Wall Shear Stress Divergence as Rupture Indicator of Cerebral Aneurysms

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What is cerebral aneurysm?

An aneurysm is an abnormal ballooning of artery due to weakening of the arterial wall. Cerebral aneurysm is a category of aneurysm located at the Circle of Willis of human brain.

Research goal is to discriminate ruptured from unruptured aneurysms. Wall Shear Stress Divergence (WSSD) is proposed as a new rupture indicator.

WSSD identifies the state of stress on aneurysmal wall.

\[ WSSD = \frac{\partial T x}{\partial x} + \frac{\partial T y}{\partial y} + \frac{\partial T z}{\partial z} \]

- WSSD > 0 means “pulling” (tension)
- WSSD = 0 means “relax”
- WSSD < 0 means “pushing” (compression)

High OSI and high WSSD regions overlap with each other at the tips of ruptured aneurysms. The tip is very likely to be the rupture point. This overlapping feature is not present on unruptured aneurysms.

What is cerebral aneurysm?

A ruptured cerebral aneurysm can cause serious complication, including subarachnoid haemorrhage.

Dilemma of neurosurgeons

Natural history of this lesion has shown that the size of lesion has weak correlation with rupture risk.

Grid independence study shows

- Large divergence angle of WSS vectors during systole in ruptured aneurysms
- The divergence angle of WSS vectors shown in Figure 5 is nearly 180°. This means strong “pull” at the tip.
- >90,000 times of “pulls” in a day!!

In short, WSSD could be a good rupture risk indicator for cerebral aneurysms. Combination of WSSD, OSI and divergence angle can be useful for neurosurgeons to predict rupture risks.

Is existing OSI suitable as a rupture risk indicator?

Existing OSI only shows the oscillation of a WSS vector at a point and quantifies the disturbance of flow.

\[ OSI = \frac{1}{2} \left[ 1 - \frac{\int_0^T \vec{f} \cdot \vec{dt}}{\int_0^T |\vec{f}| dt} \right] \]

where,

- \( T \) = period of 1 cardiac cycle
- \( \vec{f} \) = WSS vector

Figure 1. A real-patient cerebral aneurysm (left)

A ruptured cerebral aneurysm can cause serious complication, including subarachnoid haemorrhage.

Figure 3. Aneurysms at the internal carotid artery. R1 and R2 are ruptured. U1 and U2 are unruptured.

Figure 4. An example showing the tetrahedral and prism elements that constitutes the meshed model. Notice the prism layers located at the arterial wall.

Figure 2. Risks associated with aneurysm rupture and surgical intervention if treated