Real time evaluation of flow patterns of AAA depending on intra-mural thrombosis using AneurysmFlow.

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AAA Rupture Risk Prediction

- AAA size
- AAA expansion rate
- Only 25% of AAAs rupture in a patient’s lifetime.

New tools for AAA rupture risk evaluation

- AAA wall shear stress
- Vessel asymmetry
- Finite element analysis rupture index (FEARI)
- Rupture potential index (RPI)
- Severity parameter (SP)
- Growth of intraluminal thrombus
- Method of determining AAA growth and rupture based on mathematical models

Darling RC, Circulation. 1977
Aneurysm Flow in Cerebral Aneurysm

Evaluation before and after Flow diverter

DSA with 60 fr/s 3-5cc contrast /s for 4 second

Contrast Transit time

Contrast concentration

Flow velocity

Flow direction
Real time hemodynamics for individual AAA

Concentric thrombus

Without thrombus
## AAA with/out Thrombus

<table>
<thead>
<tr>
<th></th>
<th>AAA with intramural thrombus</th>
<th>AAA without intramural thrombus</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AAA size (mm)</strong></td>
<td>64</td>
<td>64</td>
</tr>
<tr>
<td><strong>Thrombus burden</strong></td>
<td>Circumferential</td>
<td>minimal</td>
</tr>
<tr>
<td><strong>Radiation dose, mGycm² (DAP)</strong></td>
<td>13144</td>
<td>145469</td>
</tr>
<tr>
<td><strong>Percentage of radiation dose from total dose during EVAR</strong></td>
<td>8.7%</td>
<td>9%</td>
</tr>
<tr>
<td><strong>Vortex/Lineal blood flow</strong></td>
<td>Relatively laminated</td>
<td>Relatively vortex</td>
</tr>
<tr>
<td><strong>Contrast transit time (second)</strong></td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td><strong>Maximum contrast intensity at proximal to distal aorta</strong></td>
<td>?</td>
<td>?</td>
</tr>
</tbody>
</table>
Biomechanical Modeling for AAA Rupture Risk Prediction

- Finite element analysis (FEA)
- AAA wall shear stress
- AAA wall thickness
- AAA wall strength
- Intaluminal thrombus thickness
- Intraluminal thrombus strength
- Peak wall stress

Stanislav J. R. Soc. Interface: 2015
Abstract

Background and purpose—Hemodynamic factors are thought to play an important role in the initiation, growth and rupture of cerebral aneurysms. This report describes a study of the associations between qualitative intra-aneurysmal hemodynamics and the rupture of cerebral aneurysms.

Methods—210 consecutive aneurysms were analyzed using patient-specific CFD simulations under pulsatile flow conditions. The aneurysms were classified into categories depending on the complexity and stability of the flow pattern, size of the impingement region, and inflow concentration by two blinded observers. A statistical analysis was then performed with respect to history of previous rupture. Inter-observer variability analysis was performed.

Results—Ruptured aneurysms were more likely to have complex flow patterns (83%, p<0.001), stable flow patterns (75%, p=0.0018), 66% concentrated inflow (66%, p<0.0001), and small impingement regions (76%, p=0.0006) compared to unruptured aneurysms. Inter-observer variability analyses indicate that all the classifications performed are in very good agreement, i.e., well within the 95% confidence interval.

Conclusions—A qualitative hemodynamic analysis of cerebral aneurysms using image based patient-specific geometries has shown that concentrated inflow jets, small impingement regions, complex flow patterns, and unstable flow patterns are correlated with a clinical history of prior aneurysm rupture. These qualitative measures provide a starting point for more sophisticated quantitative analysis aimed at assigning aneurysm risk of future rupture. These analyses highlight the potential for CFD to play an important role in the clinical determination of aneurysm risks.
<table>
<thead>
<tr>
<th>Case number</th>
<th>ID</th>
<th>Run number</th>
<th>Flow complexity</th>
<th>Flow Stability</th>
<th>Inflow concentration</th>
<th>Flow impingement</th>
<th>Adicional remarks</th>
</tr>
</thead>
</table>

**1. Flow complexity**
- **Simple (S):** flow patterns consisting on a single recirculation zone or vortex structure within the aneurysm.
- **Complex (C):** flow patterns exhibiting flow divisions or separations within the aneurysm sac and containing more than one recirculation zone or vortex structure.

**2. Flow stability**
- **Stable (S):** flows patterns that persist (do not move or change) during the cardiac cycle.
- **Unstable (U):** flow patterns where the flow divisions and/or vortex structures move or are created or destroyed during the cardiac cycle.

**3. Inflow concentration**
- **Concentrated (C):** inflow streams or jets that penetrate relatively deep into the aneurysm sac and are thin or narrow in the main flow direction.
- **Diffuse (D):** inflow streams that are thick compared to the aneurysm neck and flow jets that disperse quickly once they penetrate into the aneurysm sac.

**4. Flow impingement**
- **Small impingement (S):** if the area of the impingement region is small compared to the area of the aneurysm (less than 50%).
- **Large impingement (L):** if the area of impingement is large compared to the area of the aneurysm (more than 50%).
6 cm sized AAA without intramural thrombosis
Treatment: EVAR
AF Dose: 20.3% of total procedural AK (mGy)

<table>
<thead>
<tr>
<th>Sac thrombosis</th>
<th>%</th>
<th>AAA (mm)</th>
<th>Lumen (mm)</th>
<th>RCIAA lumen</th>
<th>LCIAA lumen</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>63</td>
<td>57</td>
<td>16</td>
<td>16</td>
<td>13</td>
</tr>
</tbody>
</table>

AAA without sac thrombosis
Based on the average flow pattern (integrated over one full heart cycle), we observe a complex flow pattern that exhibiting flow divisions or separations within the aneurysm sac and containing more than one recirculation zone or vortex structure.
Pre-stent placement flow stability is unstable
- flow patterns where the flow divisions and/or vortex structures move or are created or destroyed during the cardiac cycle

After stent placement flow does not seem to radically change during the cardiac cycle and appear to be more Stable
Large impingement
: the area of impingement is large compared to the area of the aneurysm (more than 50%)
Flow transit time and Intensity

6 cm sized AAA without intramural thrombosis

Treatment : EVAR
AF Dose : 20.3% of total procedural AK(mGy)

Pre : contrast transit time of 1.2s from proximal to distal side of the aneurysm

Post : contrast transit time of 0.5s from proximal to distal side of the aneurysm
### 6 cm sized AAA without intramural thrombosis

**Treatment:** EVAR  
**AF Dose:** 20.3% of total procedural AK (mGy)

<table>
<thead>
<tr>
<th>Subject Number</th>
<th>Flow complexity</th>
<th>Flow Stability</th>
<th>Inflow concentration</th>
<th>Flow impingement</th>
<th>Contrast Transit time</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>How</strong></td>
<td>Average flow contrast flow and arrows integrated over heart cycle</td>
<td>Arrows speed and direction of blood in different phases of heart cycle (systole and diastolic phase)</td>
<td>Use 60fps DSA run</td>
<td>Flow color visualization</td>
<td>Time intensity Curve</td>
</tr>
<tr>
<td><strong>Classify</strong></td>
<td>complex (C)/ Simple (S)/ Not Sure (NS)</td>
<td>Stable (S) / Unstable (U) / Not sure (NS)</td>
<td>Concentrated (C) / Diffuse (D) / not sure (NS)</td>
<td>Small impingement (S) / Large (L) / Not Sure (NS)</td>
<td>From proximal to distal side of the aneurysm</td>
</tr>
<tr>
<td><strong>Result Pre-AF</strong></td>
<td>S</td>
<td>U</td>
<td>C</td>
<td>L</td>
<td>1.2s</td>
</tr>
<tr>
<td><strong>Result Post-AF</strong></td>
<td>S</td>
<td>S</td>
<td>D</td>
<td>S</td>
<td>0.5s</td>
</tr>
<tr>
<td><strong>DSA Angio (3fps)</strong></td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td><strong>DSA Angio (60fps) Pre Post</strong></td>
<td>C</td>
<td>U</td>
<td>C</td>
<td>S</td>
<td>Long Short</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>S</td>
<td>D</td>
<td>L</td>
<td>Short</td>
</tr>
</tbody>
</table>
Conclusion

• New rupture risk model of AAA reflecting individual characteristics including hemodynamics needs to be evaluated.

• AneurysmFlow has been used for evaluation of cerebral aneurysm before and after treatment.

• There seems be a possibility to apply this image to evaluation of rupture risk of AAA and treatment result.
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