Can rupture be predicted by 4D US wall stress analysis

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Disclosure

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I have the following potential conflicts of interest to report:

Consulting and speakersfee

- W.L Gore & Associates
- Medtronic

Unrestricted research grants

- Medtronic
- W.L Gore & Associates
- Philips Healthcare
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
the 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 performed using CT and sparsely with MRI.
Mechanical modeling:

Blood Wall

However there are limitations with CTA and MRI:
Semi patient-specific mechanical AAA model
Unsuitable for longitudinal studies
Pre-operative monitoring

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

Now:
- Following > 300 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
CT-scan vs 4-D Ultrasound

CT-imaging
- Geometry
- Mechanical Properties
- Wall Thickness
- Blood Pressure

Ultrasound
- Geometry
- Deformation
- Wall Thickness
- Blood Pressure

Flowchart:
- Semi Patient-Specific Mechanical AAA Model
- Wall Stress
- Patient-Specific Mechanical AAA Model
- Wall Stress
- Mechanical Properties
From strain imaging & elastography to patient specific modelling
4D Ultrasound data

- No ionizing radiation/contrast
  - Allows follow-up over time
- 4D data
  - Mechanical characterization
- Limited field of view
  - Can we obtain an accurate geometry?
- Low contrast
  - Can we obtain the same wall stresses as with CT?
Limited field of view

High stress regions:

Von-Mises wall stress:

You need the shoulders

You do not need the bifurcation

van Disseldorp et al. JBM 2016; 49:2405-12
Limited field of view

High stress regions:

Von-Mises wall stress:

Reconstruction

You need the shoulders

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

Similar geometry

25\textsuperscript{th} to 99\textsuperscript{th} percentile wall stress in agreement

van Disseldorp et al. EJVES 2016;52:635-42
Low contrast

Similar geometry

25th to 99th percentile wall stress in agreement

van Disseldorp et al. EJVES 2016;52:635-42
Model predictive clinical decision support

4-D ultrasound \(\rightarrow\) Full patient specific AAA modeling

Limitations:
- Field-of-view (‘need the shoulders’)
- Manual segmentation &
- Uniform wall thickness

Current work:
- Multi-view 4D US
- Automatic segmentation
- RF capture
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