How can we evaluate flow?  
When is it good enough?

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What do we do currently to evaluate flow after procedure?

- "Eyeball" it
- Look for absence of collaterals
- Look at speed of contrast emptying
- Good enough when...
  - Stent stays open
  - Patient symptoms improve/resolve

Can we obtain a more objective measure?

How can we apply flow dynamics to the venous system?

It’s not that simple!

Fluid Mechanics: Poiseuille’s Law

\[ Q = \frac{\Delta P \pi r^4}{8 \eta l} \]

- \( Q \) = volumetric flow
- \( \Delta P \) = change in pressure
- \( r \) = pipe or vessel radius
- \( \eta \) = viscosity
- \( l \) = pipe or vessel length

This assumes:

- Tube is straight
- Tube is circular
- Radius is constant
- Flow is laminar
- Fluid is Newtonian
Newtonian v. Non-Newtonian fluids

- Newtonian fluids that have a constant viscosity for any given temperature and pressure, and viscosity that does not change with shear
- Non-Newtonian: viscosity changes with shear
  - Rheopectic: viscosity increases with shear
  - Thixotropic: viscosity decreases with shear (ketchup, blood, Lahar)

Bottom line of this physics review:

- Simple physics formulas for straight tubes and simple fluid really don’t work for veins
- Would need to make a new model for every patient because of the high variability
- Can we use surrogate marker such as ultrasound derived flow volume to predict iliac vein stent failure?
- Currently we are using flow volumes in dialysis access to predict adequacy...let’s learn more about this application in veins!

What do we do to maximize flow?

- Radius → use appropriately sized stents
- Pressure gradient → cover all disease, angioplasty to desired size, look for collaterals
- Viscosity → anticoagulation?
- Length → shorter lesions do better (you need to cover what you need to cover)

Volume Flow-duplex scanning

Can be calculated based on velocity and vessel diameter measurements obtained by duplex scanning

\[ Q = n \times A \times 60s = n \times \frac{p(d^3)}{4} \times 60s \]

- \( Q \): Volume flow (mL/min)
- \( n \): Time-averaged velocity across the vessel lumen (cm/s)
- \( A \): Cross-sectional area of vessel at site of measurement (cm²)
- \( d \): Lumen diameter (cm)

Volume Flow Measurement of DAF by Duplex

- Ogawa, et al. JVS 2002
- Measured at 30 degree reverse trendelenberg, 60 degree angle to vessel, 40 seconds
- Mean values:
  - CFV 360 cc/min
  - FV 147 cc/min
  - GSV 38cc/min

Flow volumes in 25 healthy volunteers in the lower extremity

- Slide courtesy of Mariah Elliott BS, RVT, RPHT, and Dr. Gene Zierler, Univ. Wa
Volume Flow Examples:

- Good
  - Diameter
  - Doppler angle
  - Sample volume
  - Mean tracker
  - Flow pattern
- Avoid: turbulence, branching, curving, irregular shape

Slide courtesy of Mariah Elliott BS, RVT, RPhS, and Dr. Gene Zierler, Univ. Wa

Flow volume data from the University of Washington- flow volumes in patients with iliac stents

<table>
<thead>
<tr>
<th>Segment</th>
<th>n</th>
<th>Flow volm (mean) ml/min</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left common iliac</td>
<td>31</td>
<td>707</td>
<td>271-1238</td>
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<tr>
<td>Left external iliac</td>
<td>14</td>
<td>813</td>
<td>441-1318</td>
</tr>
<tr>
<td>Left common femoral</td>
<td>7</td>
<td>517</td>
<td>216-955</td>
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</tbody>
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Are there flow volumes that predict failure? Next steps

- Establish intra and interrater reliability of flow volumes in normal and stented patient
- Measure flow volumes before and after intervention
- Prospectively follow patients to see if there is a flow volume (absolute) or change in flow volume that can assess success or failure of iliac stent
- Understand that finding a perfect flow model will be challenging, finding a reliable surrogate marker may be possible.