Arterial System
Lecture Block 10

Vascular Structure/Function
Functional Overview

Vessel Structure

Diameter

Aorta 25 mm
Artery 4 mm
Vein 5 mm
Vena Cava 30 mm
Arteriole 30 µm
Capillary 8 µm
Venule 20 µm

Wall thickness

2 mm
1 mm
0.5 mm
1.5 mm
6 µm
0.5 µm
1 µm

Endothelium

Elastic tissue

Smooth Muscle

Fibrous Tissue
Aortic Compliance

- Factors:
  - age
  - atherosclerosis

- Effects
  - more pulsatile flow
  - more cardiac work
  - not hypertension

Laplace’s Law
(thin-walled cylinder):
\[ T = Pr \]

For thick wall cylinder:
\[ \sigma = \frac{Pr}{w} \]

<table>
<thead>
<tr>
<th></th>
<th>Tension [dyne/cm]</th>
<th>Wall Stress [dyne/cm²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aorta</td>
<td>2 x 10⁵</td>
<td>10 x 10⁵</td>
</tr>
<tr>
<td>Capillary</td>
<td>15-70</td>
<td>1.5 x 10⁵</td>
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Arterial System

Arterial Hydraulic Filter
Arterial System as Hydraulic Filter

- Pulsatile --> smooth flow
- Cardiac energy conversion
- Reduces total cardiac work

Elastic Recoil in Arteries

1. Ventricle contracts
2. Aortas and arteries expand and store pressure in elastic walls.
3. Isovolumic ventricular relaxation
4. Semilunar valve opens
5. Elastic recoil of arteries sends blood forward into rest of circulatory system.
Effects of Vascular Resistance and Compliance
**Basic Pressure Equations**

Mean arterial pressure:

\[ \overline{P}_a = \frac{\int_{t_1}^{t_2} P_a \, dt}{t_2 - t_1} \]

which we can approximate as

\[ \overline{P}_a = P_d + \frac{1}{3}(P_s - P_d) \]

with \( P_s = \) systolic pressure
\( P_d = \) diastolic pressure

Total peripheral resistance is

\[ R_p = (\overline{P}_a - \overline{P}_{ra})/\overline{Q}_r \]

with \( \overline{P}_a = \) mean arterial pressure
\( \overline{P}_{ra} = \) right atrial pressure
\( \overline{Q}_r = \) runoff flow into veins (=\( Q_h \) at equilibrium)

If we assume \( \overline{P}_{ra} = 0 \)

\[ \overline{P}_a = R_p \overline{Q}_r \]

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**Time Course of Arterial Flow**

We can estimate change in arterial volume as:

\[ \frac{d\overline{V}_a}{dt} = Q_h - Q_r \quad (1) \]

Arterial compliance we define as

\[ C_a = \frac{d\overline{V}_a}{d\overline{P}_a} \quad (2) \]

Which we differentiate w.r.t time to get

\[ \frac{d\overline{V}_a}{dt} = \overline{Q}_a = C_a \frac{d\overline{P}_a}{dt} \quad (3) \]

Substituting (1) into (3), we get

\[ Q_h - Q_r = C_a \frac{d\overline{P}_a}{dt} \quad (4) \]

or

\[ \frac{d\overline{P}_a}{dt} = \frac{Q_h - Q_r}{C_a} \quad (5) \]
Arterial Pressure Response to Cardiac Output

- Stable pressure determined by flow and peripheral resistance
- Increase in CO or $R_p$ both increase pressure
- Pressure always changes to force CO to equal runoff flow
- Compliance affects rate but not final values

\[
P_a = R_p Q_r
\]
\[
\frac{dP_a}{dt} = \frac{Q_h - Q_r}{C_a}
\]

Pressure and Age (Compliance)

Mean Pressure

Systole  Diastole  Systole  Diastole

Young  Elderly
Peripheral Pulse Pressure

- Pressure wave velocity
  - \( v_p = k/C \)
  - \( v_p \) increases along the arteries and with age
- Pressure wave pulse amplitude grows with distance from heart
  - reflection/superposition
  - decrease in C
  - dispersion

Venous System
Venous System

- Venous volume
  - Large volume, low pressure system
  - Reservoir of blood (50% of total volume)
  - Blood loss covered by venous system
    - Vasoconstriction, drinking (blood doning)

- Venous flow
  - Skeletal muscle activity
  - Valves
  - Breathing
  - Paristaltic contractions in venules

Venous Valves

- Muscle pump
- Unidirectional flow
- Vericose veins
Measuring Blood Pressure: Catheters

- **Liquid column and external manometer**
  - frequency response of transducer and fluid column
  - calibration and zeroing
  - motion artifacts
- **Manometer-tipped catheters**
  - higher frequency response
  - less motion artifact
Auscultatory Blood Pressure Method

- Effect of arm position
- Alternate measurement locations (leg)
- Pressure varies during the day (lowest during sleep)
- Psychological bias in measurements (in subject and operator)

Automated Pressure Measurement

Auscultatory

Oscillometric

(Figure: Goldstein IA: Cardiovascular Cancers and Their Applications. New York: John Wiley, 1984, Fig. 34-1. Reprinted by permission of John Wiley & Sons, Inc.)
Measuring Blood Flow

- Ultrasound flowmeter (velocity)
- Electromagnetic flowmeter (velocity)
- Thermal dilution
- Functional MRI (diffusion or oxygenation)

Measuring Blood Flow II

- Bioelectric impedance (plethysmography)
- Light (pulse oxymetry)