Doppler Imaging: The Basics

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Doppler Equation

- $F_D = 2F_0 \mathbf{v} \cos \theta / c$
- $F_D$ = Doppler shift (measured)
- $F_0$ = insonating frequency (known)
- $\theta$ = angle of insonation (measured)
- $c$ = speed of sound (1540 m/sec)
\[ F_D = 2F_0 v \cos \theta / c \]
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Hemodynamics

- Flow in most vessels laminar
- Blood viscous - shear stress
- Parabolic velocity profile
  - Near zero at edge (boundary layer)
  - Mean velocity $\approx 1/2$ max velocity
Parabolic Laminar Flow
Parabolic Laminar Flow

Narrow gate

Wide gate
Bernoulli’s Principle

• Flow is constant
• $Q = \text{Velocity} \times \text{Area}$

Daniel Bernoulli
1700 - 1782
Poiseuille’s Law

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

Flow \approx \text{Pressure}

\( \Delta P = \) pressure change
\( r = \) vessel radius
\( l = \) vessel length
\( \eta = \) fluid viscosity

Assumes steady flow, rigid tube

Jean Louis Marie Poiseuille
1799 - 1869
Hemodynamics - *in vivo*

- Blood flow - difference in fluid energy
  - Pressure
  - Kinetic
  - Potential (gravity)
  - Inertial (pulsatile systems)
  - Viscous (usually neg)

- Energy is conserved

Isaac Newton
1643 - 1727
Flow constant
To maintain flow:
↑ velocity, ↓ pressure
Laminar flow maintained

Adapted From: Taylor, Burns, and Wells.
Clinical Applications of Doppler Ultrasound
Reality

Energy lost through stenosis

Shape, length, $\eta$

Inertial losses

Viscous losses

Downstream pressure may be maintained

Adapted From: Taylor, Burns, and Wells. Clinical Applications of Doppler Ultrasound
Reynolds Number

\[ R = \frac{d \cdot v \cdot \rho}{\eta} \]

- \( d \) = vessel diameter
- \( v \) = velocity
- \( \rho \) = fluid mass density
- \( \eta \) = fluid viscosity

For blood \( R = 2300 \)

Adapted From: Taylor, Burns, and Wells. Clinical Applications of Doppler Ultrasound
Reynolds Number

LAMINAR FLOW

TURBULENT FLOW

\[ R = \frac{d \cdot v \cdot \rho}{\eta} \]

- \( d \) = vessel diameter
- \( v \) = velocity
- \( \rho \) = fluid mass density
- \( \eta \) = fluid viscosity

For blood \( R = 2300 \)

Osborne Reynolds
1842 - 1912

Adapted From: Taylor, Burns, and Wells. Clinical Applications of Doppler Ultrasound
Critical Stenosis

Stenosis narrows, velocity ↑
As velocity ↑, Reynolds number ↑
Laminar flow lost to turbulence
Energy losses ↑↑
Perfusion is impaired

Elevated velocities infer energy loss
Downstream perfusion impaired
“Significant” or “Critical” stenosis

Adapted From: Taylor, Burns, and Wells.
Clinical Applications of Doppler Ultrasound
Waveform

Velocity vs. Time

Local conditions

Proximal / upstream conditions
  Stenoses, cardiac output, shunts

Distal / downstream conditions
  Impedance (pressure, vessel diameter, etc)
Peak Systolic Velocity

Increased
  - Larger volume flow
  - Stenosis (length, impedance)

Decreased
  - Low volume flow
  - Critical stenosis

SMA fasting

SMA post-prandial
Liver - Portal Vein

Fasting

Post-prandial
End Diastolic Velocity

Increased

Low impedance (vasodilatation)
Downstream from stenosis

Decreased

High impedance (vasoconstriction)
Acceleration Time

Normally very short (< 0.07 s)

Delayed

Stenosis

High compliance

Low resistance (AVF)

High downstream area
Hemodynamics - Veins

Isolated from arterial pulsation
Slower flow
Turbulence uncommon ($R \approx \text{velocity}$)
Sensitive to downstream pressures
Always Remember

Medications

Shunts

Cardiac disease
Hepatic Artery - Pressors

Epi

No Epi
Cardiac Disease

Aortic Coarctation

PDA
Abnormal hepatic waveforms...
Tricuspid atresia with intact septum and elevated right heart pressures
The Quick Review

Poiseuille
Flow ≈ Pressure

Bernoullie
Constant volume flow through stenosis

Reynolds
Turbulence ≈ velocity
The Quick Review

PSV – volume flow and stenoses

EDV – impedance

AT – stenoses and impedance
Conclusions

Properties of blood flow

Conservation of flow and energy
Laminar vs. turbulent flow
Behavior with stenoses, impedance

Doppler waveform - velocity vs. time
PSV, EDV, AT
Conclusions

Doppler is good

And it’s not that hard

Predictable blood flow alterations allow application to clinical scenarios

Makes US more fun and rewarding