

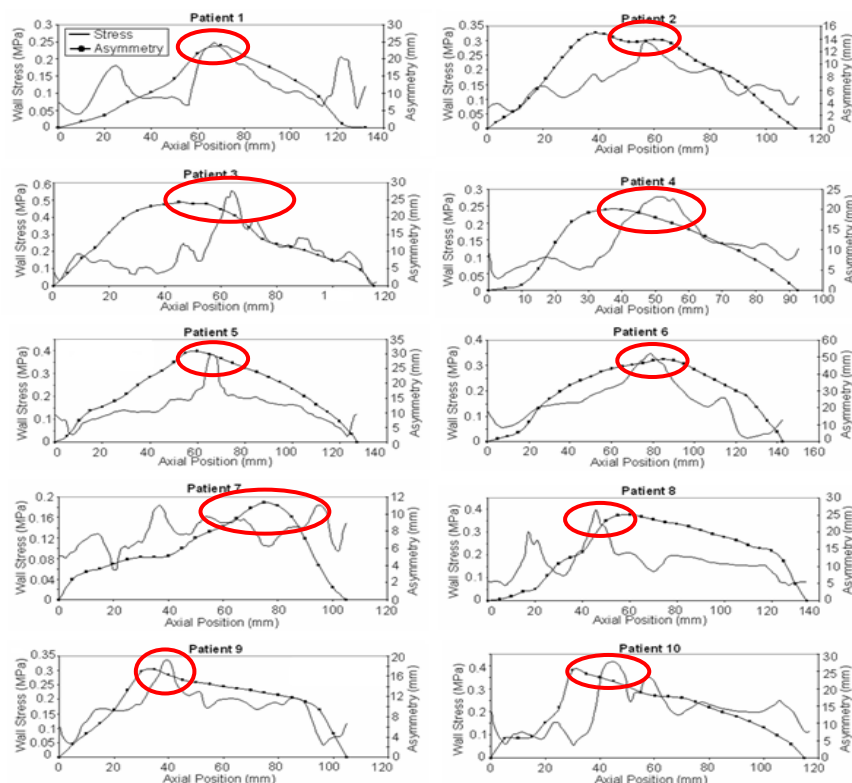


REGIONAL MECHANICAL PROPERTIES OF AAA TISSUE AND FINITE ELEMENT ANALYSIS OF RUPTURE

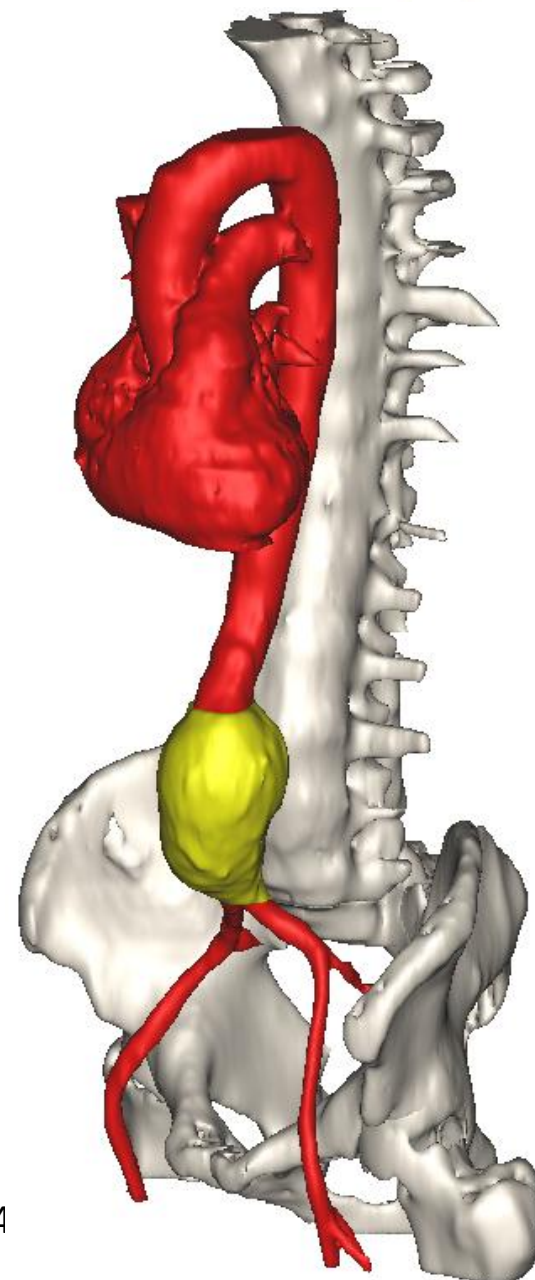
Professor Tim McGloughlin

Centre for Applied Biomedical Engineering Research (CABER),
Materials and Surface Science Institute (MSSi),
Head, Department of Mechanical, Aeronautical, and Biomedical Engineering,
University of Limerick, Ireland.

Asymmetry of Abdominal Aortic Aneurysms



Wall Stress - Asymmetry Relationship



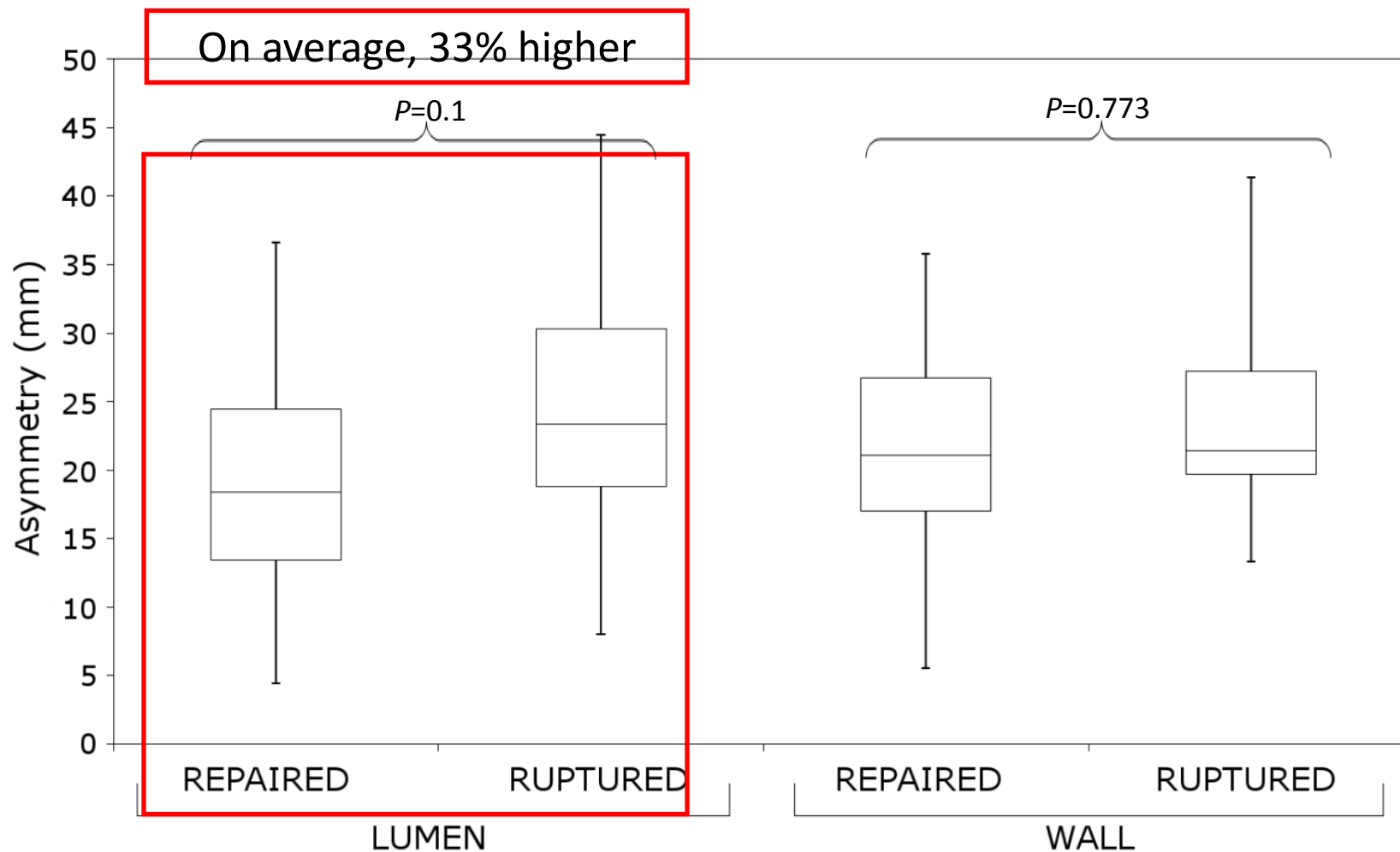
Doyle et al, Journal of Vascular Surgery 2009;49:443-4

More Recently....

- Improved and automated the asymmetry measurement
- ILT included into the models
 - Arguably important
- Large number of cases ($n = 52$)
 - Electively repaired = 42
 - Ruptured = 10



3D Asymmetry

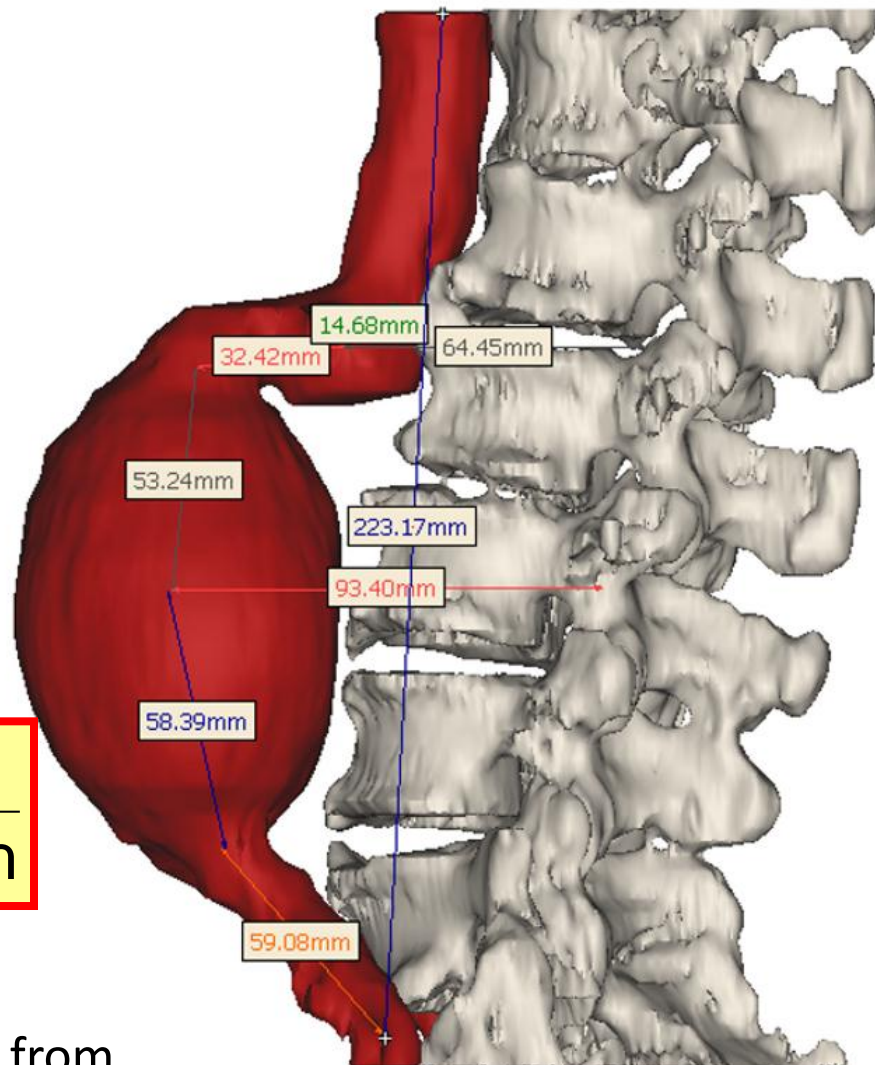


FEARI

- Same cohort as before
 - 52 cases
 - Repaired = 42
 - Ruptured = 10

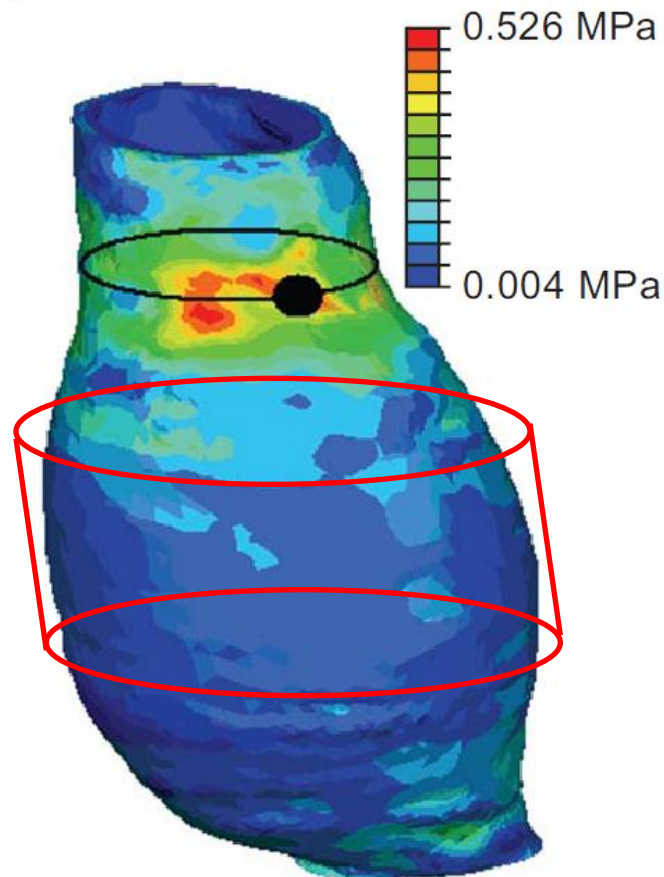
$$\text{FEARI} = \frac{\text{FEA Wall Stress}}{\text{Averaged Wall Strength}}$$

- Averaged Wall Strength obtained from previous reports on tensile strength



FEARI – Results

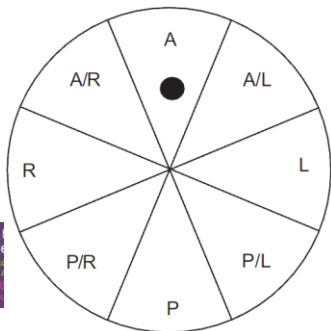
- Peak stress primarily at regions of inflection
 - Not at maximum diameter region



$$\text{FEARI} = \frac{0.5263}{0.7744}$$

$$\text{FEARI} = 0.6796$$

68% chance of rupture

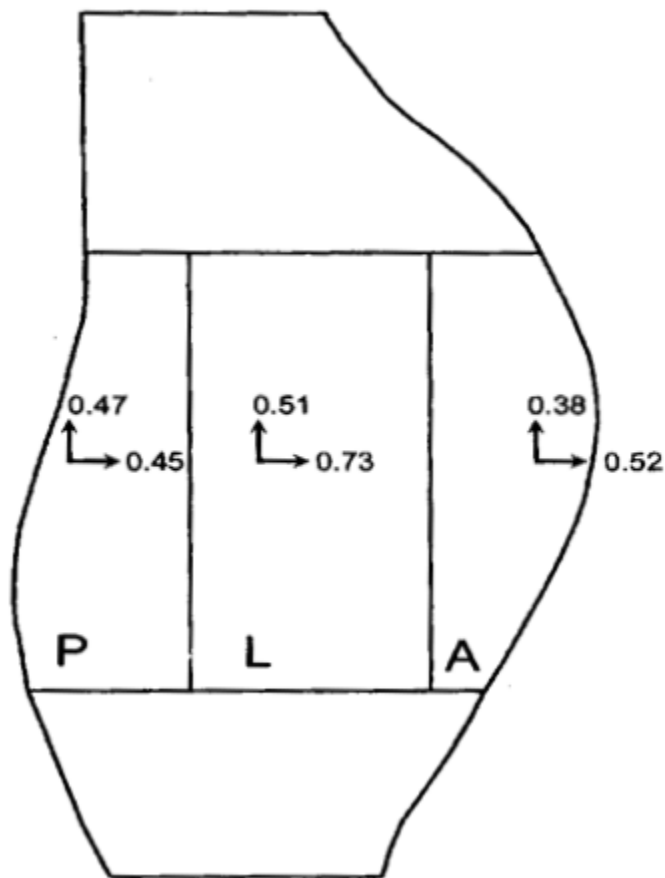


Summary of earlier work

- Asymmetry is **33% higher** in ruptured AAAs
 - Repaired = 18.9 mm
 - Ruptured = 25.2 mm
$$\left. \begin{array}{l} \text{Repaired} = 18.9 \text{ mm} \\ \text{Ruptured} = 25.2 \text{ mm} \end{array} \right\} P = 0.1$$
- FEARI is **60% higher** in ruptured AAAs
 - Repaired = 0.65
 - Ruptured = 1.04
$$\left. \begin{array}{l} \text{Repaired} = 0.65 \\ \text{Ruptured} = 1.04 \end{array} \right\} P = 0.019$$
- *However, size (diameter) remains an influencing factor and mechanical property information is not patient specific*

MOTIVATION

- Mechanical properties of AAAs vary regionally



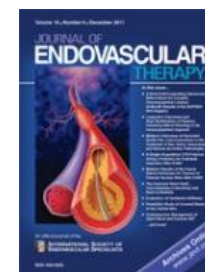
P – Posterior
L – Lateral
A – Anterior

Regional Variations in Yield Stress
(N/mm²) (Thubrikar 2007)

MOTIVATION

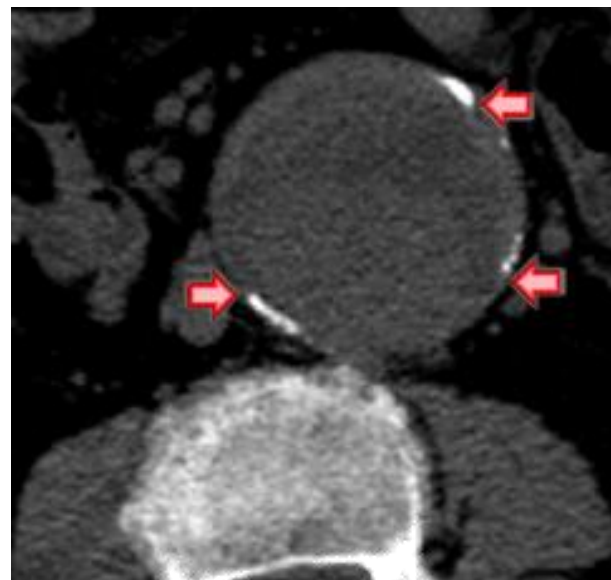
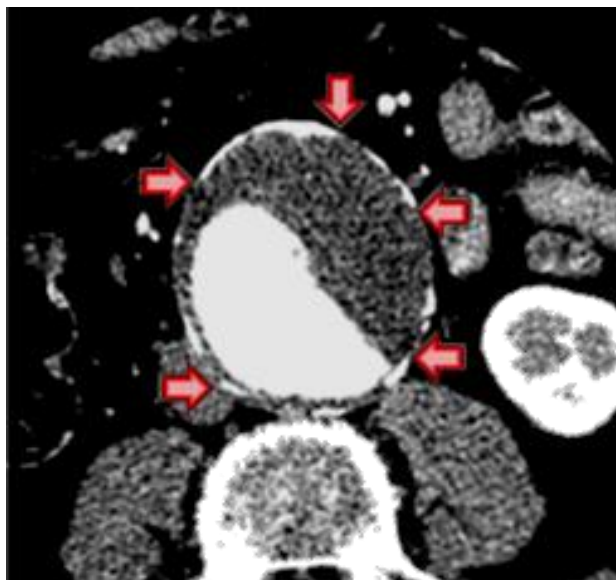
- Local variations → large influences on stress distributions and magnitudes (Van Dam, 2007)
- Very little work on local nature of human AA tissue
- Assumption of stress-free in vivo configuration
- Previous studies: wall and thrombus = homogeneous material
- Include local mechanical properties into rupture risk analysis

Tierney et al., JEVT, 2012. 19(1): p. 100-114.



METHODOLOGY

- Gated CT Acquisition
- Use of anatomical markers for segmental elastic quantification (Hudetz Incremental Modulus, Compliance, Circumferential Cyclic Strain)



Anatomical Markers

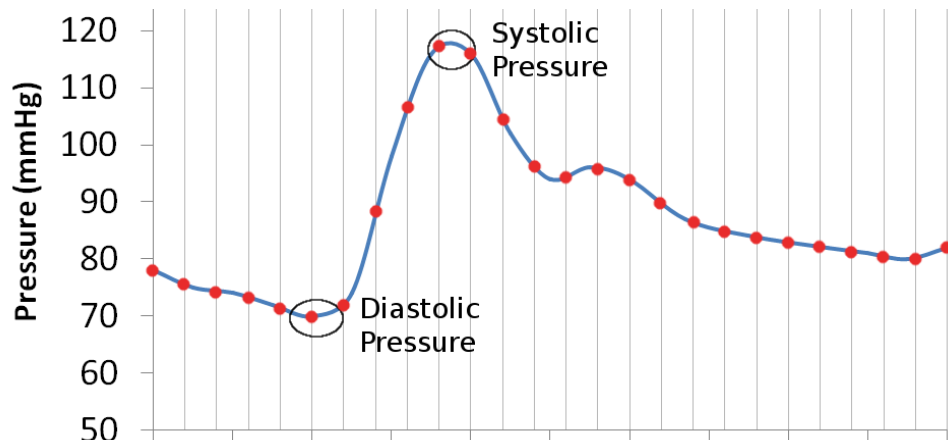


METHODOLOGY

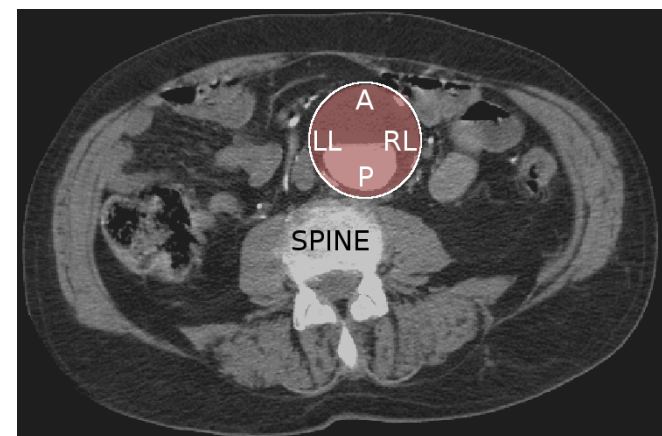
- Gated CT Acquisition
- Use of anatomical markers for segmental elastic quantification (Hudetz Incremental Modulus, Compliance, Circumferential Cyclic Strain)
- Generation of segmental strain energy functions and prestress calculation based on average AAA behaviour
(Raghavan and Vorp, 2000)
- Realistic AAA geometry - Finite Element Analysis
- Regional Prestress Rupture Index (RPRI) – Combination of FEA Stresses with tissue mechanical behaviour

ELASTICITY QUANTIFICATION

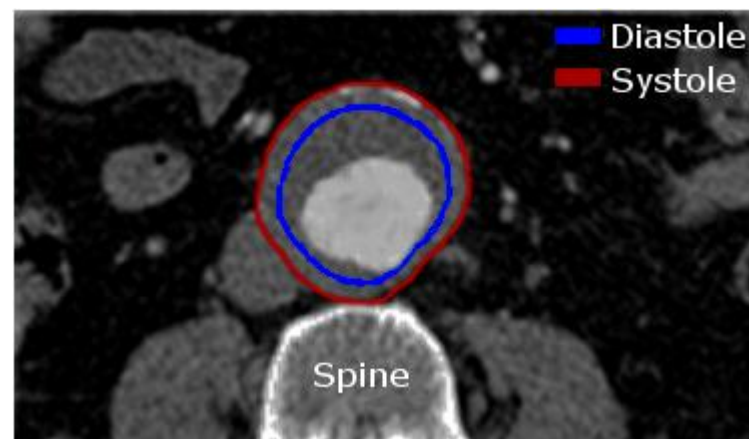
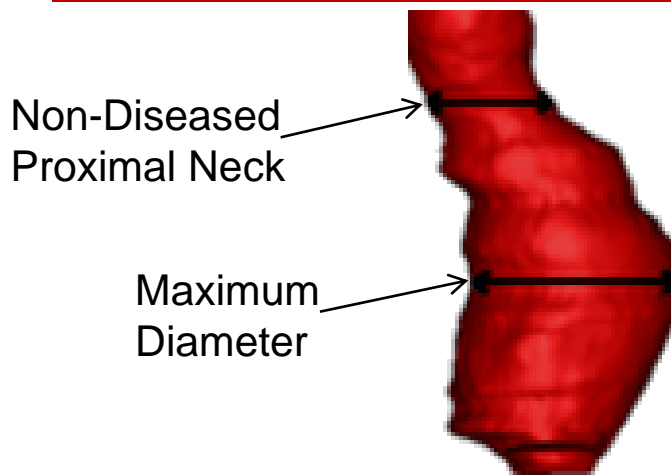
Dynamic Scans - 20 images/cycle



4 segments



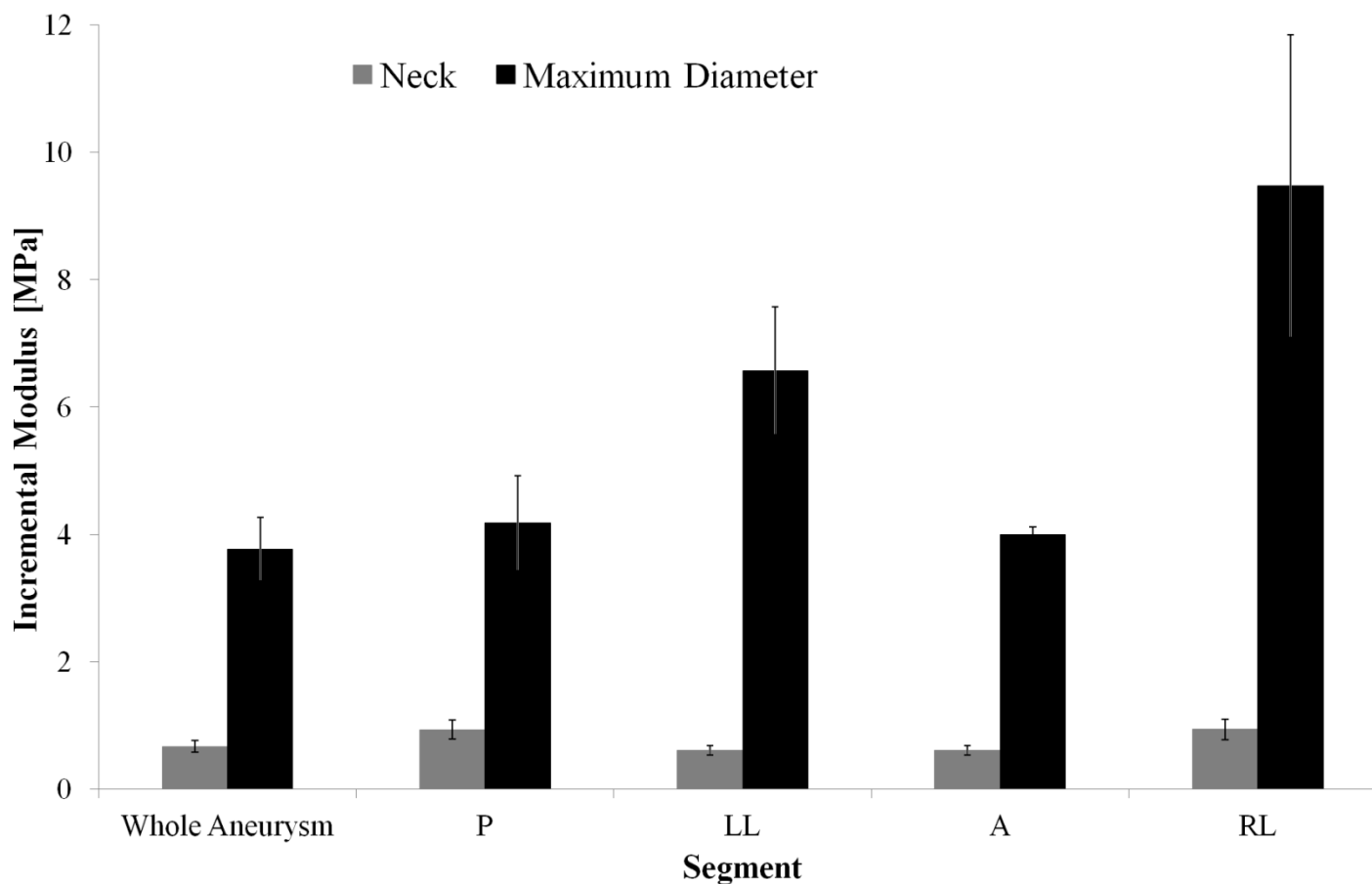
2 Slices – Undilated Neck and Max Diameter



ELASTICITY QUANTIFICATION

HUDETZ INCREMENTAL MODULUS

$$H_{\theta\theta} = 2 \left[\left[\frac{(d_{out} \times d_{in}^2)}{(\Delta d_{out}/\Delta P)} \right] + (P \times d_{out}^2) \right] \times \left[\frac{1}{(d_{out}^2 - d_{in}^2)} \right]$$

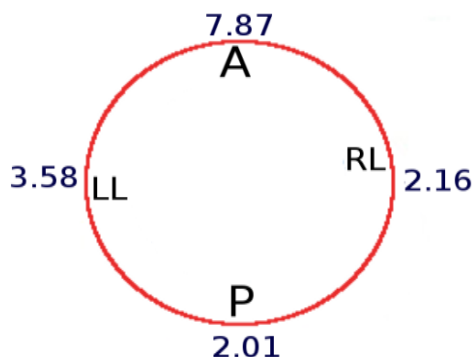
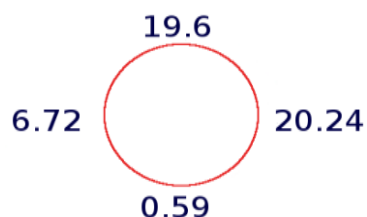


ELASTICITY QUANTIFICATION

Neck

Maximum Diameter

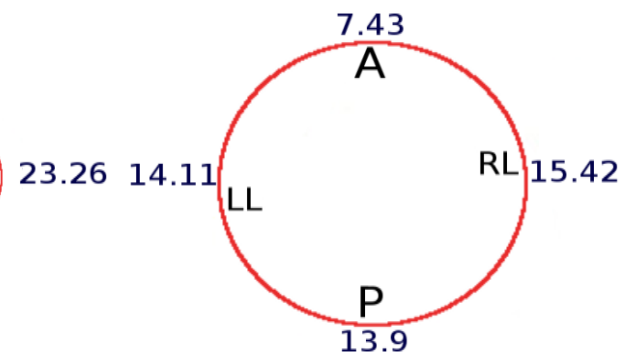
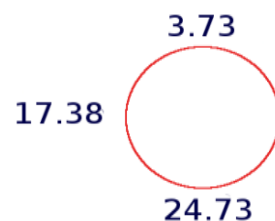
Patient 1



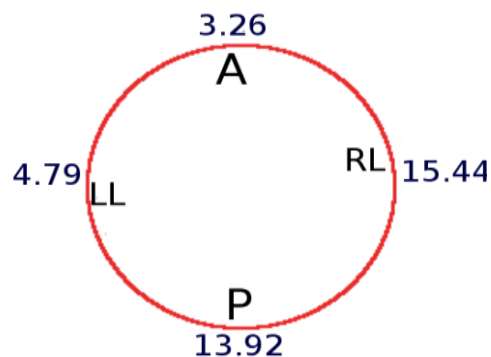
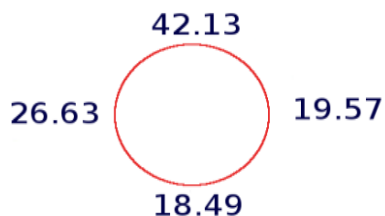
Neck

Maximum Diameter

Patient 2



Patient 3



Compliance =

$$\frac{\Delta L}{(L_s (\Delta P))}$$



ELASTICITY QUANTIFICATION

$$\text{Circumferential Cyclic Strain} = \frac{1}{2} \left[\left(\frac{L_s^2}{L_d^2} \right) - 1 \right]$$

	P	LL	A	RL	Whole Aneurysm
Patient 1 - Neck	0.5%	22%	21%	7%	13%
Max diameter	1.8%	1.7%	1.8%	6%	3%
Patient 2 - Neck	7.4%	20.9%	19.4%	6.9%	13.5%
Max diameter	5.0%	10%	11%	5.2%	8.2%
Patient 3 - Neck	20%	11.2%	11.9%	31.9%	17.3%
Max diameter	5.6%	1.1%	4.6%	0.5%	2.5%
Average - Neck	9.3%	18.4%	17.8%	15.1%	14.7%
Max diameter	4.2%	4.5%	6.1%	4.4%	4.7%

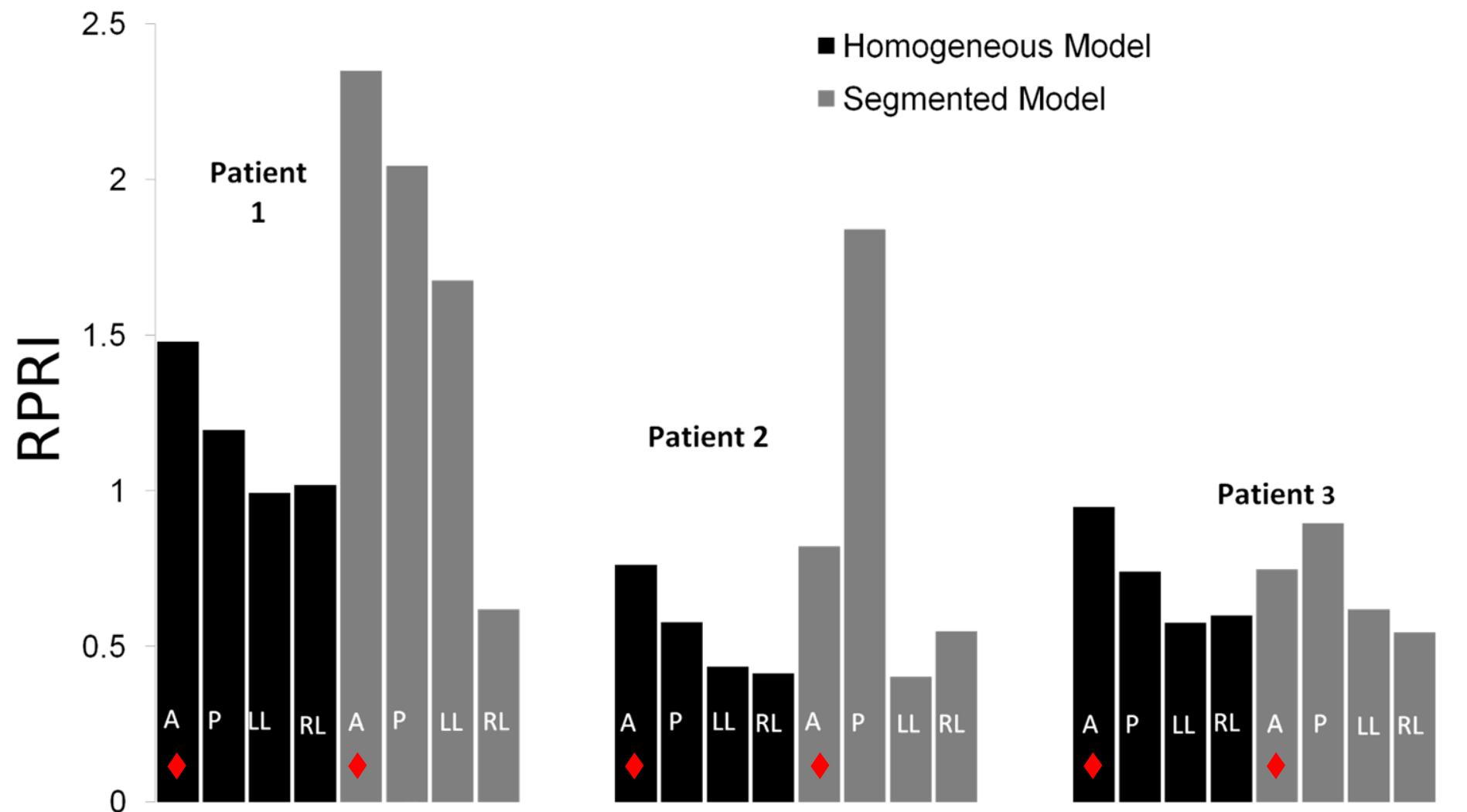
REGIONAL PRESTRESS RUPTURE INDEX (RPRI)

Principle : A material will fail when total stress acting on the wall exceeds the strength of the wall

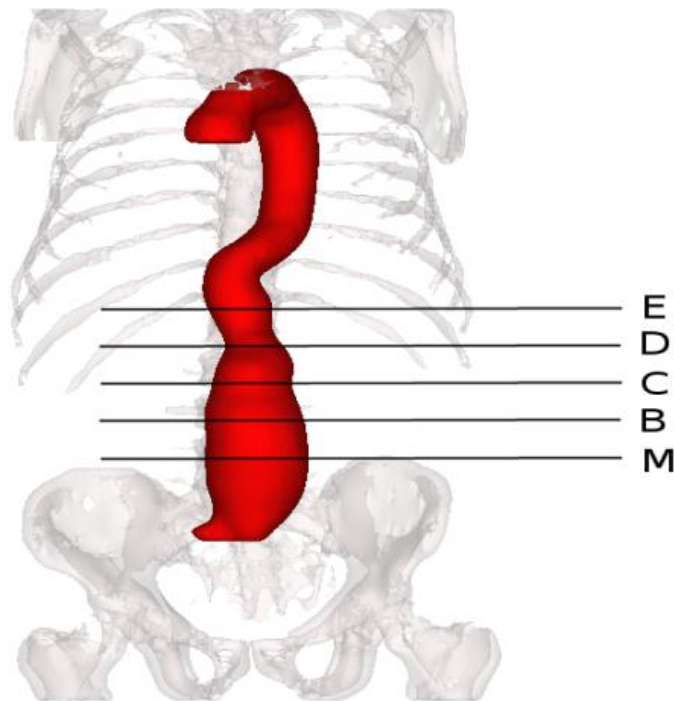
$$RPRI_R = \frac{(PeakStress_R + Prestress_R)}{WallStrength_R}$$



REGIONAL PRESTRESS RUPTURE INDEX (RPRI)

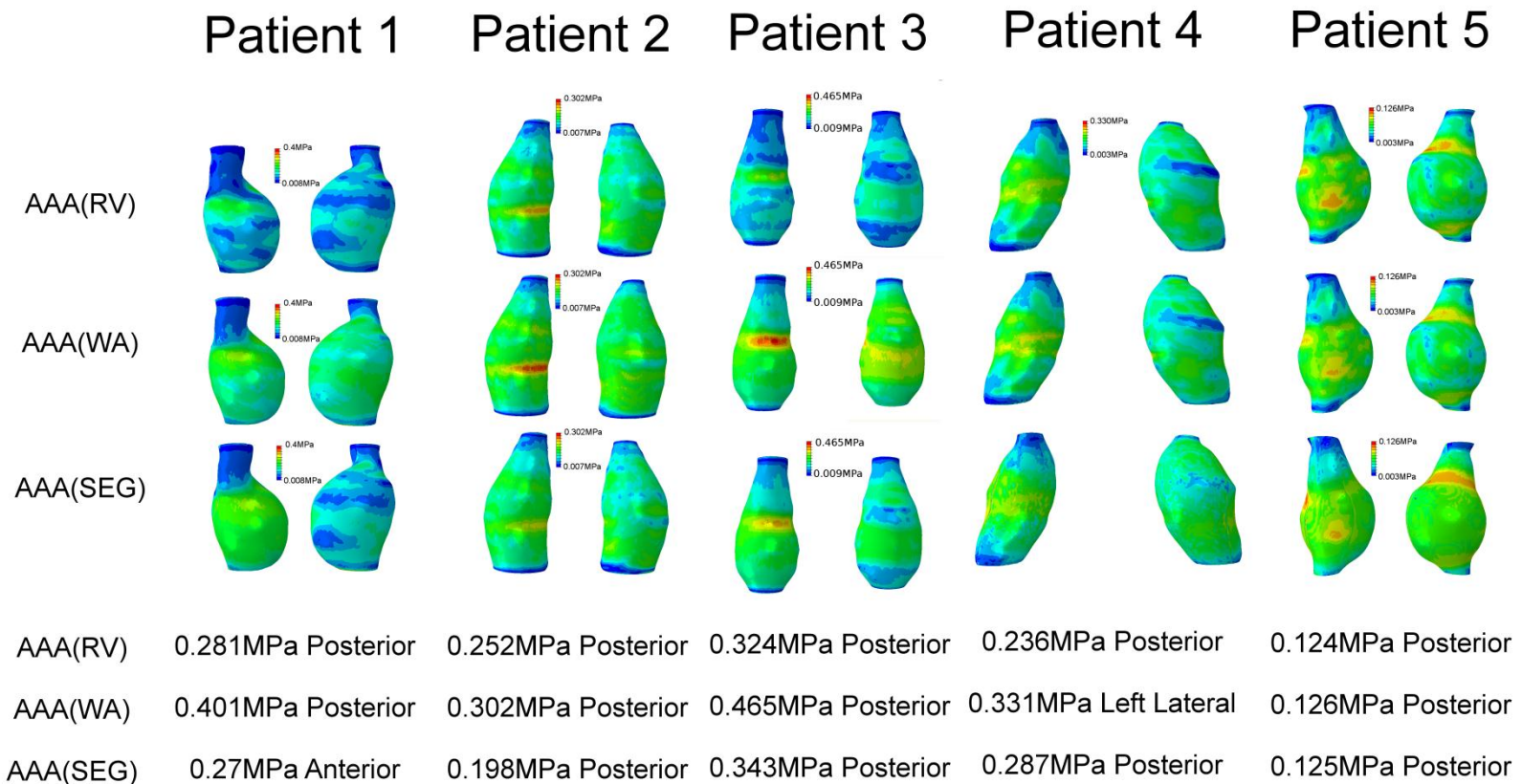


Patient Specific Cardiac Gated CT



Maximum diameter, M, and 4 levels proximally (30mm apart) from the level of maximum diameter (Figure M, B-E). Diameter and circumference changes were measured at each time point of the cardiac cycle. To observe the local regional variation in mechanical properties, each aortic image was sectioned into segments: anterior (A), posterior (P), right lateral (RL), and left lateral (LL). The circumferential lengths of these segments were measured and changes calculated to allow for elasticity calculation.

***In vivo* Quantification of Regional Abdominal Aortic Aneurysm
Elastic Properties: Implications for FE Analysis Tierney et al
(JEVT, in review)**



Anterior and Posterior view of Von Mises wall stress distributions for AAA(RV), AAA(WA) and AAA(SEG). Peak stresses and location for each model are displayed in the image.



CONCLUSION

This work contributes to the understanding and quantification of the local regional properties in healthy and diseased aorta

A greater understanding of the local AAA properties and their incorporation into FE models is essential and may reduce the uncertainty associated with AAA rupture prediction



ACKNOWLEDGEMENTS

- Dr Aine Tierney, Dr Anthony Callanan and Dr Barry Doyle (CABER, University of Limerick)

- Dr. Marika Ganten, Dr. Stefan Delorme, Department of Radiology, Heidelberg, Germany

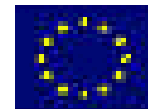
- Herman J. Zandvoort, M.D.²; Joost A. van Herwaarden, M.D, Department of Vascular Surgery, University Medical Center Utrecht, The Netherlands

- Irish Research Council for Science, Engineering (EMBARC Scholarship, Tierney)

- Irish Research Council for Science, Engineering and Technology (IRCSET) - Marie Curie International Mobility Fellowship co-funded grant (Callanan and Doyle)



Irish Higher Education Authority Irish National Development Plan European Union Structural Funds





UNIVERSITY of LIMERICK

OILLSCOIL LUIMNIGH



Thank you for your attention



3rd International Meeting
on Aortic Diseases
New insights into an old problem
CHU Liege, FAD, APF
October 4-6 2012
Liege - Belgium