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Extensibility and Distensibility of the Thoracic Aorta in Patients with Aneurysm

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WHAT THIS PAPER ADDS

In this paper, radial and longitudinal pulsatile aortic deformations were quantified and a new definition of longitudinal deformation is proposed. This definition is based on the physiological principle that the changes in aortic length are caused by heart movement pulling the proximal end of the aorta up and down combined with the load of the blood flow ejected into the aorta. In a cohort of 10 patients with abdominal or thoracic aortic aneurysm, pulsatile aortic deformations are considerable in both directions, with important variations between individuals, and the largest deformations occurring in the ascending aorta.

Objectives: Reference values of aortic deformation during the cardiac cycle can be valuable for the pre-operative planning of thoracic endovascular aortic repair (TEVAR) and for facilitating computational fluid dynamics. This study aimed to quantify normal aortic extensibility (longitudinal extension) and distensibility (radial expansion), as well as pulsatile strain, in a group of 10 (>60 years) individuals with abdominal or thoracic aortic aneurysms.
Methods: ECG gated CT images of the thoracic aorta were reconstructed into virtual 3D models of aortic geometry. The centre lumen line length of the thoracic aorta and three longitudinal segments, and the aortic diameter and luminal areas of four radial intersections were extracted with a dedicated software script to calculate extensibility, longitudinal strain, distensibility, and circumferential area strain.
Results: Mean extensibility and longitudinal strain of the entire thoracic aorta were 3.5 [1.3–6.8] $\times 10^{-3}$ N^{-1}, and 2.7 [1.0–4.5]%, respectively. Extensibility and longitudinal strain were most pronounced in the ascending aorta (20.6 [5.7–36.2] $\times 10^{-3}$ N^{-1} and 15.9 [6.6–31.9]%) and smallest in the descending aorta (4.4 [1.6–12.3] $\times 10^{-3}$ N^{-1} and 2.2 [0.7–4.7]%). Mean distensibility and circumferential area strain were most pronounced at the sinotubular junction (1.7 [0.5–2.9] $\times 10^{-3}$ $mmHg^{-1}$ and 11.3 [3.3–18.5]%, respectively). Distensibility varied between 0.9 [0.3–2.5] $\times 10^{-3}$ $mmHg^{-1}$ and 1.2 [0.3–3.3] $\times 10^{-3}$ $mmHg^{-1}$ at the intersections in the aortic arch and descending aorta.
Conclusions: Pulsatile deformations in both longitudinal and circumferential directions are considerable throughout the thoracic aorta. These findings may have implications for pre-operative TEVAR planning and highlight the need for devices that can mimic the significant aortic longitudinal and circumferential strains.

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INTRODUCTION

Clinical success of thoracic endovascular aortic repair (TEVAR) depends partly on correct sizing of the stent graft. Mis-sizing may lead to stent graft related complications such as type I endoleaks, retrograde or antegrade dissection, stent graft migration, or collapse.[1–4] Dynamic imaging is important to correctly assess the conformational changes of the aorta over the cardiac cycle. ECG gated computed tomography (CT) and magnetic resonance imaging (MRI) have been widely used in various aortic pathologies,[5–8] with good accuracy because of high resolution and tissue contrast. Using these imaging modalities, the quantification of aortic distensibility assesses aortic stiffness as it takes the load (i.e. pulse pressure) into account, on which

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deformations greatly depend.[9] This is important as aortic stiffening is a known predictor of cardiovascular disease and death.[10–14] Moreover, quantification of aortic distensibility has been reported to have important value in pre-operative planning.[15] Local aortic wall stress can also be derived from estimates of aortic stiffness and measured aortic strain.[16] Most studies thus far have been limited, however, to examining the circumferential strain and radial distensibility, but have neglected the significant longitudinal strain experienced by the aorta over the cardiac cycle.[11]

This study presents a computer aided, semi-automatic measurement method to measure aortic dimensions during the cardiac cycle, based on ECG gated CT imaging of non-dilated and aneurysmal thoracic aortas of eight patients with abdominal aortic aneurysm and two patients with descending thoracic aortic aneurysms (seven male, three female) unaffected by connective tissue disorder. Thus, the study aimed to quantify thoracic aortic distensibility (radial expansion) and circumferential strain as well as extensibility (longitudinal extension) and longitudinal strain.

MATERIALS AND METHODS

Study population and image acquisition

Images were retrospectively selected from a group of abdominal and thoracic aortic aneurysm patients (aged 66–89 years) who underwent routine imaging of the entire aorta at the University Medical Centre Utrecht, the Netherlands, with ECG gated CTA. Exclusion criteria were connective tissue disorder, or prior aortic surgery. Brachial blood pressures at the time of imaging were collected. The study protocol was evaluated by the local ethical review board and formal approval and informed consent was waived.

Imaging was performed using a 64 row multislice CT scanner (Philip Medical Systems, Best, The Netherlands) with a standardised acquisition protocol (slice thickness 0.9 mm, increment 0.7 mm) using 90–150 mL of intravenous non-ionic contrast (Iopromide, Schering, Berlin, Germany) injected at 6 mL/s, followed by a 60 mL saline chaser bolus. Scanning started using bolus triggering software with a threshold of 100 HU over baseline. Eight equally spaced phases were acquired over the cardiac cycle for each patient.

Image processing and 3D geometric analysis

Eight three dimensional segmentations of the aortic luminal boundary were created for each patient using the dynamic CT data and ITK-Snap software.[17] Next, the Vascular Modeling Toolkit libraries[18,19] were used to extract aortic centre lines for each phase. After manual designation of the proximal and distal ends of the aortic segmentation, the libraries automatically create a centre lumen line from sinotubular junction to coeliac bifurcation.

Each centre lumen line was divided into three different regions (ascending aorta, aortic arch, and descending aorta, Fig. 1A). Reference cross sections perpendicular to the centre lumen lines were defined at anatomical landmarks at the sinotubular junction, brachiocephalic trunk, left subclavian artery, and coeliac artery (Fig. 1B).

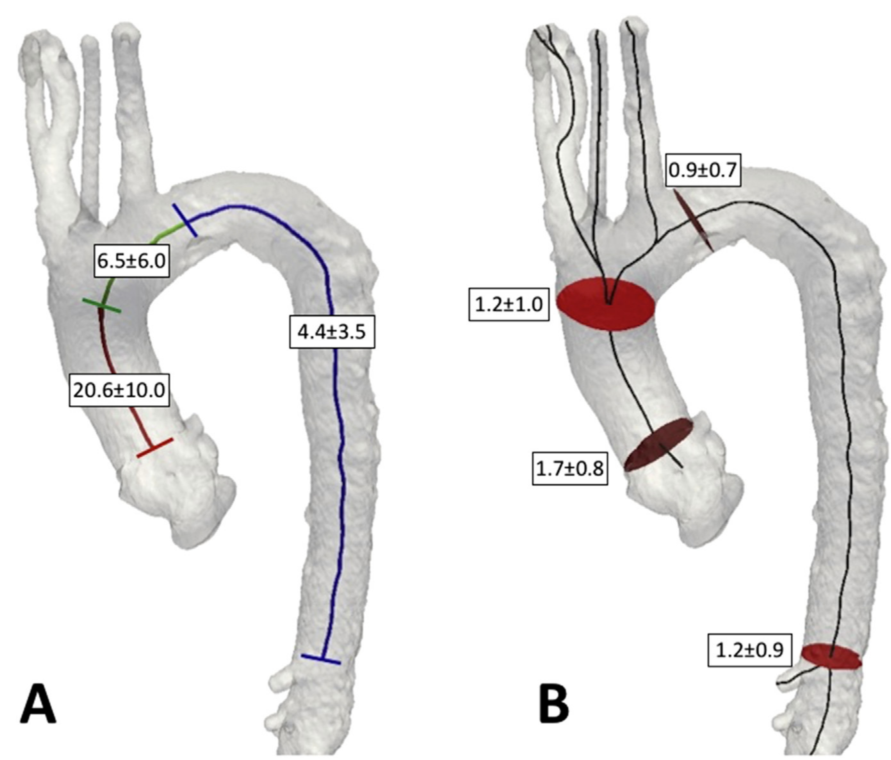

Figure 1. Longitudinal segments and radial intersections of the thoracic aorta delineated by anatomical landmarks, the sinotubular junction and centreline bifurcations of the brachiocephalic trunk, left subclavian artery, and coeliac trunk. Also included are the average values of regional extensibility (A) and distensibility (B) for the study population.

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