CIRCULATORY PHYSIOLOGY SECTION 4: Lymph and the Lymphatic System*

I. The Lymphatic System

A. Functions

1. Immunity – an important means of movement of cells (lymphocytes) and proteins of the immune system and also a point of their production.

2. Return of material filtered from the capillaries (see vascular system notes).

3. Important in movement of nutrients between the GI tract and liver during the digestive process.

B. **Lymphatics**: As lymph is formed in the capillaries, it gradually collects in a series of small capillary-like vessels. These gradually coalesce into larger vessels that merge in structures called lymph nodes. Eventually, the lymph is returned to the blood circulation via a portal in a vein.

C. Lymph is a fluid formed due to a filtration process in the capillaries. It contains water, ions, various small organics and many proteins, especially various blood albumins. It also contains a number of different types of white cells that are concerned with immunity.

1. To get a sense of the amount of fluid involved – in a typical mammal, the total volume of fluid that moves through the lymph system per day totals about the plasma volume (but no where near that much at any one time).

2. In terms of protein, the amount of circulating albumin that is returned by the lymph to the blood each day is about equal to ¼ the entire plasma albumin supply.

II. Lymph Formation

1. General: As we have seen before, lymph is essentially an interstitial fluid. It slowly percolates between cells and eventually enters certain vessels called **lymph ducts** that are part of the **lymphatic circulation**. Places where ducts expand briefly, for instance, to contain large numbers of lymphocytes and remove bacteria, etc., that may have been present in the lymph are called **lymph nodes**. Eventually the lymph is returned to the blood circulation.

2. **Lymph Production:**

a. Lymph is produced in the capillaries by a filtering process that we have just seen in regard to the capillary pores. We know that these will allow small polar molecules to pass.

b. All else being equal, we would assume that as in any filter, the greater the pressure across the filter (here the capillary wall) the greater the amount of fluid and other filterable materials that is filtered. This difference in pressure between the capillary and tissues is termed the transmural pressure, as we have seen before. It is also called the **hydrostatic filtration pressure,** $P_{\text{hydrostatic}}$:

$$\textbf{1.} \qquad P_{\text{hydrostatic}} = P_{\text{cap.}} - P_{\text{tissue}}$$

where $P_{\text{cap.}}$ is the pressure at any point along the length of capillary and P_{tissue} is the pressure at any point along the length of the capillary but on the tissue side.

i. Normally, capillary pressure is considerably higher and tends to decrease from the A to V side of the capillary. The result is that transmural pressure is not constant -- it tends to decrease from A to V ends of the capillary.

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ii. However, it is usually always positive along the entire length and therefore $P_{hydrostatic}$ tends to favor filtration from the capillary to the tissue.

? Explain how a filter in lab might work according to the principles just mentioned. Suppose you are filtering blood with a lab-type filter. What would be the concentration of water, small solutes and very large (bigger than the pores) solutes on filtrate and solution sides of the filter?

c. If this were all there was to the formation of lymph, we would make large amounts indeed as fluid and small ions flooded through the pores from one end to the other of the capillary. But, as usual it is not all there is to it.

d. When discussing water, which is the main constituent of lymph, we must also consider **osmotic effects**.

i. At the arterial end of the capillary, the total concentration of dissolved solutes tends to be close to the same in both the blood and interstitial fluid. Therefore, there is no net osmotic (diffusive as compared to hydrostatic pressure) effect at this end of the capillary.

ii. However, as more and more fluid is filtered out, some things cannot leave. These include all large polar compounds -- for example, blood proteins. The result is that although small polar solutes and water pass freely (the solutes are in the same concentration on both sides of the capillary wall) water tends to become more concentrated inside the capillary, primarily as a result of the reduced volume containing the same number of blood proteins. As a result, **a diffusion (osmotic) gradient increasingly arises for water to come back into the blood**. Since this gradient is due to the difference in osmotic pressure across the capillary, it is termed the **osmotic pressure gradient, Π_{osm}**:

2. $$\Pi_{osm} = \Pi_{icf} - \Pi_{cap}$$

where Π_{cap} is the osmotic pressure of the blood and Π_{icf} is the osmotic pressure of the interstitial fluid.

iii. As the blood becomes more concentrated, the osmotic pressure of the capillary, Π_{cap} increases and the osmotic gradient becomes more negative (which means that the next osmotic force on water is favoring return to the capillary).

? Why can osmotic forces be thought of as pressures? Do you know any way to measure these forces as pressures?

d. The total force acting on water at any point along the vessel, called the **filtration pressure** will be the sum of the two forces; this is called the **STARLING HYPOTHESIS**. For water in the formation of lymph it can be written as:

3. $$\text{Filtration pressure} = P_{hydrostatic} + \Pi_{osm}$$

e. **To find the filtration rate**, we need to also consider a **permeability (conductance** -- review early material from lab) f**actor determined largely by the density of capillary pores** -- the more pores, the more water can move for a given filtration pressure:

4. Filtration rate = $\boldsymbol{k} * (P_{\text{hydrostatic}} + \Pi_{osm})$

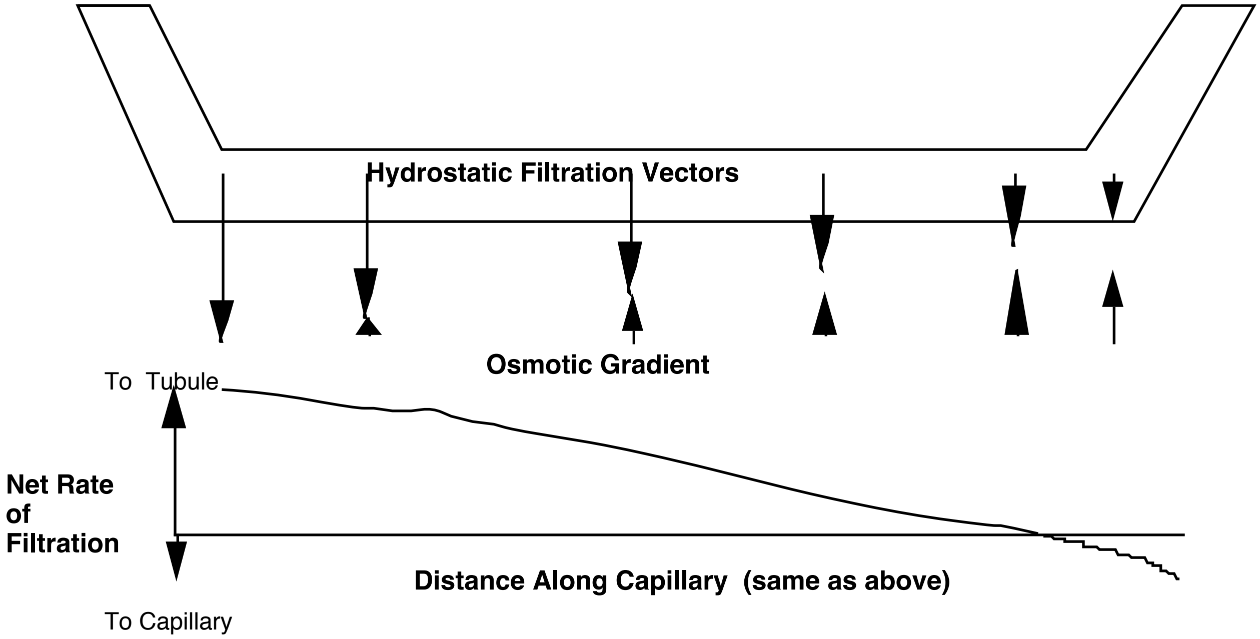
where $\boldsymbol{k}$ is the conductance for water.

f. Let's look at this equation in detail. IF EVERYTHING ELSE REMAINS CONSTANT:

i. if the capillary hydrostatic pressure (P_{cap}) increases or the tissue hydrostatic pressure decreases, there will be a greater pressure tending to drive materials across the membrane and the filtration rate will increase.

ii. By contrast, a relatively higher intercellular fluid osmotic pressure (Π_{icf}) will tend to encourage fluid to leave the capillary as will a relative lower tubule osmotic pressure.

g. We can envision the net forces of each of the hydrostatic and osmotic pressures as:



h. The net effect is that **although quite a bit of fluid moves across the capillary wall,** the **<u>net effect is for it to leave on the arterial end and return on the venous end</u>**.

i. By the time the blood has left the capillary for the venule, the **<u>blood volume has only been reduced very slightly -- about 2%</u>**. **<u>This becomes the lymph.</u>**

ii. Over the period of a typical day, the total volume of lymph that has been formed and returned to the blood is about equal to the total plasma volume! Yet the system is so well balanced that generally there is ever little additional excess accumulation of fluid (called **edema).**

? Name a disease caused by parasites blocking portions of the lymphatics that produces severe disfiguring edema.