Cardiovascular System
Fluid Shifts Between Capillaries and Tissue

- Fenestrated capillaries allow plasma and solutes to pass into interstitial space ➔ Interstitial or Extracellular fluid (ECF)
  - Facilitates exchange of resources and wastes between cells and plasma
  - Dynamic equilibrium
  - Imbalances?
  - Exceptions?
Regulation of ECF Movement

- **Hydrostatic and osmotic pressure**
  - Hydrostatic “pushes” osmotic “sucks”
  - 4 types

  - **Capillary hydrostatic pressure**
  - **Interstitial osmotic pressure**
    - Move water out of the vascular system
  - **Interstitial hydrostatic pressure**
  - **Capillary osmotic pressure**
    - Move water into the vascular system
**Figure 19.17**

**HP = hydrostatic pressure**
- Due to fluid pressing against a wall
- “Pushes”
- In capillary (HP<sub>c</sub>)
  - Pushes fluid out of capillary
  - 35 mm Hg at arterial end and 17 mm Hg at venous end of capillary in this example
- In interstitial fluid (HP<sub>f</sub>)
  - Pushes fluid into capillary
  - 0 mm Hg in this example

**OP = osmotic pressure**
- Due to presence of nondiffusible solutes (e.g., plasma proteins)
- “Sucks”
- In capillary (OP<sub>c</sub>)
  - Pulls fluid into capillary
  - 26 mm Hg in this example
- In interstitial fluid (OP<sub>f</sub>)
  - Pulls fluid out of capillary
  - 1 mm Hg in this example

**NFP (net filtration pressure)**
- 10 mm Hg; fluid moves out
- ~8 mm Hg; fluid moves in
Regulation of ECF Movement

- **Hydrostatic**
  - Capillary hydrostatic pressure ($HP_c$)
    - Capillary blood pressure
    - Tends to force fluids through the capillary walls
    - Is greater at the arterial end (35 mm Hg) of a bed than at the venous end (17 mm Hg)
  - Interstitial hydrostatic pressure ($HP_{if}$)
    - Pressure of fluid within intercellular spaces
    - Constantly enters lymphatic drainage
    - Averages 0 mmHg
Regulation of ECF Movement

- **Colloid**
  - Interstitial fluid osmotic pressure ($OP_{if}$)
    - The osmotic pressure force created by the interstitial solute
    - Low (~1 mm Hg), due to low protein content
  - Capillary colloid osmotic pressure ($OP_c$)
    - Created by non-diffusible plasma proteins, which draw water toward themselves
    - ~26 mm Hg
The movement of fluid between the extracellular compartments is driven by a pressure gradient

- Most influenced by capillary hydrostatic pressure
Regulation of ECF Movement

- **Net Filtration Pressure (NFP)**
  - Comprises all the forces acting on a capillary bed

\[
NFP = (HP_c - HP_{if}) - (OP_c - OP_{if})
\]
Regulation of ECF Movement

- **Arterial NFP**
  - Arterial end of a capillary bed = hydrostatic forces dominate
    - Fluid moves out
    - NFP = (35-0) – (26-1) = 10 mm Hg

- **Venous NFP**
  - Venous end of a capillary bed = osmotic forces dominate
    - Fluid moves in
    - NFP = (17-0) – (26-1) = -8 mm Hg

- **Excess fluid**
  - Returned to the blood via the lymphatic system
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  - 35 mm Hg at arterial end and 17 mm Hg at venous end of capillary in this example
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  - Pulls fluid into capillary
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  - 1 mm Hg in this example

Net HP—Net OP
(35—0)—(26—1)

Net HP—Net OP
(17—0)—(26—1)

**Filtration** = fluid moves out

**Reabsorption** = fluid moves in

NFP (net filtration pressure)
is 10 mm Hg; fluid moves out

NFP is ~8 mm Hg; fluid moves in

Arteriole

Interstitial fluid

Capillary

Venule
Edema

- Occurs when filtration greatly exceeds re-absorption
  - Abnormal increase in interstitial fluid volume
Venous Blood Pressure

- Changes little during the cardiac cycle
- Low pressure due to cumulative effects of peripheral resistance
- Central venous pressure
  - Pressure at the point where vena cavae enter heart
  - Average = 4.6 mm Hg
Venous Return

- Venous hydrostatic pressure relatively low
- Returning blood to heart requires adaptations
Mechanisms of Venous Return

1. **Thoracic pump**
   - Pressure changes created during breathing move blood toward the heart by squeezing abdominal veins as thoracic veins expand

2. **Cardiac Suction**
   - During systole, movement of AV valves enlarges atria = lower pressure = increasing pressure gradient between vena cava.

3. **Muscular pump**
   - Contraction of skeletal muscles “milk” blood toward the heart and valves prevent backflow

4. **Vasoconstriction**
   - Veins under sympathetic control

5. **Gravity**
   - Helps with return of blood from superior regions
Mechanisms of Venous Return

- **Circulatory shock**
  - Cardiac output is insufficient to meet the metabolic demands of the tissues

- **Cardiogenic shock**
  - Heart’s ability to pump blood is impaired

- **Other types of shock**
  - Due to low venous return (LVR)
    - Hypovolemic shock
    - Vascular shock
      - Neurogenic shock
      - Septic shock
      - Anaphylactic shock
Types and Causes of LVR Shock

1. **Hypovolemic shock**
   - Most common form of shock
   - Result of blood loss
     - Direct losses: hemorrhage, trauma, burns, bleeding ulcers
     - Indirect losses: fluids other than blood lost
   - Burns and dehydration
Types and Causes of LVR Shock

2. Vascular shock
   - Body retains normal blood volume but blood accumulates in extremities
     a) Neurogenic shock
        - Usually follows spinal cord trauma \(\Rightarrow\) widespread vasodilation
     b) Septic shock
        - Bacterial endotoxin simulates vasodilation
     c) Anaphylactic shock
        - Following allergic reaction
        - Sudden release of histamine \(\Rightarrow\) massive vasodilation and permeability changes
Acute bleeding (or other events that cause blood volume loss) leads to:
1. Inadequate tissue perfusion resulting in O₂ and nutrients to cells
2. Anaerobic metabolism by cells, so lactic acid accumulates
3. Movement of interstitial fluid into blood, so tissues dehydrate

<table>
<thead>
<tr>
<th>Initial stimulus</th>
<th>Physiological response</th>
<th>Signs and symptoms</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemoreceptors activated</td>
<td>Baroreceptor firing reduced</td>
<td>Hypothalamus activated</td>
<td>ADH released</td>
</tr>
<tr>
<td>Activation of respiratory centers</td>
<td>Cardioacceleratory and vasomotor centers activated</td>
<td>Sympathetic nervous system activated</td>
<td>Neurons depressed by ↓pH</td>
</tr>
<tr>
<td>↑ Heart rate</td>
<td>Intense vasoconstriction (only heart and brain spared)</td>
<td>Renal blood flow</td>
<td>Kidney</td>
</tr>
<tr>
<td>Rate and depth of breathing</td>
<td>Tachycardia, weak, thready pulse</td>
<td>Skin becomes cold, clammy, and cyanotic</td>
<td>Urine output</td>
</tr>
<tr>
<td>CO₂ blown off; blood pH rises</td>
<td>Blood pressure maintained; if fluid volume continues to decrease, BP ultimately drops. BP is a late sign.</td>
<td>Thirst</td>
<td>Restlessness (early sign)</td>
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<td></td>
<td></td>
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<td>Coma (late sign)</td>
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</tbody>
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Questions?