Hemodynamic significance of vascular access stenosis: computational fluid dynamic analysis

Surendra Shenoy MD., PhD.
Washington University in St. Louis
School of Medicine
Missouri

Disclosures
No disclosures pertaining to the topic of presentation or the materials used and discussed in this presentation.
Presenter performs funded and non-funded research in vascular access and transplantation.

Proposed mechanism VNH

Upstream events
- Tissue quality
- Surgical trauma
- Genetic factors
- Old vein injury
- Blood flow changes

Downstream events
- Platelet activation
- Increased production of free radicals
- Upregulation of growth factors
- Degradation of extracellular matrix
- Smooth muscle cell migration

VNH

Problem of VA stenosis
Lack of understanding of upstream cause
What causes the stenosis?
Why in certain areas?
Why at certain times?

Emerging data suggest the key factor for injury is the shear stress caused by increased flow

Not all patients develop stenosis
Develop at different location
Develop at different times
Diagnosed only when symptomatic

Hypothesis
Acute increase in the blood flow caused by AV communication creates flow related ‘stress zones’ in the outflow veins.
Stress that exceeds physiological threshold results in injury response.
Flow modulation and alteration of this stress can mitigate this response’

....... S. Shenoy

Computational fluid dynamics - CFD
Is a branch of fluid mechanics that uses numerical methods and algorithms to analyze and solve problems that involve fluid flows.
Computers are used to perform the calculations required to simulate the interaction of liquids with surfaces defined by boundary conditions.

CFD modelling may provide an opportunity to evaluate the functional implications of vascular access stenosis.

CFD modelling has been used to study various aspects of vascular access.

References:
Ene-lordache. NDT 2013; 28: 997-1005
Chiu H. Physiol Rev 2011; 91:327-47
Ene-lordache. NDT 2012; 27:358-68
Clinical observation
Vascular access is a complete circuit
Effect of stenosis depends on location
Inflow - ↓ flow
Conduit – NS problem
Periphery - Aneurysm
Central stenosis - VHTN

Computational flow modelling and Validation
- Inlet pressures varied 50-160 mmHg
- Outlet pressures fixed at 10 mmHg
- Non-newtonian blood model used
- CFD analysis completed with FloWorks within SolidWorks (Dassault Systems, MA)
- Confirmation with Fluent (ANSYS, PA.)
- 3D model of fistula stenoses
  - Range of stenoses diameters 0.5 – 3.5 mm
  - Range of stenoses lengths 5 – 60 mm

Results

<table>
<thead>
<tr>
<th>2mm stenosis</th>
<th>Stenosis Length (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean inlet Pressure (mmHg)</td>
<td>5</td>
</tr>
<tr>
<td>50</td>
<td>626</td>
</tr>
<tr>
<td>60</td>
<td>720</td>
</tr>
<tr>
<td>70</td>
<td>814</td>
</tr>
<tr>
<td>80</td>
<td>908</td>
</tr>
<tr>
<td>90</td>
<td>1002</td>
</tr>
<tr>
<td>100</td>
<td>1106</td>
</tr>
<tr>
<td>110</td>
<td>1210</td>
</tr>
<tr>
<td>120</td>
<td>1314</td>
</tr>
<tr>
<td>130</td>
<td>1418</td>
</tr>
<tr>
<td>140</td>
<td>1522</td>
</tr>
</tbody>
</table>

Extremes of mean pressures

Hoganson D. J Vasc Acc 2014:15:409

Mean Blood pressure

<table>
<thead>
<tr>
<th>Blood pressure</th>
<th>80 (mmHg)</th>
<th>90 (mmHg)</th>
<th>100 (mmHg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 mm</td>
<td>165</td>
<td>165</td>
<td>192</td>
</tr>
<tr>
<td>2 mm</td>
<td>896</td>
<td>896</td>
<td>1060</td>
</tr>
<tr>
<td>3 mm</td>
<td>2253</td>
<td>2253</td>
<td>2534</td>
</tr>
</tbody>
</table>

Is there room to optimize the diameter?

Why the blood flow max out at a certain level?
Do access fail due to acute high flow injury??

Hoganson D. J Vasc Acc 2014:15:409
Multiple stenosis model

V A is a complete circuit
stenotic diameter of >3mm is usually not hemodynamically significant
In setting of multiple stenosis the narrowest stenosis is the most hemodynamically significant
Proximal stenosis plays a role in development of distal stenosis
Locations of stenosis development may be predictable

Hemodynamic significance of vascular access stenosis: CFD analysis
Surendra Shenoy M.D., Ph.D.
Barnes-Jewish Hospital