Aortic root morphology in patients undergoing percutaneous aortic valve replacement: Evidence of aortic root remodeling

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Objective: Percutaneous aortic valve replacement is an emerging therapy for selected patients with severe aortic stenosis. Preoperative imaging of the aortic root facilitates sizing and deployment of the percutaneous aortic valve replacement device. We compared morphologic characteristics of the aortic root in patients with aortic stenosis versus elderly gender-matched controls using multidetector computed tomography.

Methods: Twenty-five consecutive subjects with severe calcific aortic stenosis referred for percutaneous aortic valve replacement and 25 elderly gender-matched controls were scanned on a Siemens Definition Dual Source (Siemens Medical, Forchheim, Germany) multidetector computed tomography scanner. Distances from the valve annulus to the coronary artery ostia and sinotubular junction, dimensions of the aortic root, and characteristics of the valve cusps were determined.

Results: Subjects with aortic stenosis had reduced distance from the aortic valve annulus to the inferior margins of the left and right coronary artery ostium and sinotubular junction compared with controls. There were no significant differences in cross-sectional dimensions of the aortic root.

Conclusion: The distance from the aortic valve annulus to the coronary artery ostia and sinotubular junction is reduced in patients with aortic stenosis compared with controls. This finding suggests that longitudinal remodeling of the aortic root occurs in calcific aortic stenosis and has implications for the design and deployment of percutaneous aortic valve replacement devices.

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Percutaneous aortic valve replacement (PAVR) is an emerging therapy for selected patients with severe aortic stenosis (AS) who may not be candidates for conventional surgical valve replacement because of multiple comorbidities.[1-4] Detailed knowledge of aortic valve and aortic root morphology, including the longitudinal distance from the aortic annulus to the coronary arteries and annular diameters, is important for preprocedural planning and device deployment.

However, our understanding of the complex 3-dimensional anatomy of the aortic valve and aortic root in calcific AS is incomplete. Although there is currently no uniform method for the evaluation of the aortic valve and root before PAVR, a combination of transthoracic or transesophageal echocardiography and fluoroscopy is typically used. Both standard echocardiography and fluoroscopy, however, are limited in their ability to evaluate the 3-dimensional characteristics of the aortic root, as well as the relationship of the aortic valve cusps to the coronary ostia. In contrast, high-resolution interactive datasets obtained with multidetector computed tomography (MDCT) provide detailed anatomic information of the aortic valve and root, including their 3-dimensional relationship.[5-9] Additional cine computed tomography (CT) images (''4-dimensional'') allow limited correlation between anatomy and function.

We hypothesized that dimensions of the aortic root are decreased and that its relationship to the coronary artery ostia is altered in patients with AS. By using MDCT, we therefore evaluated morphologic characteristics of the aortic root in patients with calcific AS versus elderly gender-matched controls.

MATERIALS AND METHODS

Study Design and Patient Selection

We enrolled a total of 50 subjects, including 25 consecutive subjects with calcific degenerative AS who were referred for PAVR because of a high risk of mortality with conventional aortic valve replacement, and 25 elderly gender-matched historical controls referred for coronary CT angiography for evaluation of chest pain. In accordance with current exclusion criteria from PAVR trials, patients with congenital unicuspid or bicuspid aortic valve, prior valvular heart surgery, mixed aortic valve disease (AS and aortic insufficiency with $\geq$ 3+ aortic insufficiency), greater than or equal to 3+ mitral insufficiency, or abdominal or thoracic aortic aneurysms greater than 5.0 cm were excluded. In addition, patients with relative contraindications for MDCT, including atrial fibrillation or advanced renal insufficiency, were excluded. Data collection and analysis were performed with approval by the institutional review board.

Multidetector Computed Tomography

Subjects were scanned on a Siemens Definition Dual Source MDCT scanner (Siemens Medical, Forchheim, Germany) after administration of a non-ionic, iodinated contrast agent (80–100 mL Ultravist 370, Bayer Healthcare, Berlin, Germany) at 4 to 5 mL/sec followed by 30 to 50 mL

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Abbreviations and Acronyms

AS = aortic stenosis
CT = computed tomography
MDCT = multidetector computed tomography
PAVR = percutaneous aortic valve replacement

of normal saline at the same rate. A contrast bolus monitoring technique[10] using a region of interest in the ascending aorta was used to determine the scan delay time. Once the desired attenuation (determined visually by the technologist) was reached, scanning was initiated in the craniocaudal direction during a single inspiratory breath-hold. Patients referred for PAVR were scanned from the level of the carina to the mid-left ventricle. Control patients who underwent coronary CT angiography were scanned from the level of the carina to the diaphragm. Control patients also received intravenous metoprolol (mean dose 11 ± 3 mg) and sublingual nitroglycerin 0.3 mg before study acquisition as part of their examination protocol. Spiral data were acquired with retrospective electrocardiogram gating using the following parameters: gantry rotation time = 330 ms; beam collimation = 32 × 0.6 mm; tube voltage = 120 kV; tube current-time product per rotation = 250 to 410 mAs/rot; and beam pitch = 0.2 to 0.5. Electrocardiogram-based tube current modulation was used for all patients with a reduction in tube current by 80% during systolic phases. Images were reconstructed during 10 to 14 phases of the cardiac cycle depending on patient heart rate with a temporal resolution of 83 ms and section thickness of 0.75 mm. The average effective radiation dose was approximated for each patient after scanning by multiplying the dose-length product and a conversion factor for the chest.[11]

Data Analysis

Images were analyzed by consensus of 2 investigators on a dedicated CT workstation (Siemens Leonardo, Siemens Medical) equipped with Circulation and InSpace software. The largest cross-sectional diameters of the left ventricular outflow tract, aortic annulus, sinuses of Valsalva, and sinotubular junction were measured in systole (20%–30% phase) using double oblique images to identify the true short axis (Figure 1). The aortic valve annulus was defined at the lowest level of the insertion of the valve cusps into the aortic root;[12] the maximal diameter at this point was determined as the maximal aortic valve annulus diameter. The annulus was defined as oval if the difference between the minimal and maximal cross-sectional diameters of the annulus was greater than 3 mm. The maximum diameter of the sinus of Valsalva was determined from measurements extending from each commissure to the middle of the opposite coronary cusp. The sinotubular junction was measured at the junction of the sinuses and tubular portion of the ascending aorta. The vertical distances from the aortic valve annulus to the inferior margins of the left coronary artery ostium, right coronary artery ostium, and sinotubular junction were measured in systole and end diastole from oblique coronal views (Figure 2). Measurements were made in areas of minimal calcification to minimize the effect of calcium blooming artifact from calcified aortic valves. In a subset of 4 patients who underwent MDCT scanning after PAVR, we also measured the distance from the superior aspect of the device to the coronary artery ostia in systole. Leaflet height was defined as the longest length of the cusp from the annulus to the cusp tip and was measured in diastole (70% phase) from the long-axis view going through the center of each cusp (Figure 3). Effective cusp height was defined as the vertical distance from the annulus to each cusp tip and was measured in diastole from the long-axis view through the center of each cusp[13] (Figure 3). Cusp-free margin length was measured in diastole from the short-axis view (Figure 4).

Aortic valve opening in the AS group was described qualitatively and quantitatively. The systolic valve orifice was examined on short-axis cine CT reconstructions and described as either symmetric and star-shaped or asymmetric. Quantitatively, the aortic valve area was determined by planimetry of the aortic valve using a plane parallel to the short axis of the aortic root. The time point of maximal aortic valve opening was identified during systole (usually at 20%–30% of the R-R interval). The area of the aortic valve opening was found by scrolling through the short-axis images toward the tip of the cusps until the smallest opening was found. The planimetered aortic valve area was determined by tracing the inside borders of the coronary cusps with electronic calipers and reported in square centimeters.

Transthoracic Echocardiography

All measurements were performed using a standard sonographic system equipped with a 3.5 to 1.75-MHz transducer by an experienced observer. The peak and mean transvalvular velocities were measured in all patients using standard echocardiographic views. In addition, the aortic valve area was calculated using the continuity equation approach with a Doppler velocity-time integral.[14] The mean and peak transvalvular pressure gradients were calculated. Left ventricular ejection fraction was determined using Simpson's method.[15] Measurement of the aortic valve annulus was performed from the parasternal long-axis view from the point of insertion of the cusps into the aortic root.

Statistical Analysis

All values presented are the mean ± standard deviation for continuous variables and as the percentage of total patients for categoric variables. The independent sample *t* test and chi-square or Mann–Whitney test were used for comparison of continuous and categoric variables, as appropriate. All *P* values were 2 sided. Calculations were performed with the Statistical Package for the Social Sciences version 12.0 (SPSS Inc, Chicago, Ill).

RESULTS

We enrolled a total of 50 patients (56% were male), with 25 patients in each group. The effective radiation dose was approximated as 12 ± 5 mSv for the AS group and 10 ± 3 mSv for the control group. There was no significant difference between the AS and control groups in age (79.7 ± 8.1 years vs 76.0 ± 6.7 years, respectively; $P = .07$) or baseline left ventricular ejection fraction (49% ± 15% vs 48% ± 13%, respectively; $P = .80$). Compared with controls, patients with AS had a worse New York Heart Association functional class (2.8 ± 0.7 vs 1.6 ± 0.7; $P < .01$). The logistic euroSCORE was 28% ± 14% for the AS group. Detailed baseline clinical characteristics for both groups are shown in Table 1.

Aortic Root Longitudinal Dimensions

Compared with the control group, the AS group showed a reduced distance from the aortic valve annulus to the left coronary artery ostium (13.4 ± 3.2 mm vs 15.6 ± 2.7 mm; $P = .01$). There was a similar reduction in the distance from the aortic valve annulus to the right coronary artery ostium in the AS group compared with the control group (13.6 ± 2.8 vs 15.2 ± 2.5 mm; $P = .04$). The longitudinal distance from the aortic valve annulus to the sinotubular junction was also reduced in the AS group compared with the control group (16.7 ± 2.0 vs 21.0 ± 2.3 mm; $P < .01$). Similar changes were observed for these variables during both systole and diastole (Table 2). In the subset of 4 patients