

Autoregulation and Capillary Dynamics

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Page 1. Introduction

- Blood flow through individual organs is controlled intrinsically in response to local requirements. The phenomenon is called autoregulation. When true capillaries are flushed with blood, exchanges occur between the capillary blood and tissue cells.

Page 2. Goals

- To explain the importance of autoregulation.
- To list the chemical and physical factors that serve as autoregulatory stimuli in the various tissues.
- To describe the means by which various solutes are transported across capillary walls
- To explain factors that determine the amount and direction of fluid flows across the capillary walls.

Page 3. Autoregulation

- Autoregulation is the process by which the various organs and tissues of the body self-regulate blood delivery. This process can be compared to water flow regulation. A pumping station pumps water to individual houses via water pipes, just as the heart pumps blood to individual organs via blood vessels.

Page 4. Water Regulation and Water Pressure

- Within each house, the residents can regulate the amount of water entering the house according to their needs. As long as water pressure remains normal, they can get water anytime they want to.

Page 5. Blood Regulation and Mean Arterial Pressure

- Similarly, as long as mean arterial pressure is normal, the various organs and body tissues of the body can regulate the amount of blood that enters them according to their needs at any given time.

Page 6. Single Capillary Bed

- Blood flow regulation occurs at the capillary beds. The feeder arteriole bring blood to the capillary bed. The shunt is a short vessel that directly connects the feeder arteriole and the drainage venule at the opposite end of the bed. Exchanges of materials take place between tissue cells and the blood in the true capillaries. The precapillary sphincter is a cuff of smooth muscle fibers that surround the root of each true capillary, acting as a valve to regulate the flow of blood into the true capillaries.

Page 7. Precapillary Sphincters Open or Close

- The build-up of certain chemical signals locally acts as a metabolic control that causes the feeder arterioles to dilate, bringing more blood into the local area. These chemical signals also cause the precapillary sphincters to relax.

Page 8. Oxygen

- If the oxygen levels in the tissue cells are already high, no more blood flow is needed in that area until the oxygen levels are lower again.

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Page 9. Carbon Dioxide

- Carbon dioxide is a metabolic waste product. If it builds up in a capillary bed, then the precapillary sphincters will open to allow it to be removed from the area.

- Typically acids that accumulate must be removed from tissues. So when there is a low pH a lot of acid is present and the precapillary sphincters open.

Page 11. Nutrients

- If nutrients are already present in a capillary bed, precapillary sphincters will close. They open when nutrients are needed.

Page 12. Body Temperature

- During a fever, precapillary sphincters tend to open. In the skin, this will allow heat to dissipate from the body.

Page 13. Blood Pressure

- Local physical factors acting on the vascular smooth muscle, such as changing blood volume and blood pressure, also act as autoregulatory stimuli that affect arterioles.
- Decreased blood pressure will cause precapillary sphincters to open, allowing more blood to reach the capillary bed.
- Circle each of the following conditions that cause precapillary sphincters to open:

High O ₂	Low O ₂
High CO ₂	Low CO ₂
High pH (low acid)	Low pH (high acid)
Adequate nutrients	Lack of nutrients
Normal Body Temperature	Fever
Decreased blood pressure, decreased arteriole stretch	Increased blood pressure, increased arteriole stretch

** Now is a good time to go to quiz questions 1-4:

- Click the Quiz button on the left side of the screen.
- Work through questions 1-4.
- After answering question 4, click the Back to Topic button on the left side of the screen.
- To get back to where you left off, click on the scrolling page list at the top of the screen and choose "14. Enlargement of Capillary".

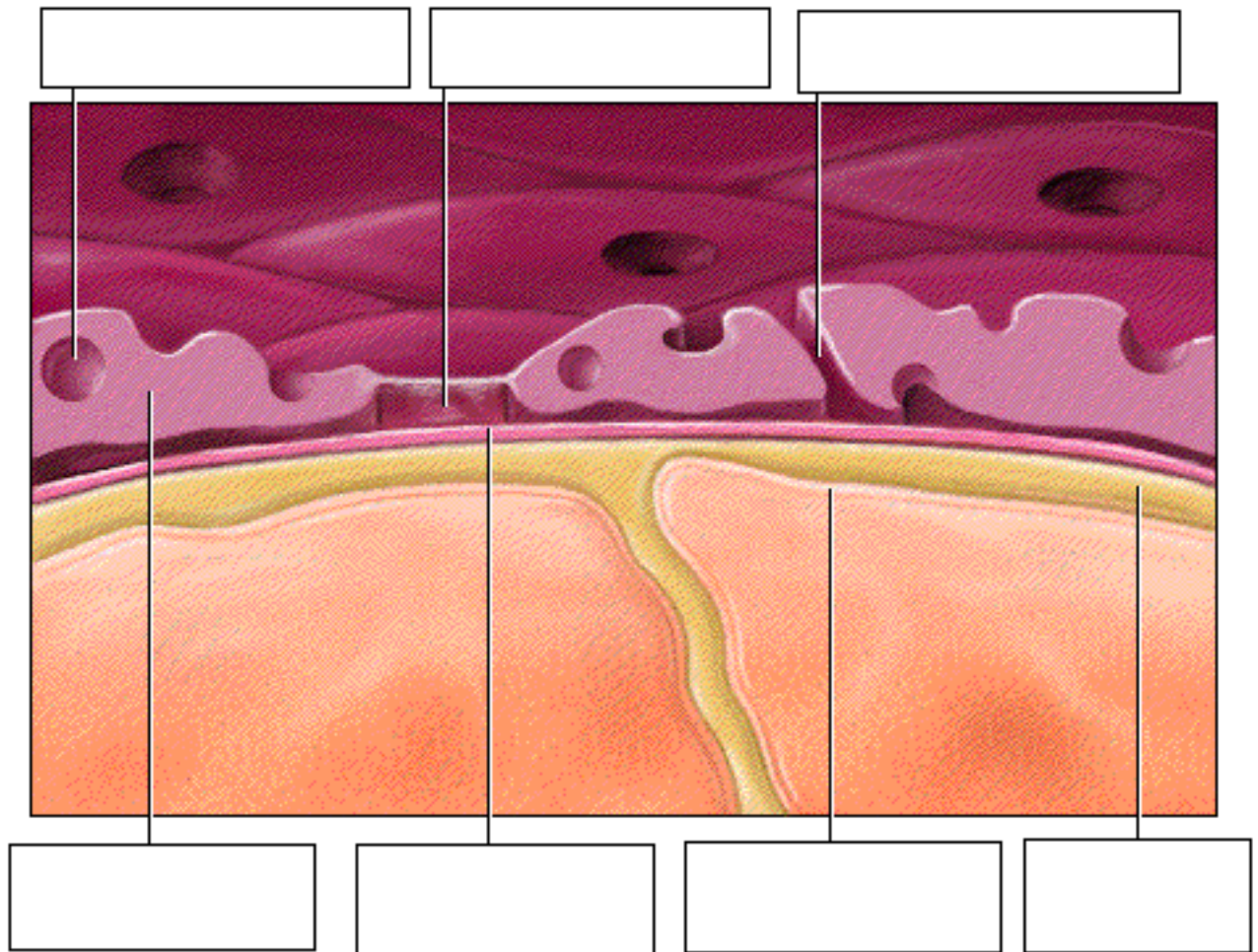
Page 14. Capillary Exchange

- True capillaries are the sites of solutes exchanges between blood in the lumen of the capillaries and the tissue cells.

Page 15. Capillary Wall Anatomy

- Several structural characteristics of capillaries aid the transport process:
 1. Capillary endothelial cells have fenestrations, which are pores that may be opened or covered by a very delicate membrane, allowing for passage of fluids and small solutes.
 2. Interactive Physiology Clostulae between cells also allow movement of materials between the blood and tissue cells.

3. Cytoplasmic vesicles move material across the capillary wall by bulk transport.
- Label the parts of the diagram on the top of the next page.



Page 16. Types of Solutes

- Most solutes move across the capillary wall by diffusion, which is the movement of solutes from an area of higher concentration to lower concentration.

Page 17. Diffusion Through Membranes

- Lipid soluble molecules, such as oxygen and carbon dioxide, diffuse through the lipid phase of the intervening plasma membranes.
- They are able to move freely across the endothelial cells from areas of higher to lower concentration without the help of transport proteins or expenditure of metabolic energy.

Page 18. Exocytosis

- Some molecules, which are not lipid soluble, are translocated across the capillary wall by cytoplasmic vesicles in a process called exocytosis.
- Proteins, which are very large molecules, are typically transported in this way. The materials would be brought into the endothelial cell via endocytosis at the side of the cell facing the lumen of the capillary. The cytoplasmic vesicle carrying the protein moves to the side of the endothelial cell facing the interstitial fluid. Then exocytosis occurs, which releases the materials into the interstitial fluid.

Page 19. Clefts and Fenestrations

- Water-soluble solutes, such as amino acids and sugars diffuse from the capillary through fluid-filled clefts or fenestrations.

** Now is a good time to go to quiz questions 5 and 6:

- Click the Quiz button on the left side of the screen.
- Click on the scrolling page list at the top of the screen and choose "5. Fluid and Capillary Exchanges".
- After answering question 6, click the Back to Topic button on the left side of the screen.
- To get back to where you left off, click on the scrolling page list at the top of the screen and choose "20. Introduction to Bulk Fluid Flows".

Page 20. Introduction to Bulk Fluid Flows

- Bulk fluid flows, which have little to do with nutrient and gas exchanges, also occur at capillary beds.
- Note that fluid leaves the capillaries at the arterial end and returns to the capillary at the venule end.

Page 21. Enlargement of True Capillary

- Bulk fluid flows are important in determining the relative amount of fluid in blood and tissue spaces.
- Interstitial fluids, including any plasma proteins which have escaped from the blood stream, enter the lymph capillaries. These leaked fluids and plasma proteins are carried back to the blood stream by the lymphatic system.

Page 22. Fluid Flow

- As the amount of fluid in the tissue spaces varies, the distance that solutes must travel between the blood and tissue cells changes proportionately.
- If there is more fluid in the tissue spaces, solutes must travel farther between the blood and the tissue cells.

Page 23. Hydrostatic Pressure Example

- Fluid flows represent the balance between hydrostatic and osmotic pressures acting at capillary beds. Let's look at just hydrostatic pressure (HP) first.
- Hydrostatic pressure is the pressure exerted on a fluid on the walls of its container.

Page 24. Capillary Hydrostatic Pressure

- In capillaries, hydrostatic pressure is exerted by blood. Thus, capillary hydrostatic pressure (HP_c) is equivalent to the blood pressure in the capillaries.

Page 25. Filtration Pressure

- Capillary hydrostatic pressure (HP_c) is also called filtration pressure because it forces fluid out of the capillaries. Because of friction encountered in the capillaries, the capillary hydrostatic pressure (HP_c) is lower at the venule end of the bed.
- At arterial end $HP_c = 35$ mm Hg
- At venous end $HP_c = 15$ mm Hg

Page 26. Interstitial Fluid Hydrostatic Pressure

- In theory, the hydrostatic pressure of the interstitial fluid (HP_{if}) in the tissue spaces opposes the capillary hydrostatic pressure (HP_c).
- $HP_{if} = 1$ mm Hg

Page 27. Lymph Capillaries

- Normally, however, there is very little fluid in the tissue spaces because fluid is quickly picked up by the lymphatic capillaries, so the hydrostatic pressure of the interstitial fluid (HP_{if}) is very low.

- Net hydrostatic pressure (Net HP) is equal to the capillary hydrostatic pressure (HP_c) minus the hydrostatic pressure of the interstitial fluid (HP_{if}).
- $Net\ HP = HP_c - HP_{if}$
- Net HP forces fluid out of the capillary.

Page 29. Arteriole Net Hydrostatic Pressure

- Let's determine the net hydrostatic pressure (HP) at the arteriole end of the capillary bed.
- Taking the capillary hydrostatic pressure (HP_c) of 35 mm Hg minus the interstitial fluid hydrostatic pressure of 1 mm Hg gives us 34 mm Hg for the net hydrostatic pressure at the arterial end of the capillary bed.
- Fill out this equation:

$$\underline{\hspace{2cm}} = \underline{\hspace{2cm}} - \underline{\hspace{2cm}}$$

Net HP at arteriole end = HP_c - HP_{if}

Page 30. Venule Net Hydrostatic Pressure

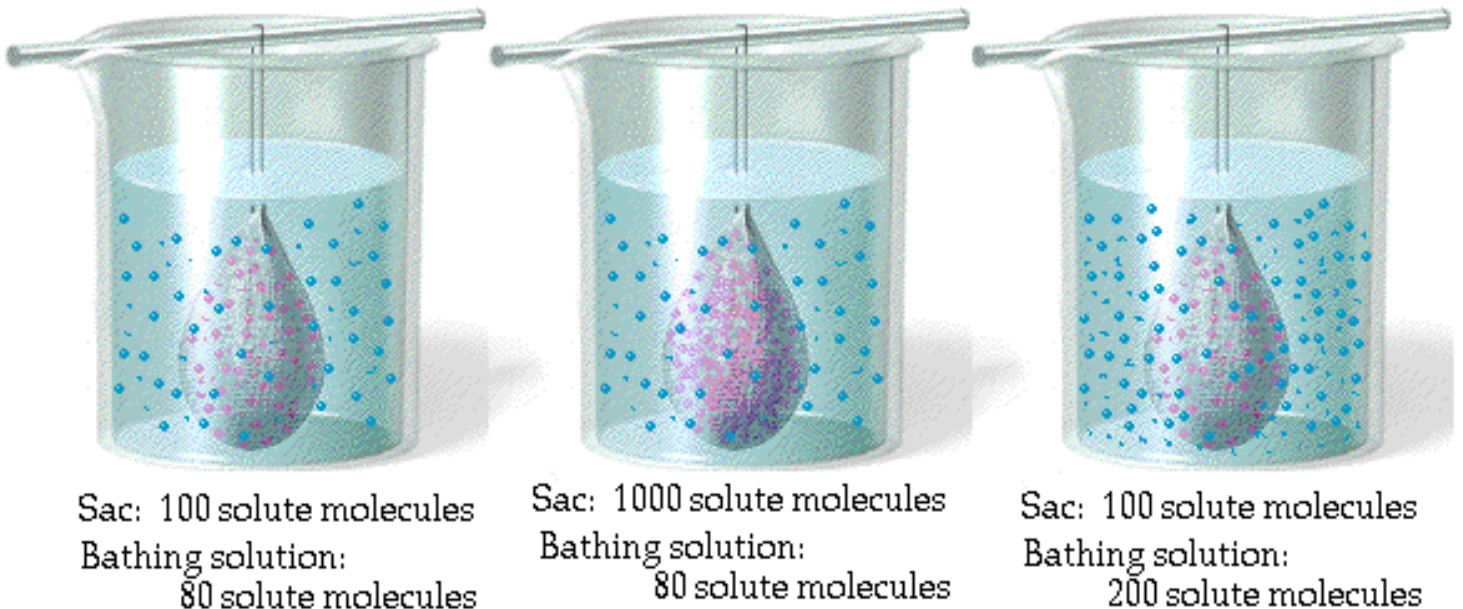
- Now let's determine the net hydrostatic pressure (HP) at the venule end of the capillary bed.
- Taking the capillary hydrostatic pressure (HP_c) of 15 mm Hg minus the interstitial fluid hydrostatic pressure of 1 mm Hg gives us 14 mm Hg for the net hydrostatic pressure at the venule end of the capillary bed.
- Fill out this equation:

$$\underline{\hspace{2cm}} = \underline{\hspace{2cm}} - \underline{\hspace{2cm}}$$

Net HP at venule end = HP_c - HP_{if}

Page 31. Osmotic Pressure Example

- Osmotic pressure is the "pull" on water exerted by large nondiffusible solutes like proteins.
- The higher the solute concentration, the more the solution pulls (or holds) water.
- The movement of a solvent, such as water, through a membrane from a more dilute solution to a more concentrated solution is called osmosis.
- Indicate the net movement of water with arrows as you observe the animation:



Page 32. Capillary Osmotic Pressure

- Because of its high content of plasma proteins, capillary blood has a relatively high osmotic pressure (OP_c) which tends to draw fluid into the capillary.
- OP_c = 25 mm Hg

Page 33. Interstitial Fluid Osmotic Pressure

- Interstitial fluid contains few proteins because leaked proteins (like leaked fluids) are quickly gathered up by the lymph capillaries. Hence, interstitial fluid osmotic pressure (OP_{if}) is very low.
- OP_{if} = 3 mm Hg

Page 34. Net Osmotic Pressure

- Net OP pulls fluids into the capillary.
- The osmotic pressure in the capillaries of 25 mm Hg minus the osmotic pressure in the interstitial fluid of about 3 mm Hg is equal to the net osmotic pressure of 22 mm Hg.
- Net OP = OP_c - OP_{if}
- Fill out this equation:

$$\frac{\text{Net OP}}{\text{Net OP}} = \frac{\text{OP}_c}{\text{OP}_c} - \frac{\text{OP}_{if}}{\text{OP}_{if}}$$

Page 35. Net Force

- Both net hydrostatic pressure and net osmotic pressure affect fluid flows at the capillary beds. Remember that hydrostatic pressure forces fluid out of the capillary blood and osmotic pressure pulls fluid into the capillary.
- If net HP is higher than Net OP, fluid leaves the capillary.
- If net HP is lower than Net OP, fluid enters the capillary.
- Net force (Determines the direction of flow) = Net HP - Net OP

Page 36. Leave or Enter at Arterial End?

- Net force (determines the direction of flow) = Net HP - Net OP
- Fill out this equation:

$$\frac{\text{Net Force}}{\text{Net Force}} = \frac{\text{Net HP}}{\text{Net HP}} - \frac{\text{Net OP}}{\text{Net OP}}$$

- The net force at the arterial end of the capillary equals 34 mm Hg minus 22 mm Hg which equals 12 mm Hg. Since the net hydrostatic pressure is greater than the net osmotic pressure, at the arterial end of the capillary, the hydrostatic pressure wins out and fluid leaves the capillary at the arteriole end.

Page 37. Leave or Enter at Venule End?

- Net force (determines the direction of flow) = Net HP - Net OP
- Fill out this equation:

$$\frac{\text{Net Force}}{\text{Net Force}} = \frac{\text{Net HP}}{\text{Net HP}} - \frac{\text{Net OP}}{\text{Net OP}}$$

- The venous net force in the capillaries equals 14 mm Hg minus 22 mm Hg which gives us -8 mm Hg. Since the net osmotic pressure is greater than the net hydrostatic pressure at the venule end, the osmotic pressure wins out and the fluid enters the capillary at the venous end of the fluid bed.

Page 38. Summary

- Local chemical and physical factors regulate blood flow to individual tissue cells.
- Lipid-soluble substances move through capillary walls by diffusion, whereas non-lipid-soluble substances are transported via pores or exocytosis. Clefts and fenestrations facilitate the process.
- The fluid flows occurring at capillary beds reflect the balance between hydrostatic pressure and osmotic pressure acting inside and outside the capillary.

** Now is a good time to go to quiz questions 7,8, and 9.

- Click the Quiz button on the left side of the screen..
- Click on the scrolling page list at the top of the screen and choose "7. Normal Fluid Flows".
- Work through quiz questions 7-9.

Notes on Quiz Questions:

Quiz Question #1. MAP and Autoregulation

- This question asks you to predict the factors that relate MAP (mean arteriole pressure) to autoregulation.

Quiz Question #2. Enhanced Blood Delivery

- This question asks you to predict what happens when the cells in a particular area require enhanced blood delivery.

Quiz Question #3. Autoregulatory Stimuli

- This question asks you to identify autoregulatory stimuli that enhance blood flow to a local area.

Quiz Question #4. Blood Delivery to Muscles

- In this question, you will be asked to identify factors that will restore blood flow to overworked muscle cells.

Quiz Question #5. Food and Capillary Exchanges

- This question allows you to predict the way various digested food molecules move from the blood to the interstitial fluid.

Quiz Question #6. Diffusion of Respiratory Gases

- This question asks you to predict the method of movement and direction of flow of respiratory gases in a capillary bed.

Quiz Question #7. Normal Fluid Flows

- This question asks you to predict the value of the various pressure that would allow a normal fluid flow.

Quiz Question #8. Hydrostatic Pressure and Osmotic Pressure of Interstitial Fluid

- This question asks you to determine why the hydrostatic and osmotic pressures of the interstitial fluid are so low.

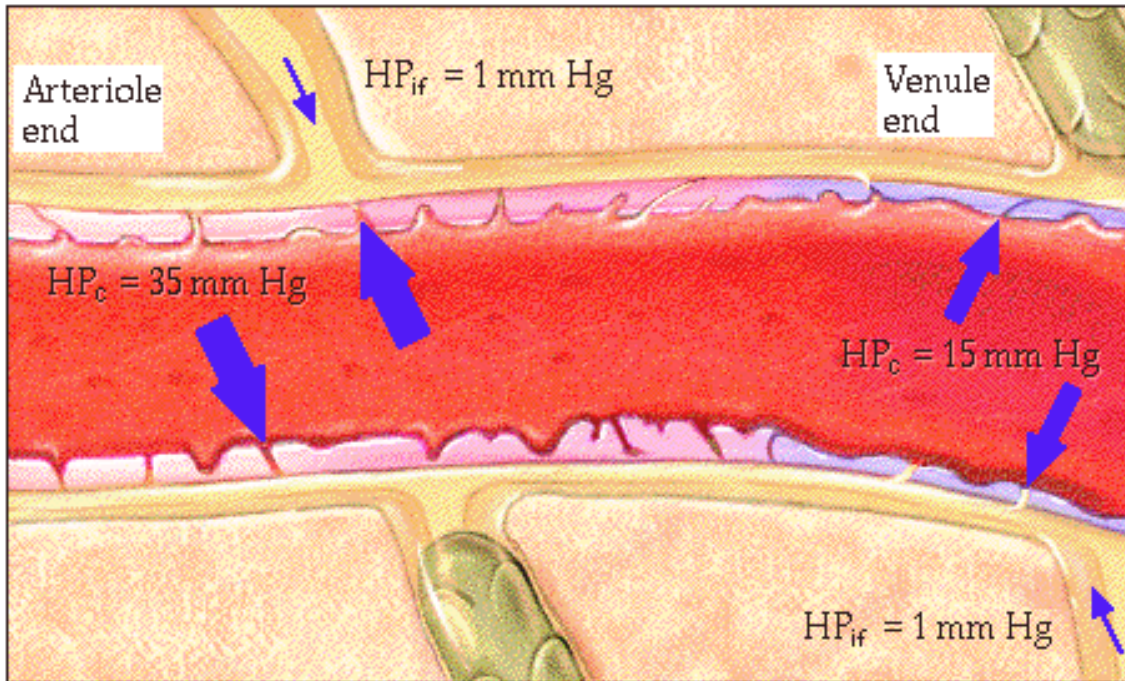
Quiz Question #9. Abnormal Fluid Flows

- This question asks you to predict what happens when there is an abnormal fluid flow.

Study Questions on Autoregulation and Capillary Dynamics:

1. (Page 1,3.) What is autoregulation?
2. (Page 6.) Where does blood flow regulation occur?
3. (Page 6.) Where does exchanges of materials take place between tissue cells and the blood?
4. (Page 6.) What regulates the flow of blood into the true capillaries?
5. (Page 7.) The build-up of certain chemical signals in an area of the body can act as a metabolic control, bringing more blood to the capillaries of the area. What two types of blood vessels do these chemical signals affect and how do they work?
6. (Page 8.) Will the precapillary sphincters open or close in a capillary bed that is high in oxygen? Explain.
7. (Page 9.) Will the precapillary sphincters open or close in a capillary bed that is high in carbon dioxide? Explain.
8. (Page 10.) Will the precapillary sphincters open or close in a capillary bed that has a high pH? Explain.
9. (Page 11.) Will the precapillary sphincters open or close in a capillary bed that is high in nutrients? Explain.
10. (Page 13.) Why would a decreased blood pressure cause precapillary sphincters to open?
11. (Page 15.) List three ways materials move from the lumen of the capillary into the interstitial spaces.
12. (Page 15.) What are fenestrations?
13. (Page 15.) How do clefts differ from fenestrations?
14. (Page 15, 17.) Explain how materials are moved across an endothelial cell via bulk transport.
15. (Page 16.) Most solutes move across the capillary wall by diffusion. Define diffusion.
16. (Page 17.) What types of solutes are able to diffuse through the plasma membranes of the endothelial cells from higher to lower concentration without the help of transport proteins or expenditure of metabolic energy. Give two specific examples.
17. (Page 18.) What types of solutes are typically transported from the blood to interstitial fluid by exocytosis and endocytosis across endothelial cells?
18. (Page 19.) What types of solutes are typically transported from the blood to interstitial fluid through clefts or fenestrations? Give two specific examples.
19. (Page 20.) What process is responsible for fluid leaving the capillaries at the arterial end and returning to the capillary at the venule end?
20. (Page 21.) What happens if more fluid leaves the capillaries than is returned to the capillaries?
21. (Page 23.) What two types of pressures influence fluid exchanges at capillary beds?
22. (Page 23.) Define hydrostatic pressure. ⁸
23. (Page 24, 25.) What term is used to denote the blood pressure in the capillaries?

24. (Page 25.) What happens to capillary hydrostatic pressure as the blood moves through a capillary bed? Explain.
25. (Page 26.) What term is used to denote the pressure of the fluid in the interstitial fluid?
26. (Page 27.) Why is the hydrostatic pressure of the interstitial fluid (HP_{if}) normally low?
27. (Page 28.) What is the net hydrostatic pressure in a capillary bed?
28. (Pages 29, 30.) Given the data in this picture, calculate the:
 - a. Net hydrostatic pressure (HP) at the arteriole end of the capillary bed.
 - b. Net hydrostatic pressure (HP) at the venule end of the capillary bed

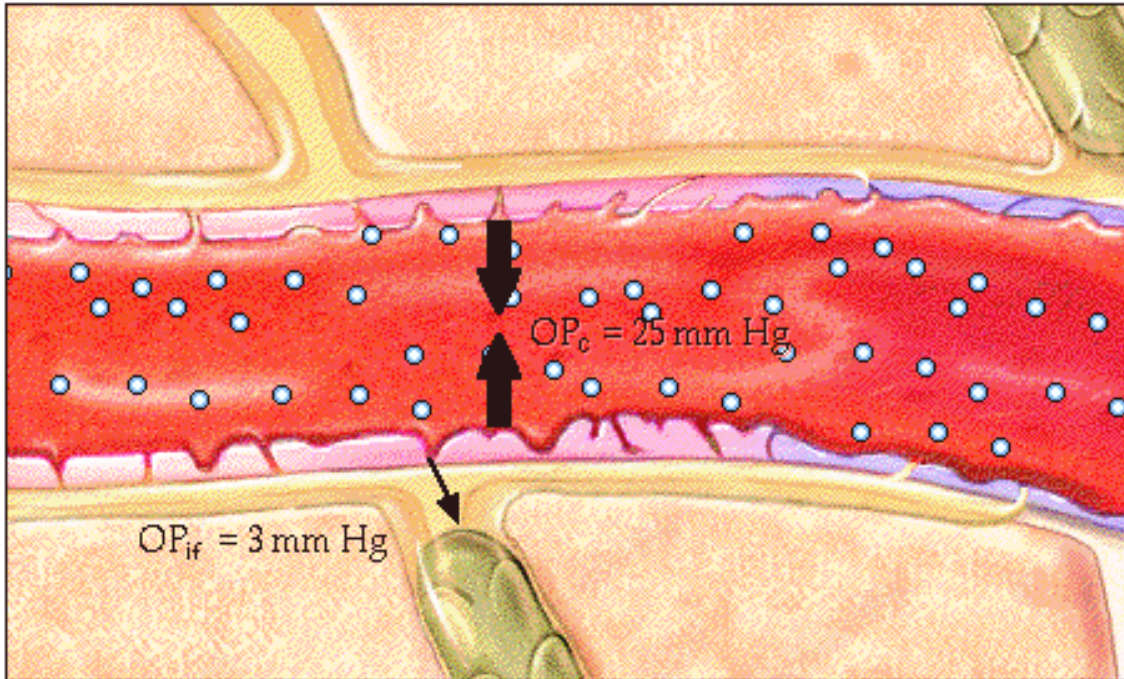


29. (Page 31.) Predict the net movement of water (osmosis) across a membrane permeable only to water in the following situations:
 - a. Higher concentration of solute inside the sac compared to outside the sac.
 - b. Higher concentration of solute outside the sac compared to inside the sac.
 - c. Equal concentrations of solute on both sides.



30. (Page 32.) When you talk about osmotic pressure in a capillary bed, why is protein the only solute that is considered?

31. (Page 33.) Why is the osmotic pressure of the interstitial fluid typically very low?
32. (Pages 34.) Given the data in this picture, calculate the net osmotic pressure (Net OP) in the capillary bed.



33. (Page 35.) What is the difference in the direction of force of net hydrostatic pressure and net osmotic pressure in a capillary bed?
34. (Page 35.) If net hydrostatic pressure is higher than net osmotic pressure, in which direction will fluid flow?
35. (Page 35.) If net hydrostatic pressure is lower than net osmotic pressure, in which direction will fluid flow?
36. (Page 36, 37) Given the data in this picture, calculate the:
- Net force at the arteriole end of the capillary bed.
 - Net force at the venule end of the capillary bed.
- What effect does each have on the movement of fluids?

