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Normal Thoracic Aorta Diameter on Cardiac Computed Tomography in Healthy Asymptomatic Adult; Impact of Age and Gender

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Abstract

Objective—To establish the normal criterion of ascending aortic diameter (AAOD) measured by 64 Multi-Detector Computed Tomography (MDCT) and Electron Beam Computed Tomography (EBT) based on gender and age.

Methods—1442 consecutive subjects who were referred for evaluation of possible coronary artery disease underwent coronary CT angiography (CTA) and coronary artery calcium scanning (CACS) (55±11 years, 65% male) without known coronary heart disease, hypertension, chronic pulmonary and renal disease, diabetes and severe aortic calcification. The ascending aortic diameter, descending aortic diameter (DAOD), pulmonary artery (PAD) and chest anteroposterior diameter (CAPD), posterior border of sternal bone to anterior border of spine, were measured at the slice level of mid right pulmonary artery by using end systolic trigger image. The volume of four chambers, ejection fraction of left ventricle, and cardiac output were measured in 56% of the patients. Patients demographic information, age, gender, weight, height and body surface area (BSA), were recorded. The mean value and age specific and gender adjusted upper normal limits (mean + 2 standard deviations) were calculated. The linear correlation analysis was done between AAOD and all parameters. The reproducibility, wall thickness and difference between end systole and diastole were calculated.

Result—AAOD has significant linear association with age, gender, descending aortic diameter and pulmonary artery diameter ($P<0.05$). There is no significant correlation between AAOD and body surface area, four chamber volume, LVEF, CO and CAPD. The mean Intra-luminal AAOD was 31.1 ± 3.9 mm and 33.6 ± 4.1 mm in females and males respectively. The upper normal limits (mean + 2 standard deviations) of Intra-luminal AAOD, mean+ standard deviation, was 35.6, 38.3 and 40 mm for females and 37.8, 40.5 and 42.6 mm for males in age group 20 to 40, 41 to 60, above 60 year respectively. Intra-luminal should parallel echocardiography and invasive angiography. Traditional cross sectional imaging (with computed tomography and magnetic resonance imaging) includes the vessel wall. The mean total AAOD was 33.5 mm and 36.0 mm in females and males respectively. The upper normal limits (mean + 2 standard deviations) of Intra-luminal AAOD, mean+ standard

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deviation, was 38.0, 40.7 and 42.4 mm for females and 40.2, 42.9 and 45.0 mm for males in age group 20 to 40, 41 to 60, above 60 year respectively. The inter and intra observer, scanner and repeated measurement variability was low (R value >0.91, $P < 0.001$, coefficient variation <3.2%). AAOD was 1.7 mm less in end-diastole than end systole ($P < 0.001$).

Conclusion—The ascending aortic diameter increases with age and male gender. Gender specific and age adjusted normals for aortic diameters are necessary to differentiate pathologic atherosclerotic changes in the ascending aorta. Use of intra-luminal or total aortic diameter values depends on the comparison study that may be employed.

Keywords

Ascending aortic diameter; Electron beam CT; MDCT; Aging aorta

Introduction

Atherosclerosis is a generalized process that may involve the aorta as well as the coronary arteries. Atherosclerotic disease of the aorta has been demonstrated to increase the risk for ischemic stroke¹⁻⁵, and been demonstrated to be associated with coronary artery disease (CAD)⁶⁻¹⁰. Ascending aortic atherosclerosis has also been associated with aortic valve disease, Marfan syndrome, and aortic aneurysms. Aortic root changes due to aging, involving aortic distensibility, is the most common cause of aortic regurgitation.¹¹ Early detection of aortic atherosclerosis before the onset of clinical symptoms may improve both the diagnosis and therapeutic interventions.

There has been some reports of the importance of aging on this process and gender related differences in aortic diameters.¹²⁻¹⁷ With more application of cardiac CT and thoracic CT, it is essential to define the normal thoracic aortic diameter changes with aging in both genders. To date, most CT studies which evaluated the thoracic aorta diameters in adults have been small in size.¹⁶⁻¹⁷ We sought to evaluate the thoracic aortic diameters in a large population of patients without known diseases to establish normals based on age and gender using high resolution cardiac computed tomography.

Methods

Study population

1442 consecutive subjects who were referred for evaluation of possible coronary artery disease underwent coronary CT angiography (CTA) and coronary artery calcium scanning (CACS), mean age 55±11 years, 65% male (table 1). We excluded patients with any known disease that may influence or enlarge the aorta including patients with hypertension (HTN), diabetes mellitus, known coronary heart disease, lung disease, renal disease, abnormal electrocardiogram, abnormal myocardial perfusion test, abnormal echocardiogram, aorta calcification, CTA diagnosed coronary artery disease (<30% luminal obstruction), CT measured left ventricular ejection fraction (LVEF) < 50%, and prior coronary revascularization procedures. 200 subjects underwent 64-Multi-Detector CT (64 MDCT LightSpeed VCT, General Electric Medical System, Milwaukee, WI) and 1242 underwent Electron Beam CT (EBT, GE-Imatron, South San Francisco, CA). 100 patients underwent dual CACS studies with both EBT and MDCT scanners to test the inter-scanner variation. The inter and intra observer and inter phase variability was estimated by using 471 subjects. The thickness of aortic wall and difference between enhanced and un-enhanced images were estimated in 85 cases. This study was approved by the Institution Review Board of our institution.

EBT study protocol 18-20

First, an EBT forty slice non-contrast study (3 mm slice thickness, 3 mm table increment, 100 msec acquisition times) was obtained with the patient's supine and no couch angulations. Second, a flow study was performed to evaluate the contrast agent transit time (scan delay time) to the ascending aorta. Third, 60-70 contiguous axial EBT images were obtained with injection protocols as described below. Prospectively electrocardiographic triggering was employed, corresponding to end systole as previously described.¹⁸⁻²⁰ A volume (2 cc/kg with an upper cutoff of 180 cc) of non-ionic contrast media (Iopamidol 370, Bracco Diagnostics, Plainsboro, New Jersey) was used.

MDCT study Protocol

CTA protocols for MDCT were similar to EBT acquisitions (calcium scan followed by flow study followed by high resolution CTA imaging). The parameters were 120 kVp, 220 -670 mAs, 350 ms rotation time and 0.6 mm slice thickness. A 60-80 cc contrast agent was injected in 5 cc/s rate following by 30 cc saline injection. Retrospective trigger reconstruction was completed, in 5-95% phases and 10% intervals.

Measurements

All measurements were done in end systolic phase at right pulmonary artery (RPA) mid slice level (4-28 range, mean 16 mm above left main coronary ostium) with EBT and MDCT angiography. The window level was 300-400 HU with 1500 HU window width to measure the aortic lumen more accurately. The diameter of ascending aorta (AAOD), descending aorta (DAOD), pulmonary artery (PAD), and chest wall from the posterior border of sternum to anterior border of spine (CAPD) were measured at the same slice images. The four-chamber size as well as left ventricular ejection fraction and cardiac output were measured. All these measurements were done by trained cardiac radiologists with extensive cardiac experience using with Advantage Workstation version 4.1 - 4.3 (General Electric Medical System, Milwaukee, WI) and Insight computer workstation (Neo, Imagery Inc, CA). The reproducibility of AAOD measurements were done using paired scans. Inter observer variability was measured by comparing the results of AAOD measurements of two skilled observers, blinded to one another's measurements. End systolic, mid diastolic and end diastolic AAOD was measured with the 35%, 75% and 95% reconstructed MDCT angiography. The total AAOD (wall thickness + lumen) was measured by MDCT angiography and by CACS. The AAO thickness was calculated by the formula: $((\text{total AAOD} - \text{lumen}) / 2)$. The window level and width for measuring the total AAOD was 50 and 500 HU respectively.

Analysis

Student's *t* tests and Chi-square tests were used to assess differences between groups. Pearson correlation test were used to assess the correlation between the parameters and age specific and gender adjusted AAOD. Bland & Altman Model, coefficient of variation, was used to measure intra and inter observer and repeated measurement variability. The mean and standard deviation of AAOD in both gender in the age groups of 20-40, 40-60 and >60 years was calculated. The mean + SD of AAOD is defined as the upper normal limit of Intra-luminal AAOD. The P value <0.05 was defined as significant.

Results

AAOD has significant linear association with aging, DAOD and PAD in both genders ($P < 0.05$) (Table 2), but there was no significant association between AAOD and heart chamber volume, LVEF, CO, body surface area, and anterior-posterior chest wall diameter in both genders ($P > 0.05$). The mean end systolic Intra-luminal AAOD was 31.1 ± 3.9 mm and 33.6 ± 4.1 mm

in females and males respectively (Table 3). The upper normal limits (mean + 2 standard deviations) of Intra-luminal AAOD, mean + standard deviation, was 35.6, 38.3 and 40 mm for females and 37.8, 40.5 and 42.6 mm for males in age group 20 to 40, 41 to 60, above 60 year respectively. Intra-luminal should parallel echocardiography and invasive angiography. Traditional cross sectional imaging (with computed tomography and magnetic resonance imaging) includes the vessel wall. The mean total AAOD was 33.5mm and 36.0 mm in females and males respectively. The upper normal limits (mean + 2 standard deviations) of Intra-luminal AAOD, mean + standard deviation, was 38.0, 40.7 and 42.4 mm for females and 40.2, 42.9 and 45.0 mm for males in age group 20 to 40, 41 to 60, above 60 year respectively.

There was a significant difference between Luminal AAOD and Total AAOD (lumen + wall) as measurement by MDCT (2.4 mm differences, $P < 0.001$, the mean aortic wall thickness = 1.2 mm) (Table 4), but there is no significant differences between total AAOD (lumen + wall) measured by CACS with MDCT and EBT ($P > 0.05$). Ascending aorta diameter was 1.7 mm more at 35% end systolic trigger phase than 95 % end diastolic trigger phase ($p < 0.05$) (Table 4). There was no significant differences in AAOD in 35% and 75% trigger phase ($P > 0.05$) as the results showed (table 4).

The inter and intra observer variability was 3.2% and 3% respectively. In addition the intra and inter scanner coefficient of variation was 2.3% and 3.2%, and finally the repeated measurements variation was 2.4 %.(Table 5)

Discussion

1. Aging Process: Aortic histology, anatomy and function

It is well appreciated that the aorta is not just a simple conduit for the distribution of blood but rather has a functional role in the cardiovascular system²¹. The function change, represented by elasticity, can influence left ventricular function, coronary blood flow, and cerebral and peripheral circulation.²²⁻²⁴ These changes in anatomic structure and function can be monitored by imaging including echocardiogram¹²⁻¹⁵, magnetic resonance imaging (MRI)^{23, 24-25} and CT^{16-17, 27}. Histologically, the characteristic feature of aging in the aorta is thickening and atherosclerosis of the intima, along with cystic necrosis, elastin fragmentation, fibrosis and medionecrosis of the media, and fibrosis in adventitia. These changes of aortic aging decrease aortic elasticity (distensibility), which is represented by arterial pulse pressure widening²⁸⁻³⁰. As a result, the aging process may set up a cycle of events, with greater pulse pressure causing more aortic damage, further widening the pulse pressure³¹. Cardiac CT is sensitive to evaluate changes in the aorta including focal or extensive plaque buildup, calcification, aortic wall thickness and density.(Fig.1) Furthermore, CTA allows for measurement of the aortic size (diameter and area) and the aortic distensibility by changes in size a cardiac cycle (Fig 2).

Measuring the aortic diameter is an important method to estimate anatomic changes. Most prior studies had insufficient sample size to establish the normal thoracic aorta dimensions.¹²⁻¹⁷ Early studies relied on CT images with an insufficient temporal resolution to freeze the motion. Also, previous studies did not use ECG triggering, which most likely introduced significant error into the measures¹²⁻¹⁷. The use of ECG gating minimizes coronary motion, but some motion artifacts with MDCT still remain (figure 2). The current study evaluated the normal thoracic aorta diameter based on age and gender measured by EBT and MDCT in a large population of patients. This allows us to provide the age and gender adjusted definition to determine pathologic changes of aorta from normal aging process in both genders.

2. Correlation between AAOD and parameters

Previous studies shown that age, gender and body surface area have a significant bearing on the aortic diameter¹²⁻¹⁷. This study evaluated for associations between the gender and age adjusted aortic diameter with DAOD, PAD, CAPD, heart chamber volumes, LVEF, CO, and body surface area. Among all these factors, only gender, age, DAOD and PAD had significant linear correlation with the aortic diameters. Significant age and gender associations were found.

3. Difference of aortic diameter by authors

Measured AAOD in our study was higher than reported values from echocardiography but was lower than some previously reported CT studies (table 3). Previous CT AAOD assessments measured both lumen and wall thickness as AAOD due to lack of enhancement and included motion^{16-17, 27}. Our total aortic values are more similar to previous studies, however we believe some of the differences from prior CT studies are related to differences in imaging methods including image acquisition modes, measuring site, imaging temporal resolution and trigger time, and sample size. Typically, invasive angiography and echocardiography use the intra-luminal diameter, while conventional cross sectional imaging includes the wall thickness (computed tomography and magnetic resonance imaging). The lack of AAOD differences with aging and gender in some studies may be due to relatively small sample sizes.¹⁶⁻¹⁷ Our study demonstrated that the aortic root underwent 2-7 mm (mean 4 mm) of motion to left, anterior and inferior respectively at the end systolic phase. Also, the AAOD was greater at end systolic phase (mean 1.7 mm) than end diastolic. In addition, the mean aortic wall thickness was 1.2 mm (range: 0.75-1.75) measured by MDCT. Previous studies measured AAOD with different trigger times such as end systolic¹⁴ or diastolic¹²⁻¹³ or without trigger time¹⁶⁻¹⁷. While our study and the study by Aronberg et al¹⁶ describe the mean AAOD + 2 SD as an upper normal limit, this could significantly decrease the sensitivity of diagnosing aortic dilation.

4. Reproducibility

Our finding showed that variability of AAOD measurements with both EBT and MDCT is very low (Table 5) and demonstrates that cardiac CT could monitor the AAOD and its changes with high precision.

5. Definition

AAOD can be measured accurately with both EBT and MDCT. The end systole trigger, with least motion and largest AAOD, should provide the most accurate and reproducible measure of AAOD. We suggests the site approximately 15 mm above the left main coronary ostium, or right pulmonary mid slice level as 15 mm above the left main coronary osmium in average as a optimal point to measure AAOD. It is necessary to select suitable widow level and width in both with or without enhanced images. The luminal AAOD measured with enhanced image is 2.4 mm less than un-enhanced images (wall plus lumen) on average.

Limitations

Partial volume effects are a major concern for all CT images which influences accurate measurement of both lumen and the wall. Because of the partial volume effect, the lumen area will be higher than its actual size and the wall border will be less than its actual sizes in all CT studies.

Conclusion

The ascending aortic diameter increases with age and gender. Gender specific and age adjusted normal AAOD is required to differentiate pathologic atherosclerotic changes of the ascending aorta. The inter- and intra-observer, intra-scanner and repeated measurement variability of intra

luminal end systolic AAOD is very low. This study suggests most reproducible measures are derived from end-systolic images, and specific-sites for AAOD measurements in both un-enhanced and enhanced CT images.

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Figure 1.

Left, 64 MDCT angiographic image and right, CACS image. AAO, DAO, RPA and PA represent ascending aorta, descending aorta, right pulmonary and pulmonary artery on CACS image and Line A, B, C and D represent AAOD, DAOD, PAD and CAPD on angiographic image. White arrow depicts the calcium foci and the black arrow points to the sclerosis aortic wall.

AAO= ascending aorta; DAO = descending aorta; PA =pulmonary artery; RPA = right pulmonary artery; CAPD = chest anteroposterior diameter

Figure 2.

Changes in the aortic location, shape and size within the RR interval. Four panel images of a MDCT scan display the reconstructed images of 15%, 25%, 35% and 95% phase of the RR interval. The 35% phase is end systolic and 95% phase is end diastolic. The 25% phase has the most motion artifact (white arrows) and 35% phase has the most anterior location, cyclical shape and the least motion artifacts. The distance between aorta and sternal bone was 3.5 and 6.5 mm, the diameter was 31 and 29 mm in 35% and 95% respectively (white dual arrow).

Figure 3.

Optimal sites to measure AAOD. Right superior panel was axial image at LM level (dual white arrow). Right inferior panel was RPA mid slice level. Left superior and inferior panel were coronal and sagittal images at AAO mid plane. AAO = ascending aorta, RPA= right pulmonary artery, LM = left main coronary artery, PA = main pulmonary artery. White dot line was RPA slice level at coronal and sagittal image, was about 16 mm superior LM ostium.

Table 1

Profile in clinical parameters

N= number of subjects, BSA=body surface area, LVEF=left ventricular ejection fraction, CO= cardiac output, A-P=anteroposterior.

Gender	N	Age	BSA (m ²)	LVEF	CO/beat	A-P chest Diameter
Female	500	56.3 (19-92)	1.73	67.5%	73.4 cc	110.2mm
Male	942	54.5 (19-93)	2.02	66.4%	83.8cc	127.2 mm

All p values>0.05 comparing both gender

Table 2**Association between AAOD and Risk Factors**

DAOD = descending aortic diameter, N= number of subjects; PAD = pulmonary artery diameter

Factors	Ascending Aorta Diameter			
	Female		Male	
	N	R value	N	R Value
Gender	487	0.28	487	0.28
Age	500	0.26	942	0.31
DAOD	500	0.48	942	0.43
PAD	500	0.21	942	0.21

All P<0.05

Table 3
Normal Ascending Aorta Diameter Measured with Echocardiogram and CT
M: Mean, SD: Standards Deviation, Echo: Echocardiography, CVCT: Cardiovascular CT

Authors	Ascending Aorta Diameter						Method	Trigger Time
	Female			Male				
	N	Age	M±SD(mm)	N	Age	M±SD(mm)		
Mao	500	56	31.1±3.9	942	54	33.6±4.1		
Mao	28	20-40	29.0±3.3	80	20-40	30.8±3.5	CVCT	End Systolic
Mao	305	41-60	30.7±3.8	595	41-60	33.3±3.6	CVCT	End Systolic
Mao	167	>60	32.2±3.9	267	>60	35.0±3.8	CVCT	End Systolic
Vasan ¹²	1816	46	28±3	1473	47	32±3	Echo	End Diastolic
Roman ¹³	67	43	27±3	68	43	30±4	Echo	End Diastolic
Sochowski ¹⁴	33	45	28±3	27	45	28±3	Echo	End Systolic
Reed ¹⁵	46 ^a	21	33±4	45 ^a	21	32±4	Echo	----
Reed ¹⁵	44 ^b	21	27±3	46 ^b	21	31±3	Echo	-----
Aronberg ¹⁶	36 ^c	20-40	33.6	36 ^c	20-40	34.7	CT	No Trigger Time
Aronberg ¹⁶	33 ^c	41-60	37.2	33 ^c	41-60	36.3	CT	No Trigger Time
Aronberg ¹⁶	33 ^c	>61	35	33 ^c	>61	39.1	CT	No Trigger Time
Pearce ¹⁷	24	49	29±3.4	46	50	32±5.2	CT	No Trigger Time

^a Caucasian,
^b African American,
^c Both Genders

Table 4**Difference in AAOD with various trigger time and measuring method**

Changes in Ascending Aorta Diameter with different trigger time and method of AAOD Measurement
 35% phase: Reference for Trigger times, Lumen AAOD: Reference for Methods

Trigger time			
N	35% Phase	75% Phase	95% Phase
107	33.9±4.1	32.9±4.1	32.2±3.9 [*]
Imaging and measuring method (64 MDCT)			
N	CTA(lumen)	CTA(lumen + wall)	CACS (lumen + wall)
85	32.8±3.8	35.2±3.8 ^{**}	35.1±3.8 ^{**}

^{*}
 P<0.05;

^{**}
 P<0.001,

Compared with 35% phase for trigger time and CTA lumen for method

Table 5**Inter-observer, Inter-measurement, Inter-scanner, inter-phase and inter-method Variability**

Inter and Intra observer, scanner and repeated measurement variability of intra luminal end systolic ascending aortic diameter

N: Number of subjects; CV= Coefficient of Variation

Measurements	N	R	CV (%)	<i>Bland Altman plot</i>
				Ratio, 95% CI limit
Inter -observer variability	144	0.91	3.2	1.00, 95% CI 0.99-1.01
Inter -reader variability	140	0.92	3.0	1.01, 95% CI 0.99-1.01
Inter -scanner variability	100	0.91	3.2	1.01, 95% CI 0.99-1.02
Inter phase variability (35% versus 75% phase)	107	0.98	2.3	1.03, 95% CI 1.02-1.04
Inter phase variability (35% and 95% phase)	107	0.97	2.4	1.05, 95% CI 1.05-1.06
Inter lumen and (lumen + wall) CTA variability	85	0.98	3.3	0.93, 95% CI 0.92-0.93
Inter wall CTA and CACS (Lumen + wall) variability	85	0.99	1.7	1.00, 95% CI 1.00-1.01