### Combined Modalities in Patient-Specific Hemodynamic Modeling for Intracranial Aneurysm Evaluation Kurt Sansom

### What's the Goal?

- The objective of this project is to couple intracranial vessel-wall MRI (VWMRI) with fluid mechanic in-silico modeling (CFD) as a better predictor of rupture risk.
- Hypothesis:
  - Areas of wall enhancement and thinning identified from intracranial VWMRI, together with abnormal hemodynamic stresses in the aneurysmal wall computed from CFD, can provide an accurate rupture risk prediction, and that this will be validated with the presence of inflammatory infiltrates and wall thinning detected in histology.
  - inflammatory infiltrates and wall thinning detected in histology.

# **Obligatory Cerebral Aneurysm slide**

UIA occurring 3.2% of the

High Morbidity (~50%) in

RIA and 80% who survive

live with impariment

population<sup>1</sup>

Aneurysms

An abnormal bulge or ballooning of a blood vessel, aneurysms occur in all parts of the body, but are most common in the brain and aorta.

#### How aneurysms form

Over time, artery walls gradually become thinner in spots and the blood flow causes the weakened wall to swell. Increased blood pressure may cause the bulge to rupture and bleed internally. A ruptured aneurysm is potentially life-threatening.

Saccular: The most common type of aneurysm bulges from one side of the artery, usually near a branch, and has a distinct neck at its base.

#### Treating brain aneurysms

Doctors use two methods of surgical treatment, and the end result of each is that the flow of blood to the weakened area of the artery is stopped, eliminating the risk of a rupture.

#### The coil method

Inserted into a catheter that is fed through the body to reach the aneurysm, a thin wire coils inside the bulge and detaches. When the bulge is packed with coils, the flow of blood to the aneurysm is blocked. Eventually a clot forms taking away the risk of rupture.

#### The clip method

Inserted through a flap cut in the skull, the brain is moved to expose the bulge. A tiny spring clip is placed on the neck of the aneurysm to block the flow of blood into the bulge. The bulge is then pierced and deflated. Doctors may inject dye to confirm that normal blood flow has been restored.



<sup>1</sup>Monique HM Vlak, Ale Algra, Raya Brandenburg, Gabriël JE Rinkel, Prevalence of unruptured intracranial aneurysms, with emphasis on sex, age, comorbidity, country, and time period: a systematic review and meta-analysis, The Lancet Neurology, Volume 10, Issue 7, July 2011. <sup>2</sup> (figure) http://dng.northjersey.com/media\_server/tr/2015/11/08chart/110815\_A\_Aneurysm-treatment.jpg

# What else can we measure Non-invasively?

- Medical Imaging
  - Contrast enhanced modalities obscure vessel wall
  - MRI offers blood suppression
    - Vessel wall imaging (VWMRI)





### Visual Comparison



### Are there other predictors besides size?

### • Hemodynamic

- Wall shear stress (WSS)
- Wall shear stress gradient (WSSG)
- oscillatory shear index (OSI)
- Viscous dissipation

 $\tau: \nabla u = \mu \Phi_v$ 

$$\Phi_{v} = 2\left[\left(\frac{\partial u_{x}}{\partial x}\right)^{2} + \left(\frac{\partial u_{y}}{\partial y}\right)^{2} + \left(\frac{\partial u_{z}}{\partial z}\right)^{2}\right] + \left(\frac{\partial u_{x}}{\partial y} + \frac{\partial u_{y}}{\partial x}\right)^{2} + \left(\frac{\partial u_{y}}{\partial z} + \frac{\partial u_{z}}{\partial y}\right)^{2} + \left(\frac{\partial u_{z}}{\partial x} + \frac{\partial u_{z}}{\partial z}\right)^{2} - \frac{2}{3}\left(\nabla \bullet u\right)^{2}$$

WSSG = 
$$\frac{1}{T} \int_0^T \sqrt{\left(\frac{\partial \mathbf{WSS}_p}{\partial p}\right)^2 + \left(\frac{\partial \mathbf{WSS}_n}{\partial n}\right)^2} \cdot dt$$

TAWSS =  $\frac{1}{T} \int_{0}^{T} |\mathbf{WSS}| \cdot dt$ 

$$OSI = 0.5 \left[ 1 - \left( \frac{\left| \int_0^T \mathbf{WSS} \cdot dt \right|}{\int_0^T |\mathbf{WSS}| \cdot dt} \right) \right]$$

## Specific Aims?

- Compute hemodynamic parameters and overlay them onto the VWMRI imaging.
- 2. Quantitatively map histological vessel wall disease state to VWMRI imaging and to hemodynamic wall stresses, independently of each other.
- 3. Develop a clinically viable rupture risk metric through retrospective analysis of outcomes for the patients imaged/modeled.