Dynamic Cine-CT Angiography for the Evaluation of the Thoracic Aorta; Insight in Dynamic Changes with Implications for Thoracic Endograft Treatment

B.E. Muhs,1 K.L. Vincken,2 J. van Prehn,1 M.K.C. Stone, L.W. Bartels,2 M. Prokop,2 F.L. Moll1 and H.J.M. Verhagen1*

Departments of 1Vascular Surgery, and 2Image Science Institute, University Medical Center Utrecht, The Netherlands

Objective. Thoracic aneurysm preoperative imaging is performed using static techniques without consideration of normal aortic dynamics. Improved understanding of the native aortic environment into which thoracic endografts are placed may aid in device selection. It is unclear what comprises normal thoracic aortic pulsatility. We studied these phenomena dynamically using ECG-gated 64-slice CTA.

Methods. Maximum diameter and area change per cardiac cycle was measured at surgically relevant anatomic thoracic landmarks in ten patients: 1.0 cm proximal and distal to the subclavian artery, 3.0 cm distal to the subclavian artery, and 3.0 cm proximal to the celiac trunk. Data was acquired using a novel ECG-gated dynamic 64-slice CT scanner during a single breath hold with a standard radiation dose and contrast load. Eight gated data sets, covering the cardiac cycle were reconstructed, perpendicular to the central lumen.

Results. There is impressive change in both maximum diameter and area in the thoracic aorta during the cardiac cycle. Mean maximum diameter changes of greater than 10% are observed in the typical sealing zones of commercially available endografts corresponding to diameter increases of up to 5 mm. Aortic area increases by over 5% per cardiac cycle.

Conclusions. ECG-gated dynamic CTA with standard radiation dose is feasible on a 64-slice scanner and provides insight into (patho)physiology of thoracic aortic conformational changes. Clinicians typically oversize thoracic endografts by 10%. With aortic pulsatility resulting in diameter changes of up to 17.8%, the potential exists for endograft undersizing, graft migration, intermittent type I endoleak, and poor patient outcome. Furthermore, aortic pulsatility is not evenly distributed, and non-circular stentgraft designs should be considered in the future since aortic distension in the aneurysm neck is not evenly distributed.

Keywords: Dynamic CT; Computerized tomography; Endograft; EVAR; Aortic motion; Aortic pulsation; Thoracic aorta; Thoracic endograft; Thoracic aneurysm.

Introduction

The introduction of thoracic endografts for the treatment of aneurysmal diseases of the descending thoracic aorta has altered pre- and postoperative evaluation. The decision to pursue endovascular treatment demands additional information when compared to traditional open repair.1–3 Precise preoperative imaging is mandatory, and surveillance protocols designed to detect clinically significant endoleaks, graft migration, and disease extension are essential postoperative treatment adjuncts.4–5 Complications following thoracic endovascular aneurysm repair (TEVAR) are greater than that of abdominal endovascular aneurysm repair (EVAR), and thoracic endografts are at an earlier stage of development and clinical application compared to their abdominal counterparts.6–8 Could improved preoperative imaging limit some of the complications that are observed following deployment of thoracic endoprosthesis? Experience with EVAR has clearly demonstrated superior outcomes can be achieved only with proper preoperative patient selection.9–10 Currently, the vast majority of all preoperative imaging used for patient selection when contemplating TEVAR is performed using static imaging.11 The most commonly used modality is computerized
tomographic angiography (CTA). Irrespective of modality, these static imaging protocols do not consider the normal aortic dynamics, and may result in aortic sizing failures and subsequent graft to aorta mismatch. Modern multislice CT scanners acquire image data at any particular level in a fraction of a second and may represent the aortic diameter at diastole, systole, or anywhere in between. It is currently unknown if this static imaging results in graft undersizing. An improved understanding of the native aortic environment into which thoracic endografts are placed may aid both patient and device selection.

The purpose of this study was to utilize high resolution ECG-gated cine-CTA to characterize normal aortic motion, during the cardiac cycle, at important thoracic aortic anatomic landmarks for TEVAR.

**Methods**

We acquired an ECG-gated CTA data set on a 64-slice Philips Brilliance CT-scanner (Philips Medical Systems, Best, The Netherlands) in ten consecutive patients with abdominal aortic aneurysms (AAA) larger than 5.5 cm in diameter. Images were acquired during a single breath-hold phase of 20 seconds during which the entire aorta from the heart to the iliac bifurcation was imaged. The imaging protocol was set at 1.25 mm collimation and a pitch of 0.25. Radiation exposure parameters were 120 kVp and 300 mAs, resulting in a CT dose index (CTDIvol) of 21 mGy. Intravascular non-ionic contrast (120 ml) (Iopromide, Schering, Berlin, Germany) followed by a 50 ml of saline chaser bolus was injected at a flow rate of 4 ml/s. The scan was started using bolus triggering software with a threshold of 100 HU over baseline. ECG triggered retrospective reconstructions were made at eight equidistant time points over the R-R cardiac cycle.

The data set of each patient was loaded into a separate workstation (Extended Brilliance Workspace, Philips Medical Systems, Cleveland, OH, USA) and processed using the cardiac review program function. Pulsatility measurements were done in the axial plane, perpendicular to the central lumen line of the vessel with computer segmentation (Fig. 1). Relevant anatomic levels of the thoracic aorta in the evaluation and follow-up of typical thoracic aneurysms and sealing zones were selected for analysis. These anatomic levels were (Level A) 1 cm proximal to the left subclavian artery, (Level B) 1 cm distal to the left subclavian artery, (Level C) 3 cm distal to the left subclavian artery, and (Level D) 3 cm proximal to the celiac artery (Fig. 2).

Analysis of the dynamic scans was performed using Dynamix software (Image Sciences Institute, Utrecht, the Netherlands). This software was developed to perform automated segmentation and measure changes in area and diameter at predetermined aortic levels. Each segmentation was reviewed manually by two blinded observers independently and in approximately 25% of the images, minor adjustments in the segmentation for small irregularities were required. Areas and minimum and maximum diameter along 256 axes, equally-spaced and through the center of mass of the aortic lumen were also calculated during cardiac cycles.

The term pulsatility was defined as radial displacement of the aorta lumen during a single cardiac cycle, and was calculated as the largest difference in both area and diameter. Interobserver variability according to the method of Bland and Altman was performed to

**Fig. 1.** CTA with intravenous contrast demonstrates excellent image quality identifying the aortic lumen (A). Custom designed image segmentation software determines area and diameter changes based on this segmentation (B).
analyse repeatability and to compare measurements by two observers.

Results

Image acquisition was accomplished successfully in all ten patients with image quality considered excellent in all. Minor adjustments were occasionally required, typically in less than 25% of the images when sidebranches off the aorta or significant calcification were present. The results are summarized in Table 1.

### Aortic diameter

The maximum aortic diameter demonstrated considerable variation during the heart cycle of approximately 10% at each anatomic level ($p < 0.05$). Level A demonstrated a mean maximum diameter change of 9.6% (range 6.2% – 12.5%, SD 2.0); Level B 10.0% (range 8.0% – 12.3%, SD 1.4); Level C 11.6% (range 7.1% – 17.8%, SD 3.5); and Level D 10.6% (range 8.3% – 13.2%, SD 1.7) (Fig. 3). This corresponded to absolute changes of 2.7 mm (range 1.8 mm – 3.4 mm, SD 0.5) at Level A, 2.8 mm (range 2.2 mm – 3.6 mm, SD 0.5) at Level B, 3.1 mm (range 2.1 mm – 5.1 mm, SD 1.0) at Level C, and 2.6 mm (range 2.0 mm – 3.2 mm, SD 0.4) at Level D. The mean maximum diameter interobserver repeatability coefficient was 1.0 mm demonstrating no significant differences between the observers.

### Aortic area

The change in aortic area demonstrated a similar pattern as that of maximum aortic diameter change with significant pulsatility at each measured level ($p < 0.05$). Level A demonstrated a mean aortic change of 4.8% (range 2.7% – 6.9%, SD 1.4); Level B 5.0% (range 3.9% – 6.9%, SD 1.0); Level C 5.5% (range 3.0% – 7.0%, SD 2.2) at Level C, and 5.1% (range 3.0% – 7.0%, SD 2.2) at Level D.

### Table 1. Changes in mean maximum diameter and aortic area per cardiac cycle are shown for each of the four measured anatomic levels covering the thoracic aorta

<table>
<thead>
<tr>
<th></th>
<th>Suprasubclavian</th>
<th>Infrasubclavian</th>
<th>3 cm infrasubclavian</th>
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<td>16.8</td>
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and Level D 7.0% (range 3.2% - 11.2%, SD 2.7) (Fig. 4). This corresponded to absolute changes of 33.1 mm² (range 17.6 mm² - 45.5 mm², SD 9.6) at Level A, 33.2 mm² (range 25.3 mm² - 48.6 mm², SD 7.2) at Level B, 36.0 mm² (range 19.9 mm² - 75.1 mm², SD 15.9) at Level C, and 37.9 mm² (range 15.6 mm² - 64.8 mm², SD 16.8) at Level D. The mean area interobserver repeatability coefficient was 44.8 mm² demonstrating no significant differences between the observers.

Discussion

Aortic compliance and cardiac pulsatility naturally result in conformational changes during the cardiac cycle. Hemodynamic forces can be tremendous in the thoracic position, and coupled with the acute angulations and branch points inherent in the arch and descending aorta, may result in significant variations in aortic diameter between diastole and systole. Endograft sizing determinations based on poor preoperative measurements may result in intermittent type I endoleaks, graft migration, prosthesis collapse, aneurysm rupture, and poor patient outcomes.

There have been very few studies assessing normal thoracic aortic pulsatility in patients with risk factors for aneurysm development. The location of the aortic arch and descending aorta, confined within the rib cage and surrounded by air filled lung, makes reliable ultrasound imaging with echo tracing difficult. Intravascular ultrasound (IVUS) is invasive and unlikely to be used preoperatively on a large scale. New dynamic imaging is now becoming available to assess preoperative aortic pulsatility at relevant anatomic landmarks used in measuring, sizing, and planning TEVAR. An improved understanding of natural aortic pulsatility may result in improved preoperative patient and device selection for TEVAR and subsequent improved graft durability and patient outcome.

This study utilized dynamic cine-CTA to assess pulsatility of the thoracic aorta. By coupling high acquisition speeds using a 64-slice scanner to an ECG trigger, we were able to reconstruct eight images per cardiac cycle providing excellent temporal and spatial resolution. Our patient population consisted of patients with known AAAs being scanned for routine follow-up after EVAR, and all imaging was performed without additional intravenous contrast or radiation exposure. In this feasibility study, we have demonstrated that dynamic cine-CTA can detect significant changes in thoracic aortic pulsatility with no added radiation or contrast exposure.

Development of automatic software to accurately segment aortic slices and provide reproducible, reliable measurements of area and diameter, virtually eliminated human error. Manual adjustments were occasionally needed when significant aortic wall calcification was present resulting in x-ray attenuation similar to, and adjacent to intravenous contrast. We purposefully measured aortic pulsatility proximal or distal to branch points to avoid another problem with the segmentation software. Segmentation performed at the level of a branch vessel is difficult with extreme precision. The software is unable to determine were the lumen of the aorta ends and the branch vessel lumen begins. It is conceivable that with further improvements in this software, it could be made commercially available on new CT scanners and pulsatility measurements automatically...
calculated at the time of image acquisition. These pulsatility measurements could subsequently be used for endograft sizing.

We selected four positions along the thoracic aorta to measure pulsatility. One centimeter proximal and distal to the subclavian artery was selected, as this is the typical proximal sealing zone for thoracic endografts. Three centimeters proximal to the celiac artery was chosen for the same reason. This is the typical distal sealing zone. The fourth selected position was three cm distal to the subclavian, which is a common site for aneurysms to form. We demonstrated pulsations of up to 17.8% at these levels. Many clinicians use a standard of 10% oversizing when sizing endografts. Clearly an endograft oversized by 10% would be too small in an aorta which increases its maximum diameter by 17.8% with each cardiac cycle. However, we were limited by the two dimensional nature of our measuring system. In the future, volumetric analysis might provide better information along a much greater distance. At the present, this technology is not available to us.

None of the patients in this feasibility study had thoracic aneurysms (TA), although they all had large AAAs. We selected this population, because patients with known AAAs have similar risk factors as those who develop TAs. However, thoracic aortic dynamics might be different in patients with thoracic aneurysms. Future studies directed at aneurysm dynamics both before and after endovascular exclusion are anticipated.

This study introduces the feasibility of cine-CTA imaging of dynamic thoracic aortic motion. Patients with AAAs demonstrate changes in thoracic aortic diameter with each heart cycle that can be imaged with excellent temporal and spatial resolution using dynamic cine-CTA. The native aorta exhibits significant pulsation with each heart cycle, and this may have serious consequences for endograft efficacy and durability. Future studies utilizing cine-CTA to determine rupture risk, effects of different endografts and volumetric analysis are anticipated. The maximum aortic diameter change exceeded the minimum diameter change signifying pulsatile asymmetry. In the future, non-circular stent graft designs may be designed for improved sealing in these asymmetric thoracic aortas.

References


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