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A correlative study of aortic valve rotation angle and thoracic aortic sizes using ECG gated CT angiography

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ABSTRACT

Objective: Various degrees of aortic valve rotation may be seen in individuals with no history of congenital cardiovascular malformations, but its association with aortic sizes has not been studied.
Methods: Gated computed tomographic (CT angiograms in 217 patients were studied (66.7 ± 15; 22–97 years old)). Aortic diameters were determined at 5 anatomic locations. The length of the aorta from sinus to left subclavian artery was measured. The angle of valve rotation was recorded by measuring the angle between a line connecting the midpoint of the non-coronary sinus to the anterior commissure and another line along the interatrial septum. Rotation angles were correlated with aortic measurements. Patients were separated into two groups based on aortic sizes and into three groups based on age. The threshold for aortic dilatation was set at maximum ascending aorta diameter ≥40 mm (≥21 mm body surface area [BSA] indexed).
Results: No significant difference in rotation angles was seen between the three age groups or between genders. Rotation angles were significantly correlated with maximal, average, and BSA adjustment of the aortic root and ascending aortic measurements. The aortic root angles were significantly different between the dilated versus nondilated aortas. There was no significant association between the rotation angles and age, length of ascending aorta, or diameters of descending aorta. Multivariate adaptive regression splines showed 25° of aortic root rotation as the diagnostic cut off for ascending aorta dilation. Above the 25° rotation, every 10° of increasing rotation was associated with a 3.78 ± 0.87 mm increase in aortic diameter ($p < 0.01$) and a 1.73 ± 0.25 times increased risk for having a dilated aorta ($p < 0.01$).
Conclusion: Rotation angles of the aortic valve may be an independent non-invasive imaging marker for dilatation of the ascending aorta. Patients with increased rotation angle of the aortic valve may have higher risk for development or acceleration of an ascending aortic dilatation.

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1. Introduction

Dilatation of the aortic root and thoracic aorta is a common pathologic state that predisposes patients to several complications including aortic regurgitation, aneurysm and dissection [1–3].

The effects of age, height, weight, sex, and major cardiovascular risk factors on thoracic aortic sizes of normal adult patients have been studied in the past with inconsistent results [3–7]. Aortic dilatation is also a frequent complication in conotruncal anomalies that include tetralogy of Fallot (TOF) and transposition of the great arteries (TGA), and also in bicuspid aortic valve [8–11]. In these conditions, the thoracic aorta enlarges more rapidly than in the normal population and intrinsic histological abnormalities that change the elasticity of the aortic root and ascending aortic wall have been suggested as important causative factors [12–14]. Common imaging features of TOF are overriding, dextroposition and clockwise rotation of the aorta [15,16]. Clockwise rotation and dextroposition of the aorta are interrelated and probably secondary to abnormal conotruncal rotation [15]. However, mild degrees of aortic rotation are also common in the normal population [15]. Normally, the mid-point of the non-coronary sinus of the aortic valve resides on the interatrial septum when viewed from downstream. This relative location may vary in a clockwise or uncommonly counterclockwise direction.

Since clockwise aortic root rotation with dilatation of the ascending aorta are common in conotruncal malrotation and various degrees of it can also be found in healthy population, the

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angle of aortic root/valve rotation could be a potential indicator of mild outflow tract maldevelopment in otherwise healthy individuals and may predispose the aorta to dilate. To better elaborate this concept, we conducted this preliminary study to evaluate the relationship of aortic rotation angles with sizes of the thoracic aorta in normal and dilated aortas at defined levels using electrocardiographically (ECG)-gated computed tomographic (CT) angiography images.

2. Materials and methods

This study was approved by the Institutional Review Board at our institution and was compliant with Health Insurance Portability and Accountability Act regulations. Informed consent was not required for this retrospective analysis of clinical indicated CT angiograms.

2.1. Study population and data collection

were reviewed over a period of 15 months (2013–2014). Pertinent clinical information and imaging reports were collected. We excluded patients with known, clinically apparent, or image diagnosed structural cardiac disease that may enlarge the aorta or influence the orientation of the aortic root. Patients with aortic dissection (N = 194), history of moderate to severe aortic insufficiency (N = 7), severe aortic stenosis (N = 11), moderate to severe cardiomegaly (N = 8), Marfan syndrome (N = 2), and bicuspid aortic valve (N = 6) were excluded. We excluded cases with apparent congenital heart disease (N = 6) including TOF and TGA. 9 patients with history of aortic valve replacement were also excluded.

2.2. CT imaging protocol: scan protocol and image reconstruction

All ECG-gated CT angiograms of the aorta and heart were performed using a 320–detector row Toshiba scanners (Aquilion One; Toshiba America Medical Systems, Tustin, Calif.). Gated angiograms covered the thoracic aorta and heart to the level of the diaphragm in the craniocaudal direction in a single breath hold. 0.5–2 mm slices were reconstructed depending on the clinical application. Diastolic data sets were automatically reconstructed on the basis of a relative delay strategy at 70%- 80% of the R-R interval.

2.3. Image analysis and measurements

235 patients were evaluated for image review and inclusion (Vitrea; Vital Images, Inc., Toshiba Medical Systems, Minnetonka, Minn). Poor quality images due to severe artifacts (N = 8) and poor opacification of the aorta (N = 4) that interfered with measurements were excluded. During detailed imaging analysis of the aorta, 6 more cases of possible bicuspid aortic valve were excluded. The total number of the final study cohort was 217 [mean ± standard deviation (SD), 66.7 ± 15; range 22–97 years].

All measurements were performed by two radiologists (H.A, and J.Z. with 5 and 3 years of experience in CT interpretation, respectively) and supervised by a senior radiologist (F.S. with twenty years of experience in cardiothoracic imaging). Using multiplanar reformations, cross-sectional diameters of the aorta (one maximal and the second perpendicular to it) were determined on images orthogonal to the long axis of the aorta at 3 anatomic locations: a) aortic root at the sinotubular junction, b) the ascending aorta and c) descending aorta at the level of the right pulmonary artery take off (Fig. 1). The cross-sectional area of the aortic annulus was also measured. Cusp-commissure dimensions at three directions were measured at the mid portion of the sinus of Valsalva [17]. The length of ascending aorta was defined as distance from the aortic annulus to the origin of the left subclavian artery using centerline of the aorta.

The aortic root/valve rotation (in plane) was defined as any clockwise or counterclockwise rotations of the aortic valve (viewed from below) about the centerline of the aortic root. To measure the angle of the aortic valve rotation, using true short axis view of the aortic valve a line connecting the mid-point of the non-coronary sinus to the interleaflet commissure between the coronary sinuses, as defined in a previous publication [15], was drawn and its angle with the plane of the interatrial septum was measured (Fig. 1). Images we also reviewed for any anomalies around the ventricular outflow tracts.

Patients were also divided into dilated and non-dilated based on ascending aortic sizes and compared. The threshold for aortic values was set at maximum ascending aorta diameter ≥40 mm (≥21 mm BSA indexed) for dilated aorta and ≥35 mm for upper 95% confidence limit [3,6,11,17].

2.4. Statistical analysis

Data distribution was inspected using histogram since the sample size was relatively large and normality test was over powered to reject the null hypothesis. Pearson or Spearman correlation was used for testing the correlation depending on the data distribution. The chi square test was used to compare the categorical demographic measurement between patients with aortic dilatation or not. The independent *t*-test or Wilcoxon rank sum test was used for continuous measurement between outcome categories. Multivariate adaptive regression splines (MARS) was used to explore potential diagnostic cut point for aortic root rotation in predicting average ascending aorta diameter [18]. Hinge function transfor-

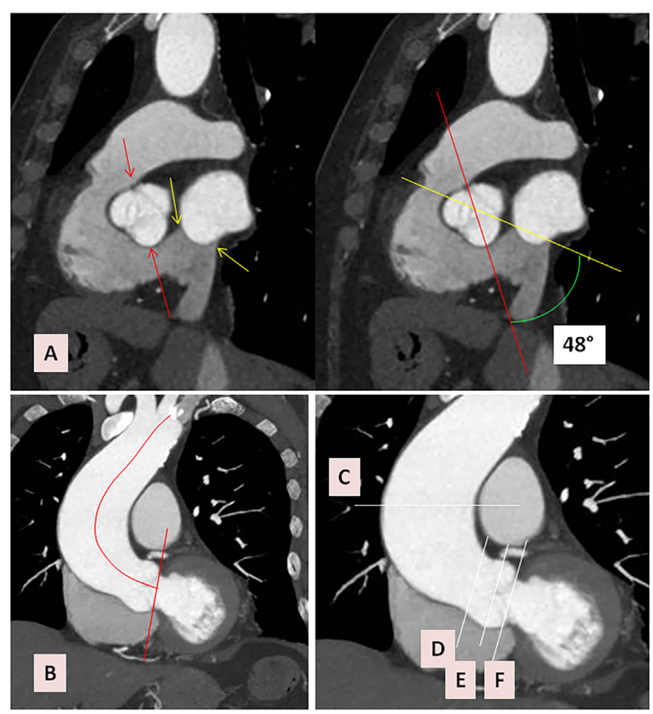

Fig. 1. Method of aortic measurements. A = rotation angle is the angle between the red line (connecting middle of the noncornary sinus and the anterior commissure) and the yellow line (the plane of the interatrial septum) using true short axis image of the aortic valve. B = Length of the ascending aorta from the aortic annulus to the origin of the left subclavian artery using centerline of the aorta. C = level of ascending and descending aorta, D = Sinotubular junction, E = sinus of Valsalva, and F = aortic annulus measurements all in short axis. Note severe clockwise rotation of the aortic valve (48°), rightward displacement of the aortic root, and dilated ascending aorta (4.3 × 4.5 cm) in this otherwise healthy individual.