Different AAA biomechanical rupture risk assessment approaches. Model fidelity versus diagnostic predictability

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Based on a large number of interventions, a maximum transverse diameter of, on average, 55 mm appears to be the best indicator for elective AAA repair.

... but not for the individual patient!

The UK Small Aneurysm Trial, Lancet 1998

Poor specificity and sensitivity
Nine out of ten operations are unnecessary
Biomechanical risk assessment

FE simulation integrated in clinical workflow

Clinical problem → Computer model → Model prediction → Clinical intervention

Biomechanical model fidelity?  Which rupture risk index?
Peak Wall Rupture Risk (PWRI)

\[ PWRI = \max \left[ \frac{\text{Wall stress}}{\text{Wall strength}} \right] \]

Vande Geest, et al, ANABIOENG, 2006
Gasser et al, EJVES 2010
PWRI explains why....

... AAA rupture (retrospectively)
Maier et al, ABME 2010; Gasser et al, EJVES 2010/2014, ...

... AAA rupture (quasi-prospectively)
Erhart et al, JEV 2016, Siika et al (submitted)

Biomechanical risk collocates with ...

... wall patho-histology  Hyhlik–Dürr et al, JEV 2014
... FDG-uptake  Reeps et al, JVS 2008, Nchimi et al. Circ CVascImag 2013
... site of rupture  Erhart et al, JEV 2016, Siika et al (submitted)

Biomechanical stress influences growth rates
Martufi et al, JEV 2016; Lindquist Liljeqvist et al, JVS 2016
Validation

PWRI explains why AAA in females rupture at smaller diameters

Larsson, et al, JVS 2011; Gasser et al, EJVES 2014
Biomechanical Rupture Risk Assessment
A Consistent and Objective Decision-Making Tool for Abdominal Aortic Aneurysm Patients

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Input information

- Geometry
- Tissue properties
- Biology
- Constitutive modeling
- Patient characteristics
- Boundary and initial conditions
- Discretization
- Loading conditions

Validated with respect to the simulation objective
How complex should the wall model be?

Man et al, Med Eng & Phys, 2018
Polzer et al, Med Eng & Phys, 2013
Probabilistic Rupture Risk Index (PRRI)


AAA wall thickness distribution


AAA wall strength distribution

PRRI = \int_0^{\infty} \left( \rho_{\text{PWS}} \int_0^{\rho_{\text{PWS}}} \rho_Y \, d\rho_Y \right) \, d\rho_{\text{PWS}}


Polzer & Gasser, Royal Soc. Interface, 2016
Study design

48 cases from Saint Ann Faculty Hospital Brno, and General Faculty Hospital Prague, Czech Republic

In 2009 to 2016 a CT-A scans showed an intact AAA

No repair has been carried out (patient noncompliance or comorbidities)

16/48 cases ruptured at a later time point
Method/Analysis

Risk indices
- Maximum diameter
- Peak Wall Rupture Index (PWRI)
- Probabilistic Rupture Risk Index (PRRI)

Sensitivity analysis
- Receiver Operator Characteristics (ROC)
- Predict rupture in 3/6/9/12/18/24/more month
Six month predictability

Receiver Operator Characteristics (ROC)
Conclusions

Biomechanics-based risk indices have higher predictability than the diameter

PRRI slightly better than PWRI

Predictability decreases with the time to the event

Integration of additional risk factors might further improve PRRI and PWRI

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