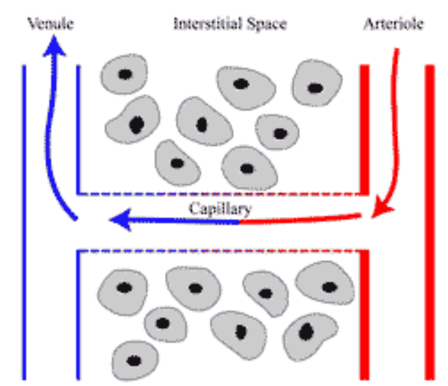
B.5.3. The Capillaries

Purpose: The function of the capillaries is to transport nutrients and oxygen from the blood to all the tissues in the body and to collect waste from these tissues back into the blood.

A. Hydrostatic Pressure in the capillaries:

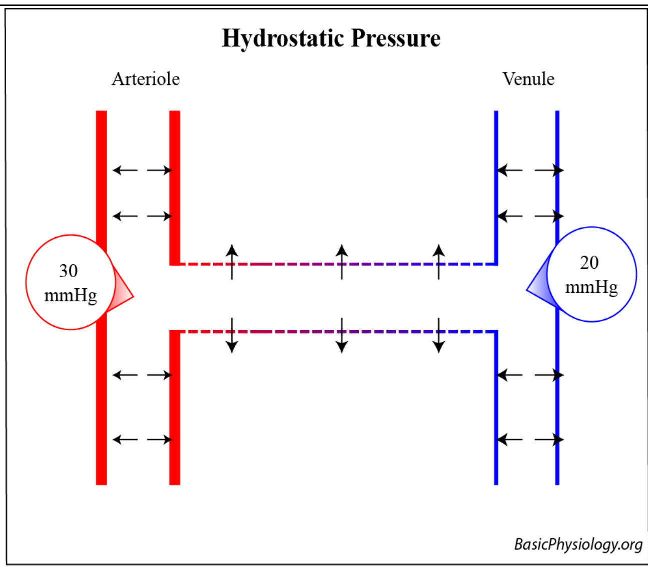
1.
The capillaries do not have a muscular wall. In fact, they only have a single layer of cells. These are called **endothelial** cells.

2.
Because of this thin wall, water and small molecules can easily filtrate (=seep) through this porous layer of cells. But the capillary membrane works as a filter; large molecules and cells **cannot** pass through the membrane.



3.
The blood pressure in the arterioles, at the start of the capillaries, is typically 30 mmHg. Remember that the blood pressure has decreased along the arterial system from about 120/80 to 30 mmHg (because of the arterioles). Furthermore, the blood flow is no longer pulsatile. This pressure is called the **hydrostatic pressure**.

4.
At the beginning of the capillary therefore, the hydrostatic pressure is 30 mmHg. But at the end of the capillary, this hydrostatic pressure has decreased to about 20 mmHg.



5.
Why? Because of the resistance of the capillary wall to the blood flow, just like in the arterioles.

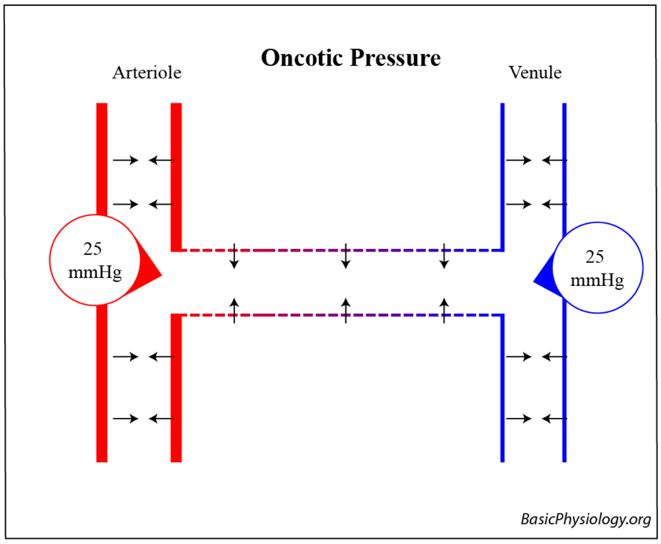
6.
At the same time, **outside** the capillaries, in the interstitial space, the pressure is much lower; about 0 mmHg.

7.
Therefore, the pressure difference (=**gradient**) between inside and outside the capillary would be 20-30 mmHg. This is quite a lot.

8.
In fact, if there were nothing else, we would quickly loose all our water (5 litres blood) into the larger interstitial space (typically 10-15 litres); we would then develop massive **oedema** and die of cardiovascular shock.

9.
Obviously, this does not happen and this is due to the **oncotic** pressure and the **capillary exchange system**.

B. Oncotic Pressure in the capillaries:

1. The **oncotic** pressure is an **osmotic** pressure. This is because the capillaries allow the filtration of water and small molecules but not of large molecules (such as **albumin**). If particles cannot pass a wall but water can, then water is transported and this is **osmosis**. *(Remember osmosis? A.2.3. Passive Transport Systems)* 2. The height of the **oncotic pressure** is determined by the number of particles that cannot filtrate through the membrane. In general, this is typically about 25 mmHg.	
3. Furthermore, in contrast to the hydrostatic pressure, the oncotic pressure is **constant** throughout the length of the capillaries.	4. Now, we are going to 'play' these two pressures against each other!
5. Remember that the **hydrostatic pressure** is a pressure from inside the capillary to the outside; it '**pushes'** the water to go out of the capillary.	6. The **oncotic pressure** works in the **opposite** direction; it is a '**sucking'** pressure. It absorbs water from outside to inside the capillary.

C. The Capillary Exchange System: (also called the Starling-exchange system):

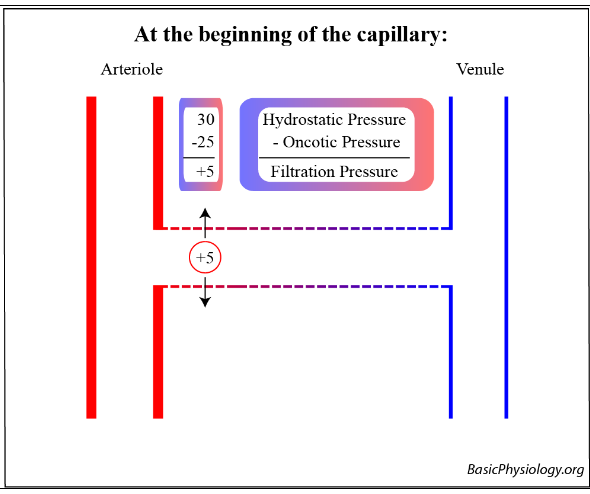
1. Now it gets interesting!	2. There are two pressures influencing the flow of fluid inside the capillaries.
3. The hydrostatic pressure pushes the blood fluid out of the capillaries.	4. And the oncotic pressure 'sucks' the fluid from outside back to the capillaries!
5. You can now calculate the pressure difference between the two pressures: Hydrostatic Pressure – Oncotic Pressure = **Filtration pressure**.	6. So, at the beginning of the capillary, the filtration pressure is: 30-25 = 5 mmHg.

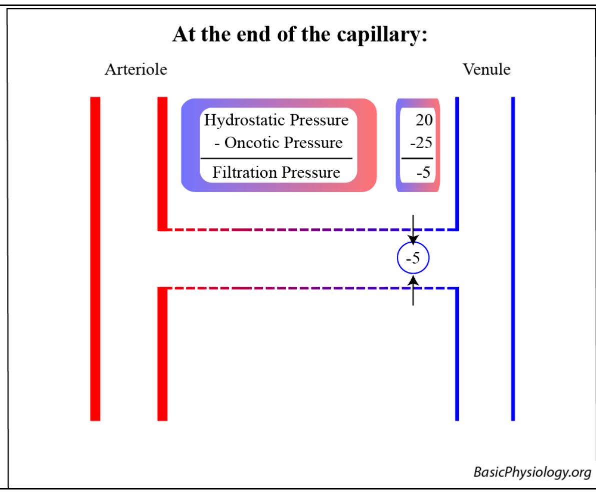
7.
This means, that some water will flow from the inside of the capillary to outside in the interstitial space.

However, this is at the beginning of the capillary.

8.
At the **end** of the capillary, things have changed. The hydrostatic pressure has **decreased** (because of the capillary resistance).

Now, at the end of the capillary, the hydrostatic pressure has decreased to about 20 mmHg.



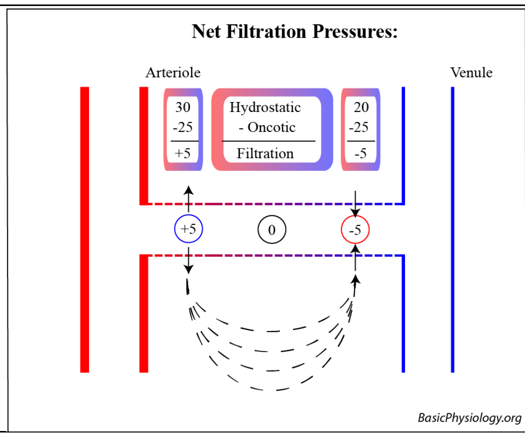


9.
But the oncotic pressure has **not changed** at the end of the capillary. This is because the number of particles that are unable to cross the capillary membrane has not decreased (they could not get out; remember?).

10.
So, at the end of the capillary, the hydrostatic pressure (20 mmHg) is **less** than the oncotic pressure (25 mmHg).

11.
The net filtration pressure is now negative (20-25 = - 5 mmHg) which means water is **reabsorbed** ('sucked') into the capillary.

12.
In conclusion, the water that leaves the capillaries at the beginning (close to the arterioles) is now reabsorbed at the end of the capillaries.



13.
Because the water that goes out contains (small) nutrients and dissolved oxygen, this will 'automatically' flow to the cells. At the same time, water from the cells that contain waste and CO_2, will automatically flow back into the capillaries. The water at the beginning is **exchanged** with water at the end; hence the **name** of the system (exchange system!).

D. Some technical details:

1. The oncotic pressure is determined by the size of the dissolved particles that cannot pass the capillary membrane. This is approximately 50,000-60,000 molecular weights. This means that all the large proteins and all the blood cells cannot pass the membrane. The most common protein that cannot pass the membrane is **albumin** (molecular weight 69,000).	2. In the description above, we assumed that the **interstitial pressure** was 0 mmHg. Likewise, we also assumed that the **oncotic pressure** in the interstitial space is also 0 mmHg. But both these assumptions are not always true. For example, in the gut, after a meal, there are many food particles in the gut interstitial space.
3. If the interstitial hydrostatic and/or oncotic pressure are not zero, then one should first calculate the **real hydrostatic pressure gradient** (= the difference between the blood pressure and the interstitial pressure) and the **real oncotic gradient** (= the difference between the blood oncotic pressure and the interstitial oncotic pressure) before calculating the filtration pressure. (See example ->).	Example: *Hydrostatic pressure gradient:* Blood hydrostatic pressure = 32 mmHg - Interstitial hydrostatic pressure = 3 mmHg Real hydrostatic pressure gradient = 29 mmHg *Oncotic pressure gradient:* Blood oncotic pressure = 25 mmHg - Interstitial oncotic pressure = 5 mmHg Real oncotic pressure gradient = 20 mmHg ***So***: the net filtration pressure is 29-20 mmHg = ***9 mmHg***
4. The hydrostatic pressure is not always the same in all parts of the body. It is about the same, everywhere, when a person is lying flat. However, when a person is standing, the blood pressure in the legs is higher because of the weight of the blood column (an additional 5-10 mmHg).	5. The permeability of most capillaries works in the way described above. However, there are also capillaries in the body that are either much more permeable (such as the **fenestrated** capillaries in the gut and the kidneys and the **sinusoidal** capillaries in liver and bone marrow) or are much less permeable (such as the **blood brain barrier** in the brain).

E. Pathology: Oedema (the Americans say "**Edema**")

1. The capillary exchange system is not only important in normal daily life to keep our cells alive. The system also explains when something goes wrong and **oedema** (= tissue swelling, also spelled Edema) develops.	2. There are essentially three situations when something goes wrong in this system and oedema develops: • when the Oncotic Pressure becomes too **low** • when the Hydrostatic Pressure becomes too **high** • when the capillary membrane becomes too **leaky**.
3. **Oncotic Pressure** is too low. This is the situation when the amount of particles in the blood, that cannot pass the capillary wall, becomes too low. This is usually the case with albumen. **Albumen** is the most common protein in our blood. In the case of malnutrition (=chronic lack of food), the blood albumen is used for energy. This will decrease the albumen blood concentration, and hence the oncotic pressure.	4. Therefore, instead of a value of 25 mmHg, the oncotic pressure could drop to, say, 20 mmHg. That means that more fluid will leave the capillary and less will be reabsorbed, leading to accumulation of fluid in the tissue; **oedema**! This is seen in cases of malnutrition as often seen in poor, underdeveloped, countries. Remember the small children on TV with a big belly but thin arms??? The bellies are big because they are filled with fluid (oedema in the peritoneal space (=belly), which is called **ascites**). These children are severely malnourished.
5. **Hydrostatic Pressure** is too high. When the hydrostatic pressure is too high, then again, more fluid will leave the capillary into the interstitial space. This can be caused either by a too high arterial pressure or a too high pressure in the veins. This condition often occurs when the heart is not working properly (swelling in the **ankles** for example).	6. A problem with the **capillary membrane**. If the capillary does not function properly and becomes too leaky, then the oncotic pressure will be lower (because this is determined by the amount of particles that do not cross the capillary wall). This can happen for example during an **infection**. A typical example is the sting of a bee. The bee injects a toxic substance that makes the capillary leak. This will cause a swelling at that location.