Starling Forces

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Learning Objectives

• At the end of the session, the students should be able to:

• Explain Bulk flow across capillary membrane

• Discuss Forces influencing bulk flow

• Explain Starling Equation

• Explain the factors altering starling forces and leading to edema

• Discuss lymphatic capillary pump
Review of Previous Lecture
Circulatory System

- Microcirculation
- Vasomotion
- Factors influencing vasomotion
- Lymphatic system
- Interstitium and interstitial fluid
Capillary Fluid Exchange Paths

Simple diffusion → Bloodstream

- Transcytosis
- Diffusion through intercellular cleft

Tissue fluid

Basement membrane

Fenestration
Forces Influencing Bulk Flow

**Figure 16-5.** Fluid pressure and colloid osmotic pressure forces operate at the capillary membrane and tend to move fluid either outward or inward through the membrane pores.
Starling Forces

The four primary forces that determine whether fluid will move out of the blood into the interstitial fluid or in the opposite direction.

• 1. The capillary pressure (Pc), which tends to force fluid outward through the capillary membrane.

• 2. The interstitial fluid pressure (Pif), which tends to force fluid inward through the capillary membrane.

• 3. The capillary plasma colloid osmotic pressure (Πp), which tends to cause osmosis of fluid inward through the capillary membrane.

• 4. The interstitial fluid colloid osmotic pressure (Πif), which tends to cause osmosis of fluid outward through the capillary membrane.
Capillary blood pressure (PC) or Capillary hydrostatic pressure

• It is the fluid or hydrostatic pressure exerted on the inside of the capillary walls by blood.

• This pressure tends to force fluid out of the capillaries into the interstitial fluid.

• By the level of the capillaries, blood pressure has dropped substantially because of frictional losses in pressure in the high-resistance arterioles upstream.

• Near 30mmHg at arteriolar end
• Near 10 mmHg at venous end
Plasma Colloid Osmotic Pressure $\pi_p$

• Also known as oncotic pressure, is a force caused by colloidal dispersion of plasma proteins; it encourages fluid movement into the capillaries.

• Because plasma proteins remain in the plasma rather than entering the interstitial fluid, a protein concentration difference exists between plasma and interstitial fluid.

• This difference exerts an osmotic effect that tends to move water from the area of higher water concentration in interstitial fluid to the area of lower water concentration (or higher protein concentration) in plasma.

• 28 mmHg
Interstitial fluid hydrostatic pressure (Pif)

- It is the fluid pressure exerted on the outside of the capillary wall by interstitial fluid.

- It is either at, slightly above, or slightly below atmospheric pressure.
Interstitial Colloid Osmotic Pressure $\pi_{\text{if}}$

• The small fraction of plasma proteins that leak across the capillary walls into the interstitial spaces are normally returned to the blood by the lymphatic system.

• Therefore, the protein concentration in the interstitial fluid is extremely low, and the interstitial fluid–colloid osmotic pressure is very close to zero.

• If plasma proteins pathologically leak into the interstitial fluid, the leaked proteins exert an osmotic effect that tends to promote movement of fluid out of the capillaries into the interstitial fluid.

• 8mmHg
Net Filtration Pressure

NFP = Outward Pressure - Inward Pressure

• If the sum of these forces—the net filtration pressure—is positive, there will be a net fluid filtration across the capillaries.

• If the sum of the Starling forces is negative, there will be a net fluid absorption from the interstitial spaces into the capillaries.
Capillary filtration coefficient

• The rate of fluid filtration in a tissue is also determined by the number and size of the pores in each capillary, as well as the number of capillaries in which blood is flowing.

• These factors are usually expressed together as the capillary filtration coefficient (Kf).

• The Kf is therefore a measure of the capacity of the capillary membranes to filter water for a given NFP and is usually expressed as ml/min per mm Hg NFP.
Filtration

Filtration = Coefficient of Filtration x NFP
**FIGURE 10-22 Bulk flow across the capillary wall.** Ultrafiltration occurs at the arteriolar end and reabsorption occurs at the venule end of the capillary as a result of imbalances in the physical forces acting across the capillary wall.

All values are given in mm Hg.
**Analysis of the Forces Causing Filtration at the Arterial End of the Capillary.** The approximate average forces operative at the *arterial end* of the capillary that cause movement through the capillary membrane are shown as follows:

<table>
<thead>
<tr>
<th>Forces Tending to Move Fluid Outward</th>
<th>mm Hg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capillary pressure (arterial end of capillary)</td>
<td>30</td>
</tr>
<tr>
<td><em>Negative</em> interstitial free fluid pressure</td>
<td>3</td>
</tr>
<tr>
<td>Interstitial fluid colloid osmotic pressure</td>
<td>8</td>
</tr>
<tr>
<td>TOTAL OUTWARD FORCE</td>
<td>41</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
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<td>28</td>
</tr>
<tr>
<td>TOTAL INWARD FORCE</td>
<td>28</td>
</tr>
</tbody>
</table>

**Summation of Forces**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Outward</td>
<td>41</td>
</tr>
<tr>
<td>Inward</td>
<td>28</td>
</tr>
<tr>
<td>NET OUTWARD FORCE (AT ARTERIAL END)</td>
<td>13</td>
</tr>
</tbody>
</table>
### Venous End

<table>
<thead>
<tr>
<th>Forces Tending to Move Fluid Inward</th>
<th>mm Hg</th>
</tr>
</thead>
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<table>
<thead>
<tr>
<th>Force</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inward</td>
<td>28</td>
</tr>
<tr>
<td>Outward</td>
<td>21</td>
</tr>
<tr>
<td>NET INWARD FORCE</td>
<td>7</td>
</tr>
</tbody>
</table>
Lymphatic System
Lymphatic System

• The lymphatic system represents an accessory route through which fluid can flow from the interstitial spaces into the blood.

• Most important, the lymphatics can carry proteins and large particulate matter away from the tissue spaces, neither of which can be removed by absorption directly into the blood capillaries.
Figure 16-7. The lymphatic system.
Lymphatic Capillaries

Figure 16-8. Special structure of the lymphatic capillaries that permits passage of substances of high molecular weight into the lymph.
Rate of Lymph Flow

• About 100 milliliters per hour of lymph flows through the thoracic duct of a resting human

• Approximately another 20 milliliters flows into the circulation each hour through other channels, making a total estimated lymph flow of about 120 ml/hr or 2 to 3 liters per day.
Lymph Flow

As the pressure rises to 0 mm Hg (atmospheric pressure), flow increases more than 20-fold.

Therefore, any factor that increases interstitial fluid pressure also increases lymph flow if the lymph vessels are functioning normally.

- Elevated capillary hydrostatic pressure
- Decreased plasma colloid osmotic pressure
- Increased interstitial fluid colloid osmotic pressure
- Increased permeability of the capillaries

Figure 16-9. Relation between interstitial fluid pressure and lymph flow in the leg of a dog. Note that lymph flow reaches a maximum when the interstitial pressure, $P_s$, rises slightly above atmospheric pressure (0 mm Hg). (Courtesy Drs. Harry Gibson and Aubrey Taylor.)
Lymphatic Pump Increases Lymph Flow.

• Valves exist in all lymph channels.

• When a collecting lymphatic or larger lymph vessel becomes stretched with fluid, the smooth muscle in the wall of the vessel automatically contracts.

• Each segment of the lymph vessel between successive valves functions as a separate automatic pump.

*Figure 16-10. Structure of lymphatic capillaries and a collecting lymphatic, with the lymphatic valves also shown.*
Pumping Caused by External Intermittent Compression of the Lymphatics.

- Contraction of surrounding skeletal muscles
- Movement of the parts of the body
- Pulsations of arteries adjacent to the lymphatics
- Compression of the tissues by objects outside the body

The lymphatic pump becomes very active during exercise, often increasing lymph flow 10- to 30-fold.

Conversely, during periods of rest, lymph flow is sluggish (almost zero).
Lymphatic Capillary Pump.

• The terminal lymphatic capillary is also capable of pumping lymph, in addition to the pumping by the larger lymph vessels.

• The walls of the lymphatic capillaries are tightly adherent to the surrounding tissue cells by means of their anchoring filaments.

• Therefore, each time excess fluid enters the tissue and causes the tissue to swell, the anchoring filaments pull on the wall of the lymphatic capillary and fluid flows into the terminal lymphatic capillary through the junctions between the endothelial cells.
Edema

• Accumulation of excessive fluid in interstitial fluid
Causes

- **Increased capillary permeability**
  - Local Causes – cellulitis
  - Systemic Causes – hypersensitivity reactions, sepsis
- **Increased capillary hydrostatic pressure**
  - Local Causes – compartment syndrome, chronic venous insufficiency
  - Systemic Causes – congestive cardiac failure, cor pulmonale, renal failure, anemia, pregnancy
- **Decreased capillary oncotic pressure**
  - Systemic Causes – Protein deficient states like chronic liver diseases, nephrotic syndrome, protein losing enteropathy, malabsorption syndrome
- **Lymphatic obstruction (lymphedema)**
  - Tumour, trauma, radiation and infections like filariasis