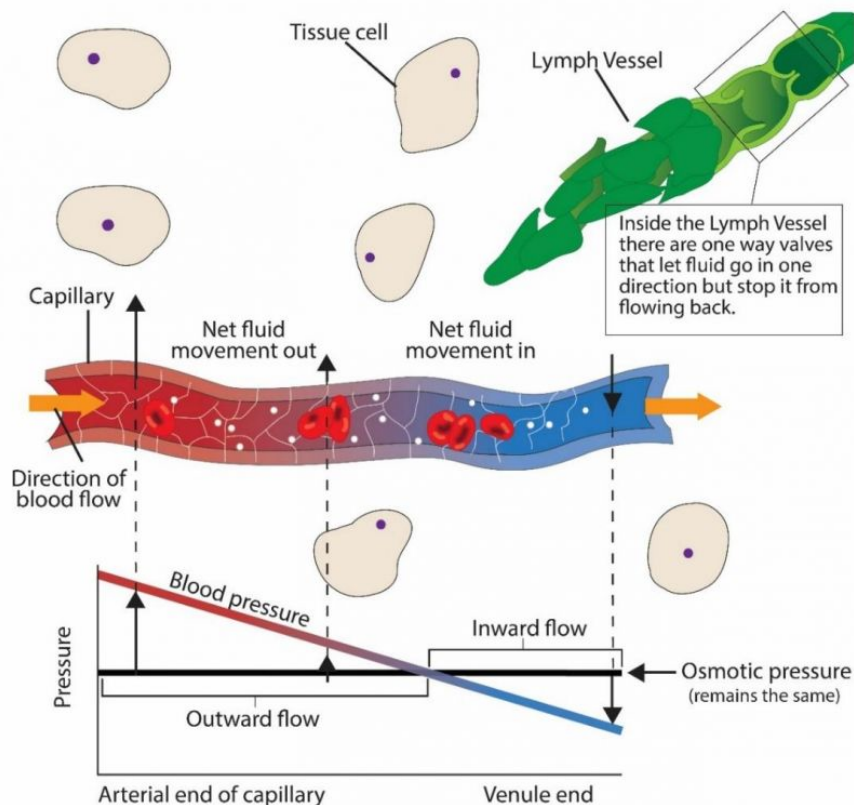


CAPILLARY EXCHANGE

Having discussed the anatomy of the circulatory system, we are now ready to study the very reason why the circulatory system exists: **capillary exchange**. Capillary exchange is simply the flow of water and dissolved particles from the blood to the tissues and from the tissues to the blood. The dissolved solutes that pass from the blood across the capillaries to interstitial spaces and from interstitial spaces across the capillaries back to the blood include everything a cell needs to have in ready supply to survive as well as everything a cell needs to get rid of. Examples of things that cells need include nutrients, regulatory chemical messengers, and electrolytes. Examples of things that cells need to get rid of include CO_2 , acids, and other waste products of metabolic processes. Please keep this image below in mind as we discuss the capillary exchange process in detail.



Capillary Exchange.

Image drawn by BYU-Idaho student Fall 2013

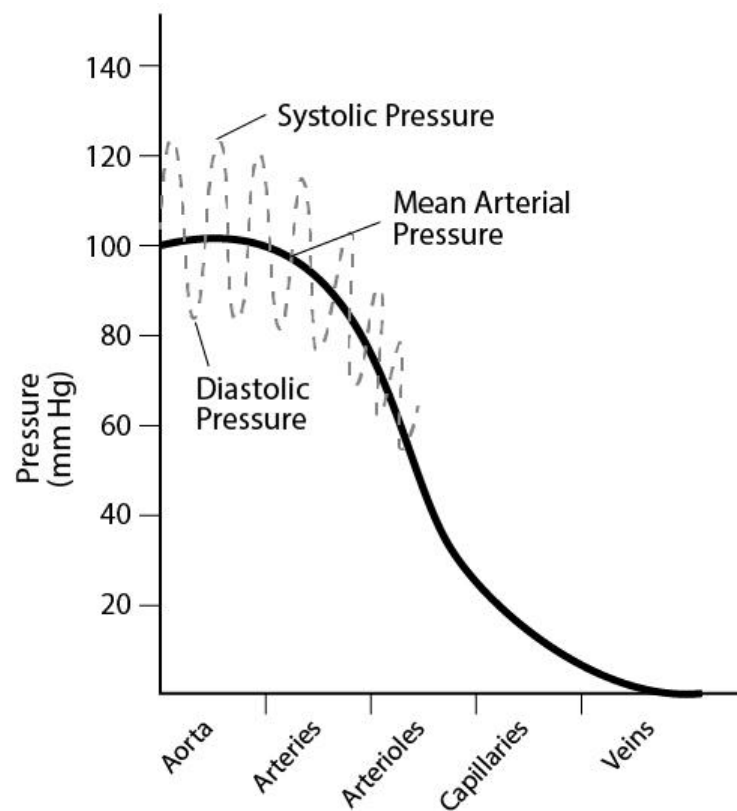
Water, oxygen and nutrients move from inside the capillaries to the interstitial fluid on the arterial end of a capillary bed and from the interstitial spaces back to the inside of the capillaries on the venous side of a capillary bed. In order for this exchange of water, oxygen, carbon dioxide and other nutrients to happen in the capillary bed, there must be

pressure that “pushes” things out and pressure that “pulls” things back into the capillary.

There are two main pressures to understand in the capillary exchange process. One is known as the “**Net Hydrostatic Pressure**” and the other is the “**Net Osmotic Pressure**” and the difference between these two pressures equals the “**Net Filtration Pressure.**” The term *hydrostatic* relates to the pressure of all the liquids involved – the blood pressure, the interstitial fluid, etc. The term *osmotic* relates to the solutes (proteins and electrolytes) and the power they have to pull water from a higher concentration to lower concentration (osmosis) in order to reach equilibrium.

Let’s study in detail all the pressures that combine to create the net hydrostatic pressure and the net osmotic pressure as they contribute to the process of the exchange that happens in the capillaries. There are four pressures that we try to keep track of as we determine the 'Net' filtration pressure.

1. **Blood pressure (BP):** Notice in the picture below how blood pressure oscillates between about 120 mmHg and 80 mmHg in the large arteries like the aorta. As blood moves peripherally and enters many branches into smaller vessels, the blood pressure oscillations are dampened. Finally, by the time the blood is branching into the capillaries, the pressure is around 30 mmHg (this can vary, however, The kidney capillaries, for example, can have pressures closer to 50 mmHg). Blood pressure tends to drive fluid and solutes out of the capillary.



Blood Pressure Variation in Blood Vessels.

Image drawn by J. Shaw at BYU-Idaho Fall 2013

2. **Blood colloid osmotic pressure (BCOP):** BCOP is an osmotic force that tends to move water towards an area of more solutes. The word colloid refers to the concentration of solutes that cannot leave the capillary. This is primarily plasma proteins (mostly albumin). Albumin is a large protein in the plasma and generally cannot fit between the pores of the endothelial cells that make up the capillary wall. If we imagined that there were no solutes outside of a capillary and calculated the number of solutes in the capillary, we could say that there is an osmotic pressure that tends to drive

water into the capillary. This calculated pressure would be about 28 mmHg. Let's take a look at the table below to help keep track of what has happened so far.

Arterial End

So Far...

Pressure moving fluid out of the capillary	Blood Pressure in the arterial end of the capillary	30 mmHg
Pressure moving fluid into the capillary	Blood Colloid Osmotic Pressure	28 mmHg
Net Pressure and Direction		2 mmHg out of the Capillary

Let's keep going, we have two more pressures to consider:

3. Interstitial Colloid Osmotic Pressure (ICOP): ICOP is an osmotic force that tends to move water out of the capillary and into the interstitial space. There are colloids (proteins) outside the blood as well surrounding the tissues. The osmotic force caused by the proteins outside the cell and pulling water out of the capillary is about 8 mmHg.

4. Interstitial Fluid Pressure (IFP): IFP refers to the pressure that the fluid in the interstitial space puts on the capillary membrane. As it turns out the lymphatic system is pulling fluid away from the interstitial space and so, the pressure on the capillary is actually a 'suction'.

So Now...

Pressure moving fluid out of the capillary	Blood Pressure in the arterial end of the capillary	30 mmHg
	ICOP at the arterial end of the capillary	8 mmHg
	IFP at the arterial end of the capillary	3 mmHg
Net Pressure Moving Fluid Out of a Capillary		41 mmHg
Pressure moving fluid into the capillary	Blood Colloid Osmotic Pressure	28 mmHg
Net Pressure Moving Fluid into a Capillary		28 mmHg
NET FILTRATION PRESSURE AND DIRECTION		41 mmHg out - 28 mmHg in
AT ARTERIAL END		13 mmHg Out

So far, we have examined the 4 forces that control flow of water and dissolved fluids out of a capillary at the *arterial end*. Now, let's look at how these 4 forces work at the venous end of a capillary.

1. **Blood pressure (BP):** The capillaries are very small and there is significant friction on the flow of blood as it moves from the arterial end to the venous end. This friction causes the pressure that the blood puts on the capillaries to drop. For this reason, we find a significant decrease in blood pressure on the venous end of capillaries (around 10 mmHg instead of 30 mmHg).

2. **Blood colloid osmotic pressure (BCOP):** BCOP is largely determined by the concentration of albumin in the capillary. Albumin does not cross the capillary membrane and so the concentration of this solute stays about the same through the length of the capillary. On the venous end, the BCOP is still 28 mmHg.

3. **Interstitial Colloid Osmotic Pressure (ICOP):** ICOP is largely a product of the proteins in the interstitial space. This does not change from the arterial to the venous end of a capillary so we find ICOP to be about 8 mmHg on the venous end.

4. **Interstitial Fluid Pressure (IFP):** IFP remains about the same on both the arterial and venous ends of a capillary because the lymph system is steadily pulling fluid away from the interstitial spaces. IFP is calculated at about a 3mmHg force pulling fluid away from the capillary. Sometimes this 'suction' effect is expressed as a negative pressure, so it is not uncommon to see some texts express IFP as -3 mmHg.

Venous End

On the Venous end...

Pressure moving fluid out of the capillary	Blood Pressure in the venous end of the capillary	10 mmHg
	ICOP at the venous end of the capillary	8 mmHg
	IFP at the venous end of the capillary	3 mmHg
Net Pressure Moving Fluid Out of a Capillary		21 mmHg
Pressure moving fluid into the capillary	Blood Colloid Osmotic Pressure	28 mmHg
Net Pressure Moving Fluid into a Capillary		28 mmHg
NET FILTRATION PRESSURE AND DIRECTION		21 mmHg out
AT VENOUS END		- 28 mmHg in
<i>*The negative sign suggests that relative to the inside of the capillary, fluid is being pulled in (reabsorbed)</i>		- 7 mmHg in
<i>rather than pushed out (filtered).</i>		

We see that there is a net flow of fluid moving out of the capillary on the arterial end (13mmHg; represented as a positive number) of a capillary and see that there is a net flow of fluid moving into the capillary on the venous end

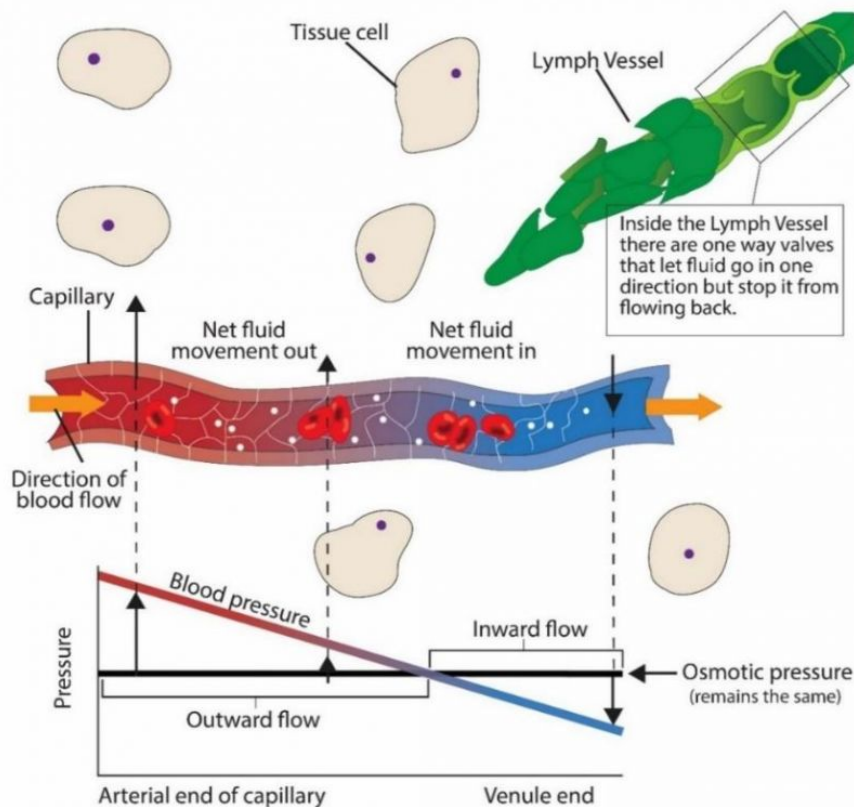
(-7mmHg; represented by a negative number) of a capillary. The net flow on the arterial end is larger than the net flow on the venous end. Logic would suggest that we would continually accumulate fluid in the interstitial spaces if more fluid always left on the arterial end and was not all reclaimed on the venous end. However, this does not happen because the lymphatic system drains away the extra fluid and returns it to the circulation at the subclavian veins (where converging lymphatic vessels connect to venous blood).

To summarize, the Net Hydrostatic Pressure (NHP) is the combination of the blood pressure (BP) and the interstitial fluid pressure (IFP). The Net Osmotic Pressure (NOP) is the difference between the blood colloid osmotic pressure (BCOP) and the interstitial colloid osmotic pressure (ICOP). The Net Filtration Pressure (NFP) is the difference between the Net Hydrostatic Pressure and the Net Osmotic Pressure.

$$\text{Net Hydrostatic Pressure (NHP)} = \text{BP} + \text{IFP}$$

$$\text{Net Osmotic Pressure (NOP)} = \text{BCOP} - \text{ICOP}$$

$$\text{Net Filtration Pressure} = \text{Net Hydrostatic Pressure} - \text{Net Osmotic Pressure}$$



Capillary Exchange.

Image drawn by BYU-Idaho student Fall 2013

The previous figure above shows how blood pressure drops through the length of the capillary. ICOP and BCOP don't change so the net osmotic pressure stays the same. On the graph we see that an outward flow of fluid on the arterial end eventually becomes an inward flow on the venous end. Even though the inward flow is smaller, the total volume of the outward flow is eventually returned to the circulation as the lymphatic vessels continually pull fluid away.

The four forces at work on net fluid movement are in a careful balance and equilibrium so that the volume of fluid and solutes that leave the capillary equals the volume that is eventually returned to the circulation. This balance of fluid movement keeps the interstitial fluid volume around the cells relatively consistent. If one or more of the four forces is increased or decreased then the balance may be lost and edema (swelling) or dehydration may occur.



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