A third plane perpendicular to both of the long-axis planes was