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Influence of limited field-of-view on wall stress analysis in abdominal aortic aneurysms

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ABSTRACT

Abdominal aortic aneurysms (AAAs) are local dilations of the aorta which can lead to a fatal hemorrhage when ruptured. Wall stress analysis of AAAs has been widely reported in literature to predict the risk of rupture. Usually, the complete AAA geometry including the aortic bifurcation is obtained by computed tomography (CT). However, performing wall stress analysis based on 3D ultrasound (3D US) has many advantages over CT, although, the field-of-view (FOV) of 3D US is limited and the aortic bifurcation is not easily imaged. In this study, the influence of a limited FOV is examined by performing wall stress analysis on CT-based (total) AAA geometries in 10 patients, and observing the changes in 99th percentile stresses and median stresses while systematically limiting the FOV.

Results reveal that changes in the 99th percentile wall stresses are less than 10% when the proximal and distal shoulders of the aneurysm are in the shortened FOV. Wall stress results show that the presence of the aortic bifurcation in the FOV does not influence the wall stresses in high stress regions. Hence, the necessity of assessing the complete FOV, including the aortic bifurcation, is of minor importance. When the proximal and distal shoulders of the AAA are in the FOV, peak wall stresses can be detected adequately.

1. Introduction

Rupture of an abdominal aortic aneurysm (AAA) leads to a fatal hemorrhage and death in 70–90% of all cases (Budd et al., 1989). Therefore, current guidelines suggest aortic aneurysm repair when the aortic diameter exceeds 5.5 cm, or when it has grown more than 1 cm per year (Moll et al., 2011; The UK Small Aneurysm Trial Participants, 1998). Using these evidence based guidelines, the overall risk of surgery outweighs the risk of rupture. However, on a patient-specific basis these guidelines can be inaccurate for individuals and have proven to be inadequate (Conway et al., 2001; Nicholls et al., 1998; Valentine et al., 2000). Studies have shown that aneurysms may rupture below these thresholds while others remain stable even when they exceeded the threshold diameters suggested in these guidelines. Therefore, previous studies have suggested new, additional rupture risk estimators, based on the mechanical behavior of the AAA wall.

Wall stress analysis has been introduced to predict the potential rupture risk of the AAA wall, which is mostly performed using computed tomography (CT) and sparsely with magnetic resonance imaging (MRI) data. Studies have shown that the peak and 99th percentile wall stresses are related to potential rupture risk (Fillinger et al., 2003, 2002; Gasser et al., 2014, 2010; Khosla et al., 2014; Speelman et al., 2008; Venkatasubramaniam et al., 2004; Vorp, 2007; Vorp et al., 1998). In a study by (Vande Geest et al., 2006), a rupture potential index was defined, which related the local wall stress to the wall strength. In general, the patient-specific geometry is assessed from neck to bifurcation, including a small portion of the iliac arteries. Next, a uniform wall thickness, a generic and population-based material, and boundary conditions are incorporated. The boundary conditions consist of the luminal pressure, mostly derived from a pressure measurement in the upper arm, and fixation of the neck and iliac arteries.

Despite promising results, these models are not widely accepted and used in the clinical setting yet. The current approach suffers from several drawbacks, such as the use of ionizing radiation and nephrotoxic contrast agents for CT imaging, the long scanning time and high cost for MRI, and the unavailability of patient-specific material properties. Three-dimensional ultrasound (3D US) imaging overcomes abovementioned disadvantages of CT and MR, and even enables the possibility to acquire the vessel's motion during the cardiac cycle. Using the dynamic behavior of the AAA wall, finite element models can be calibrated to the vessel motion and thereby

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more patient-specific material properties can be derived. Also patient-specific and FEM-regularized strains (Derwich et al., 2015; Wittek et al., 2015, 2013) and wall stresses (van Disseldorp et al., 2015) become available using 3D US. The drawbacks of 3D US are the low contrast compared to CT and MRI, but most importantly, the limited field-of-view (FOV) (Fig. 1).

In many cases, multiple ultrasound acquisitions are required to capture the complete AAA geometry, which demands sophisticated US registration techniques to combine both US acquisitions, which is not trivial and may lead to unexpected outcomes (Kok et al., 2015). Besides the limited FOV, the aortic bifurcation is not easily detected. The bifurcation lies deep, is small with respect to the transducer, and contrast is low, because of the dorsal angulation of the common iliac arteries. The latter is primarily the result of the fact that the ultrasound waves propagate mostly parallel to the vessel wall, resulting in a reduced signal to noise ratio. This makes proper imaging, and accurate segmentation of the bifurcation and subsequent iliac arteries (used to fixate the model) cumbersome when using ultrasound. However, the necessity of including a large portion of the iliac arteries, or even the bifurcation for that matter, has not been clearly proven or analyzed.

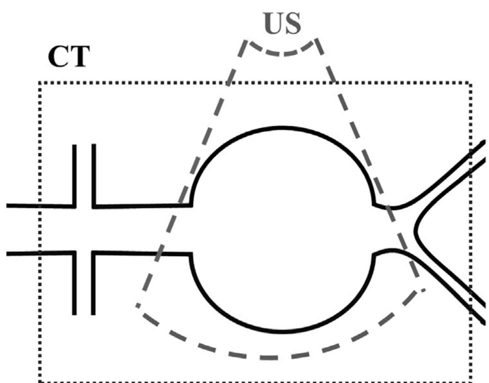

Fig. 1. Graphical illustration of an abdominal aortic aneurysm (AAA) with the field-of-view of computed tomography (CT) (black dotted line) and that corresponding to ultrasound (US) imaging (gray striped line).

In this study, the influence of a limited FOV on wall stress results is examined. Wall stress analysis was performed on CT-based AAA geometries, while systematically limiting the FOV until the geometry was comparable to that obtained in a single 3D US acquisition. Thereby the conventional sites used for fixating the model, i.e., applying the boundary conditions were excluded. Changes in wall stresses and location of peak stresses were analyzed and compared to the full geometry as measured with CT.

2. Materials and methods

2.1. Study population

Pre-operative computed tomography angiography (CTA) scans of a random selection of 10 patients (age 60–82 years) were included retrospectively. The CT-data were acquired as part of the normal clinical workflow prior to endovascular aortic repair (EVAR). The maximum aortic diameter ranged from 44 to 57 mm.

2.2. Segmentation

The CTA scans were segmented using the semi-automatic Hemodyn software package developed by Philips Medical Systems (Best, The Netherlands) and the

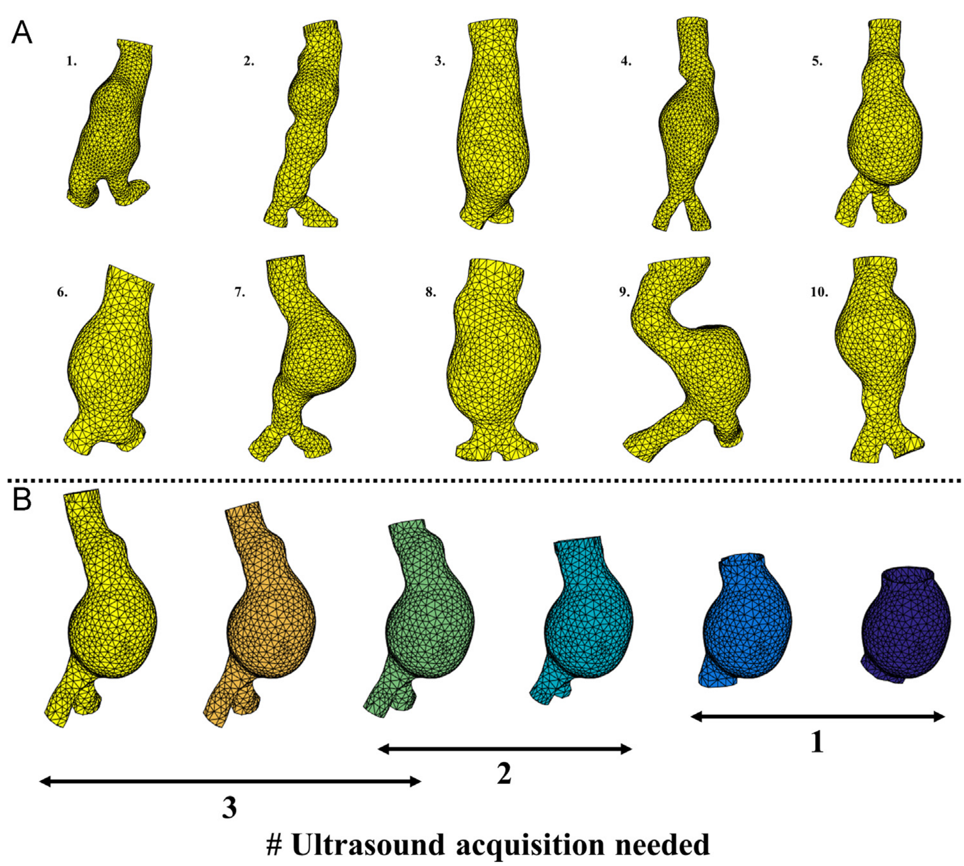

Fig. 2. The geometries of all 10 included patients based on computed tomography (A). In B an example of the shortening procedure is shown for aneurysm 5: The complete geometry of an abdominal aortic aneurysm (AAA) (left) is shortened 10 mm in the centreline direction at the proximal and distal. The final cropped AAA geometry (right) represents a typical field-of-view which can be achieved with one single three dimensional ultrasound acquisition. The larger AAA geometries (left) need two or more ultrasound acquisitions to capture the complete field-of-view.