Research Article

Comparison of Volumetric and Diameter Dimensions in Surveillance of Thoracic Aortic Aneurysm by Computed Tomography Angiography

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Abstract

Background: Thoracic aortic aneurysm (TAA), is a common condition that requires imaging follow-up to evaluate for complications and intervention timing. In asymptomatic patients, TAA evaluation is done with routine follow up of the aortic dimensions.

Purpose: To compare 3D volumetric measurement and 2D diameter measurement in surveillance of TAA using computed tomography angiography (CTA), in asymptomatic patients.

Materials and methods: Forty patients (mean age 66.2 ± 1.5 years, 29 males), undergoing surveillance of TAAs was retrospectively identified. Quantitative analysis was performed by measuring the diameters at sinus of Valsalva (SOV), and mid ascending aorta (MAA), using standard technique and measuring the volume of the ascending aorta from the annulus to the proximal arch level by two radiologists on a baseline and follow up scans.

Results: The mean interval time between baseline and follow up exams was 2.3 ± 1.5 years. There was significant diameter growth at the level of the MAA (p = 0.0056), but not at the level of the SOV (p = 0.08). There was significant growth of the ascending thoracic aorta volume (p = 0.0001). There was excellent intra-rater and inter-rater agreement. The percent growth of the volume measurement was 2.7 times greater than the MAA percentage growth (5.1% vs 1.9%, P < 0.001) and 1.8 times greater than the diameter of maximal growth percentage growth (5.1% vs 2.9%, P < 0.001) over the entire follow-up period.

Conclusions: Volumetric measurement of the ascending aorta is a reproducible method that offers greater sensitivity than conventional 2D measurements for detection of the growth rate of the ascending thoracic aorta.

INTRODUCTION

Thoracic aortic aneurysm (TAA), is a life threatening condition causing short-term and long-term mortality due to increased risk of rupture and dissection. It has an overall prevalence of 450 per 100,000 persons [1], is two to four times more frequent in male patients and is more common in elderly population. The incidence is likely underestimated as many patients are asymptomatic at the time of diagnosis and the condition is often discovered incidentally on imaging [2]. An aneurysm is defined as a permanent dilatation of the aorta exceeding the normal measurements by more than two standard deviations at a given anatomic level. The ascending aorta is considered dilated if the diameter is greater than 4 cm and considered aneurysmal if the diameter exceeds 5 cm [3]. Most TAAs are degenerative in etiology and are related to alterations in vascular wall biology that lead to loss of structural integrity and aortic wall strength [4]. The natural history of TAAs is slow expansion with an increasing risk of aortic dissection and rupture. Expansion rates range from 0.1 to 1.0 cm per year, depending upon TAA etiology, diameter, and location within the aorta [5,6]. While apparent rapid expansion of the aorta is commonly attributable to measurement error, its presence should raise concern for aortic dissection or superimposed infection. The expansion rate is higher in patients with a larger aorta, in patients with a bicuspid aortic valve, and in patients with genetic disorders related TAA [7-9].

Imaging plays an important role in the management of these patients and accurate measurements of aortic dimensions is crucial for long-term surveillance. Annual or biannual follow-up is generally performed and is dependent on the size of the TAA, its cause, and the expansion rate [10]. Computed tomography angiography and magnetic resonance angiography of the thoracic aorta are both acceptable techniques for this purpose [11,12]. Echocardiography can also be used for follow-up of aortic root aneurysms and any associated valvular disease. TAAs should
Ideally be surveilled using the same imaging technique and in the same institution [13]. Measurements are typically made in accordance with AHA guidelines, wherein aortic diameters are measured at six locations. The annual growth rate of most TAAAs is low in order of millimeters, making the detection of growth difficult. Furthermore, recent literature has shown that maximal diameter measurements of the aorta may be insensitive to focal aneurysmal changes [14], and 3D volume reconstructions have been used as alternative to study the abdominal aortic growth [14], and more recently to evaluate TAA growth in patients with bicuspid aortic valves [15]. We therefore thought to compare the sensitivity of 2D diameter measurements and 3D volumetric measurements of the ascending thoracic aorta in patients with TAAAs undergoing surveillance with CTA.

**MATERIAL AND METHODS**

**Study population**

This retrospective study was conducted on 40 adult patients (29 males, 11 females), with known TAA who underwent a baseline and follow-up computed tomography angiography (CTA), exams between September 1, 2009 and March 5, 2014. Patients with a history of aortic dissection or surgery to the heart or thoracic aorta prior to the baseline exam or in the interval between the two scans were excluded from the study. Our institutional review board approved this study and an informed consent was waived.

**Imaging technique**

All CTA studies of the thoracic aorta were performed on a 64-slice scanner (SOMATOM Definition, Siemens Healthineers, Forchheim, Germany) with ECG gating using the standard protocol in our institution. In all patients, between the initial and the follow up scan, there was no difference in the patient heart rate of more than 5 to ensure image acquisition in same R-R interval. ECG trigger range was 30% if the heart rate is more than 75 and 50% if the heart rate is less than 75. Typical slice thickness was on the order of 0.6-mm to 1-mm. Images were acquired using either iterative reconstruction or filtered back projection. kVp was selected according to the pre-determined BMI-based institutional protocol and ranged between 80 and 140 kVp. 75 ml of iodinated contrast Iohexol (350 mg Iodine / mL) was injected at a rate of 5cc/s. The timing of acquisition was determined using bolus triggering method.

**Image processing and aortic measurements**

Images were reconstructed on dedicated software Vitrea (Vital Images Inc., Minnesota, USA) allowing for multiplanar reconstruction and volumetric reconstruction and segmentation. Two radiologists with cardiovascular imaging fellowship training performed independently diameter and volumetric measurements. Measurements from baseline and follow-up scans were obtained on different days with both observers being blinded to the measurements obtained from different studies of the same subjects. The primary observer obtained the measurements of all the 40 studied subjects and repeated measurements for 10 randomly chosen subjects to evaluate intraobserver agreement. The second observer obtained measurements of 10 randomly chosen subjects to analyze interobserver agreement.

**Diameter measurements**

After multiplanar reconstruction, double oblique diameter measurements of the thoracic aorta were obtained at the levels of sinuses of Valsalva (SOV), and of the mid ascending aorta (MAA), using a plane that is orthogonal to the course of the aorta while including the aortic wall in the measurement (Figure 1). At the level of the SOV, three measurements were obtained, from each sinus to the adjacent sinus. At the level of the MAA, two orthogonal measurements were obtained. The higher value of these measurements was recorded as the maximal SOV diameter and maximal MAA diameter respectively. Diameter growth rate was derived from changes in the maximal SOV and maximal MAA diameters between baseline and follow-up scans. As surgical intervention for TAA is recommended based on the fastest growing diameter at either the SOV or MAA [12], the diameter of maximal growth (DMG), defined as the fastest growth rate at either SOV or MAA, was also recorded. The diameter growth at SOV, MAA and DMG were reported as units (mm) and percentages (%). The growth rates were reported as units per time (mm/year) and percentages per time (%/year). Diameter percentage was calculated from the difference of diameter measurements between baseline and follow-up scans divided by the baseline measurement.

**Volume measurements**

The ascending thoracic aorta was segmented semi-automatically and separated from the surrounding structures. The radiologist selected the start and end levels of the segmented volume and manually edited the contours to ensure adequate

![Figure 1](image-url) 2D Measurements of the aorta at the level of the Sinus-Of-Valsalva (a) and mid ascending aorta (b). 3D reconstruction of the aorta (c) and volumetric measurements (d) of the aortic segment from the annulus to the proximal arch.
inclusion of all the aortic lumen and wall and exclusion of the surrounding tissues. The measured volume of ascending thoracic aorta extended proximally from the aortic annulus and distally to the aorta just proximal to the origin of the brachiocephalic artery. Volumetric growth rate was derived from the difference between the baseline and follow-up ascending aortic volumes. The volumetric growth was recorded as both units (milliliter), and percentages (%). Growth rates were reported as units per time (mL/year), and percentage per time (%/year). Volumetric percentage was calculated from the difference in volume between baseline and follow-up scans divided by the baseline volume.

### Statistical analysis

Statistical analysis was performed using Stata 14 (StataCorp, College Station, TX).

The measurements obtained from baseline and follow-up scans were compared using a two-tailed paired student t test. Statistical significance was defined by p value of less than 0.05. Intra-rater and inter-rater agreement was analyzed using the intraclass correlation coefficient (ICC) and Bland-Altman analysis.

### RESULTS

The mean interval time between baseline and follow-up exams was 2.3 ± 1.5 years. The mean age of all the subjects was 66.2 ± 8.4 y at their baseline scan. Table 1 shows the baseline and follow-up diameter measurements of the ascending thoracic aorta at SOV and MAA and of the aortic volume. There was significant growth at the level of the MAA (p=0.0056) however no significant growth was observed at the level of the SOV (p=0.08). There was significant growth of the ascending thoracic aorta volume (p=0.0001).

There was excellent intra-rater and inter-rater agreement on SOV diameter, MAA diameter and ascending aorta volume measurements obtained from randomly chosen 10 subjects (Table 2).

Bland-Altman analyses for interobserver and intraobserver agreements on diameter and volume measurements are displayed in Figure 2 and showed no systematic difference.

Table 3 lists the absolute and percentage values of growth rate per year and over the entire follow-up period for the SOV, MAA, DMG and aortic volume. The percent growth of the volume measurement was 2.7 times greater than the MAA percentage growth (5.1% vs 1.9%, P < 0.001) and 1.8 times greater than the DMG percentage growth (5.1% vs 2.9%, P < 0.001) over the entire follow-up period.

### DISCUSSION

The size of the TAA is a major predictor of predictor of aortic dissection, rupture and mortality [16]. The annual risk of rupture or dissection of the aorta is less than 2% for TAAs between 4.0 and 4.9 cm but increases to 7% for aortic size greater than 6.0 cm [16]. All asymptomatic TAAs should undergo repair. For asymptomatic patients with ascending TAA, indications for intervention include [10]: 1) End-diastolic aortic diameter of 5 to 6 cm or aortic size index (aortic diameter [cm] divided by body surface area [m2]) ≥2.75 cm/m2, 2) End diastolic diameter greater than 4.5-5 cm for patients with genetically-related TAA, 3) End diastolic diameter greater than 4.5 cm for non-Turner patients undergoing aortic valve surgery, 4) Rapid expansion greater than or equal to 10 mm per year in the general population or more than 5 mm per year for patients with bicuspid aortic valve or with genetically-related TAA. For patients not meeting these criteria, serial follow up exams to determine the timing for intervention is recommended. Therefore, imaging of the thoracic aorta has a crucial role in surveillance of these subjects and accurate measurements are fundamental. While surveillance imaging can be done with either CTA or MRA of the thoracic aorta, CTA is the most widely used technique due to its widespread availability, optimal spatial resolution, potential for multiplanar and 3D reconstructions, and its fast acquisition which makes it less sensitive to motion artifacts.

There is no standardized method for measuring aortic diameter, but the general consensus is to measure the largest diameter perpendicular to the vessel lumen using multiplanar reconstruction at reproducible anatomical landmarks on.
Electrocardiogram-gated images. However, opinions differ on whether the aortic wall should be included in the vessel diameter, what phase of the cardiac cycle should be used, and whether SOV measurements should be taken at the cusps or the commissure [17].

Additionally, variability in the plane angulation and of the aortic level at which the diameter measurement is obtained can impact reproducibility of these measurements. These issues render detection of small changes in aortic diameter challenging.

Geisbusch et al., have studied the growth rate of TAAs using volumetric measurements for patients with small-to-moderate aneurysms and reported a growth rate of 0.95 ± 4.5 ml/year and 0.73 ± 3.7%/year for the ascending aorta. The authors concluded that volumetric measurements provide an objective method for ascertaining aortic size and monitoring expansion [18]. Trinh et al., studied the reliability of contrast-enhanced MRA 3D volumetry compared with 2D diameter measurements to identify thoracic aortic aneurysm growth in patients with bicuspid aortic valve and concluded that the volumetric measurements demonstrate larger effect on the percentage growth than diameter measurements [15]. Other studies have also shown the utility of volumetric measurements of the abdominal aorta and demonstrated better sensitivity to growth change when compared to conventional maximal diameter measurements [19-21]. Based on these studies, we extrapolated that 3D volume measurements of TAA on CTA should similarly produce reliable and more robust analysis than diameter measurements. The hypothesis is that maximal diameter does not always change with aortic dilatation, furthermore the exponential relationship between diameter and volume makes volume more sensitive for growth detection as suggested by Trinh et al. [15].

Our study showed an absolute and percentage growth rate of the DMG of 0.4 ± 0.6 mm/year and 0.9 ± 1.3% /year and of the aortic volume of 2.7 ± 4.7 ml/year and 2.1 ± 3.2% /year, respectively. We reported the percentage values of the growth rate and of total growth to allow for comparison of different units (mm for diameters and mL for volumes). The observed percentage of growth rate and percentage of total growth were 2.3 fold and 1.8 fold greater with volume measurements by comparison to the diameter measurements of DMG. This larger percentage change observed with volumetric measurements reflects the potential greater sensitivity of the volumetric measurements for detection of size change of the ascending thoracic aorta. These results were in concordance with the reported literature [15,19-21]. As aortic growth does not always occur at the traditionally measured levels of the thoracic aorta, the use of the greatest aortic diameter may fail to detect interval change in aortic dimensions. Volumetric measurements were obtained by including the whole ascending thoracic aorta which offers higher sensitivity for detection of growth at any aortic level.

There are some limitations of our study. First, the sample size is relatively small. Second, the clinical outcome was not evaluated.
and therefore the clinical impact of the increased sensitivity for detection of aortic size change with volumetric measurements cannot be assessed. Third, 3D reconstructions, segmentation and contouring of the ascending aorta is time consuming with the currently available softwares and requires careful selection of the proximal and distal boundaries. However, our study showed excellent intraobserver and interobserver agreement on measurements, suggesting that a volumetric measurement is reproducible and reliable. Furthermore, we included only part of the thoracic aorta in our study, a segment from the root to the proximal arch. Including the whole aorta is technically feasible with our current method, careful segmentation of the arch and the descending aorta should be done as these segments show more calcification. Fourth, selection bias of CTAs that may preclude image reconstruction thereby making volumetric measurements inaccurate. Third, 3D reconstructions, segmentation and contouring of the ascending aorta is a highly reproducible method that offers greater sensitivity than conventional 2D measurements for detection of the growth rate of the ascending thoracic aorta and can be reported in addition to the diameter measurements. Further studies should be done to determine the influence of volume change on patient clinical outcome and to establish a threshold growth volume for appropriate timing of intervention.

The current guidelines for surgical intervention for TAA are based on the aortic greatest diameter and there is no current consensus on management based on volumetric measurements. The encouraging results of several studies along with the relative simplicity and reliability of volumetric measurement warrants further investigation to better understand how aortic volume correlates with the risk of TAA complications and potentially the inclusion of aortic volumes in the guidelines for monitoring and risk stratification of patients with TAA.

In conclusion, volumetric measurement of the ascending aorta is a highly reproducible method that offers greater sensitivity than conventional 2D measurements for detection of the growth rate of the ascending thoracic aorta and can be reported in addition to the diameter measurements. Further studies should be done to determine the influence of volume change on patient clinical outcome and to establish a threshold growth volume for appropriate timing of intervention.

REFERENCES


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