Mechanical characterisation of abdominal aortic aneurysm, using 4D ultrasound

Marc van Sambeek
Emiel van Disseldorp, Frans van de Vosse, Richard Lopata

Vascular Surgery
Catharina Hospital Eindhoven
The Netherlands

Cardiovascular Biomechanics
Eindhoven University of Technology
The Netherlands
Disclosure

Marc RHM van Sambeek

I have the following potential conflicts of interest to report:
Consulting and speakersfee
WL Gore & Associates
Medtronic
Unrestricted research grants
Medtronic
W.L Gore & Associates
Philips Medical Systems
From a biomechanical point of view, aneurysms will rupture if the mechanical stress exceeds the local strength of the vessel wall.

Therefore, the state of the aortic wall mechanical properties of the wall and stresses in the wall combined could be a better predictor for rupture risk than AAA diameter.
In recent years, 3-D image-based biomechanical models using finite element analysis (FEA) have been on the rise, providing additional parameters such as wall stress.

Wall stress analysis has been introduced to “predict” growth and potential rupture risk of the AAA wall, which is mostly by CT and sparsely MR.
CT-scan vs 4-D Ultrasound

CT-imaging
- Geometry
- Mechanical properties
- Wall thickness
- Blood pressure

Ultrasound
- Geometry
- Deformation
- Wall thickness
- Blood pressure

Literature

Semi patient-specific mechanical AAA model

Patient-specific mechanical AAA model

WALL STRESS

Mechanical properties
Pre-operative monitoring

Acquire 3D and 4D (3D+t) US:
- 3D acquisition for geometry
- 4D acquisition for dynamic behaviour

Now: Following > 320 patients
- Longitudinal study
- Clinical CT data for verification

Goal: Develop and validate a patient-specific method using 4D ultrasound

Equipment:
- Philips iU22 X6-1 matrix probe
  - $f_c = 3.5$ MHz
Where are we at this stage?

Structured analysis of all ultrasound data sets

2017

✓ adequate geometrie
✓ adequate wall stress and mechanical parameters

van Disseldorp et al. JBM 2016; 49:2405-12

2018

• increase field of view
• automatic segmentation
Multi-perspective Imaging + automatic segmentation

3D US acquisition

Automatic segmentation and registration
Active deformable contour models

First: 2D slice-by-slice approach
Afterwards: 3D regularization

The segmentation algorithm is based on the well-established active deformable contour models or snakes as introduced by Kass et al. (1988)

These active contours are energy minimizing functions that attract towards image features (in this case the aortic wall) and on the other hand are constrained by internal forces that resist deformation of the contour.
Segmentation and registration

Segmentation
- Proximal segmentation
- Distal segmentation

Registration/merge
- First estimate based on centerline
- Optimalisation

Combine
- Merge US data
- Final segmentation
Re-segmentation of merged sub-volumes
Validation with CT

Quantitative results:
- SI single: 0.88 – 0.95
- SI multi: 0.87 – 0.94
Wall stress verification

Wall stress verification with CT (N=40)

Calculate diastolic stresses and inflate to patient-specific systolic pressure

Percentile Von-Mises wall stress for overlapping region of AAA
Conclusion and future perspective
Wall stress follows the typical trend

No difference between non- and ruptured cases

In 3 out of 4 ruptured cases, stiffness was lower compared to the average values
Mechanical characterisation of abdominal aortic aneurysm, using 4D ultrasound

Marc van Sambeek
Emiel van Disseldorp, Frans van de Vosse, Richard Lopata

Vascular Surgery
Catharina Hospital Eindhoven
The Netherlands

Cardiovascular Biomechanics
Eindhoven University of Technology
The Netherlands