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The kidney

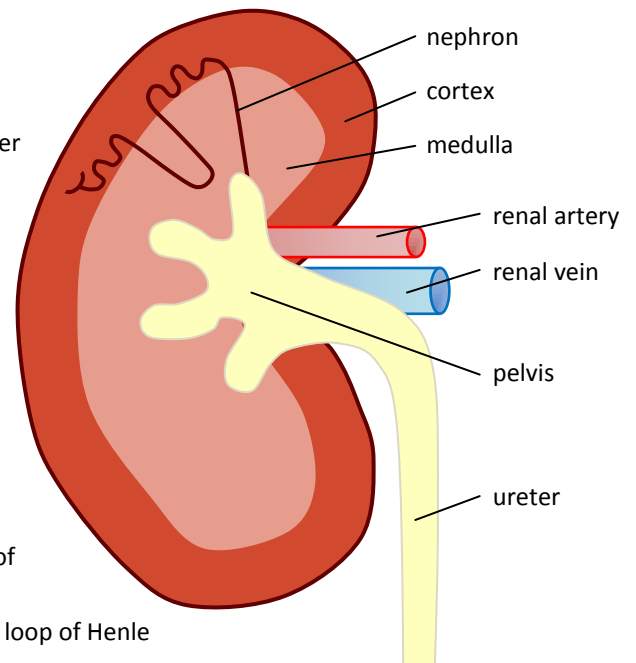
The function of the kidney and how the structure of a nephron helps its function

Structure of the kidney

The regular human body has two kidneys. The urinary system consists of four major parts:

- the two **kidneys**
- the **ureters** which transport urine from the kidney to the bladder
- the **bladder** temporarily stores urine
- the **urethra** to take urine to the outside world

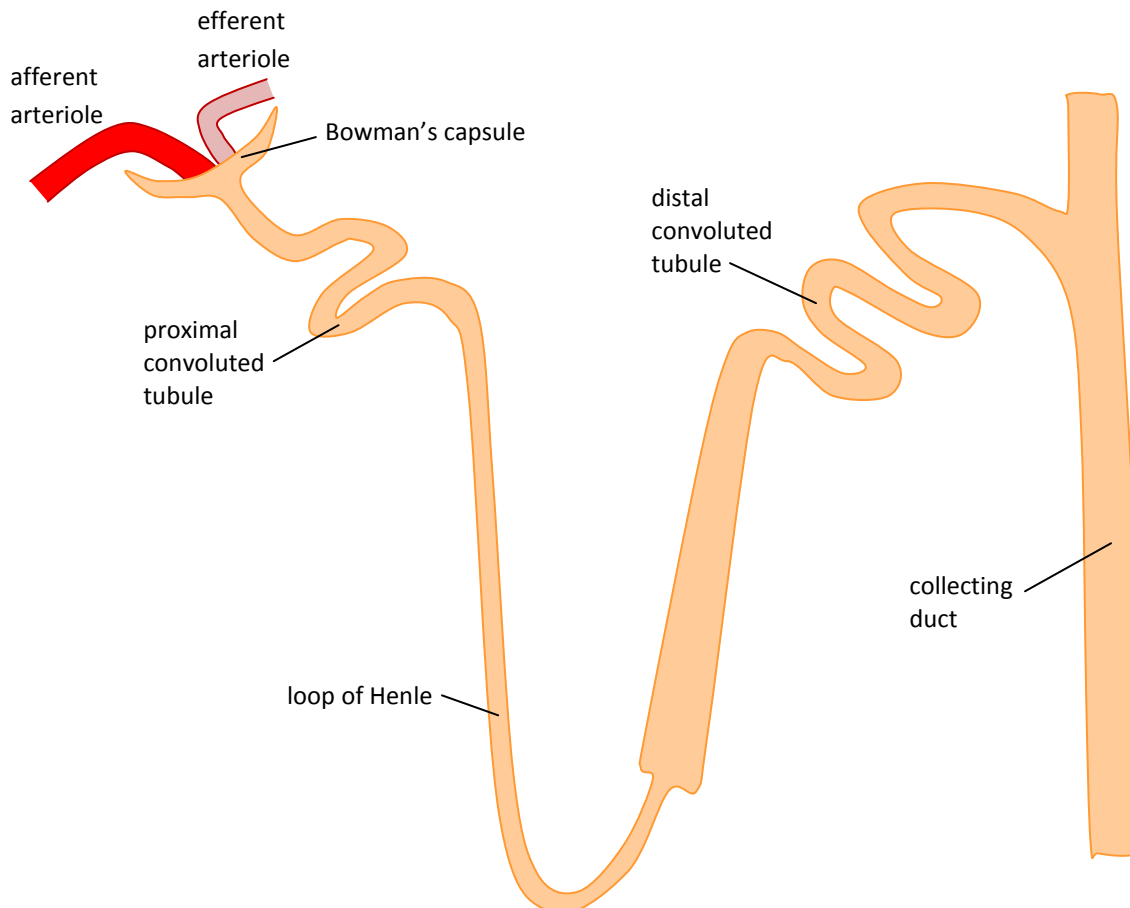
There are approximately one million tubules within a kidney called **nephrons**, which consist of several parts each with a different function. A nephron exists through each section of the kidney: the outer **cortex**, the **medulla** in the middle, and the innermost **pelvis**.



The nephron

A single nephron is made up of the:

- concave *Bowman's capsule* structure which houses a network of capillaries called the *glomerulus*
- *proximal convoluted tubule* which runs from the capsule to the loop of Henle
- *loop of Henle*, where water reabsorption occurs
- *distal convoluted tubule*
- and the *collecting duct* which connects to many nephrons and ultimately ending up in the pelvis region

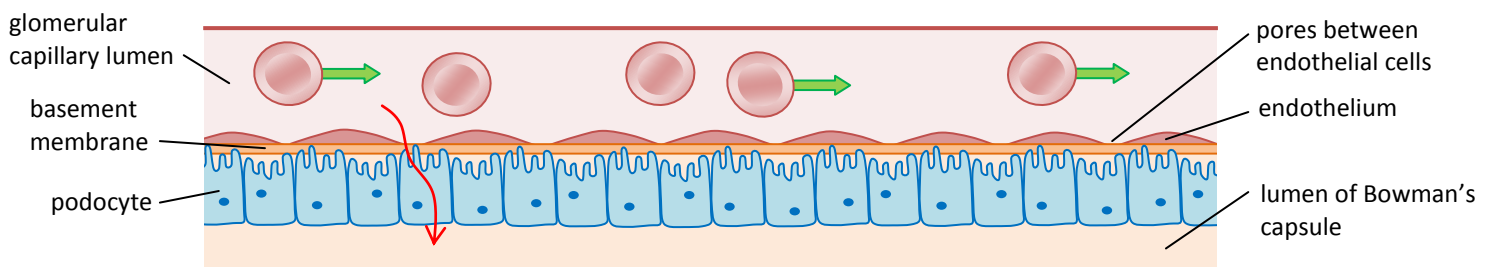


Ultrafiltration

The kidney is concerned with filtering out waste products from the blood plasma, which are to be excreted in the urine. However, this cannot be done simply by selectively removing the waste products, as it is important that those substances we need to retained are kept: instead, all molecules from the blood plasma below a certain size are passed through the filtration membrane, and those materials which need to be kept are selectively *reabsorbed* later on.

The **afferent arteriole** which supplies the glomerulus (a network of capillaries in close contact with the Bowman's capsule) has a much larger width than the **efferent arteriole** leading away from the glomerulus. This means that there is a largely increased pressure inside the glomerular capillaries than there is in the efferent arteriole. This forces fluid from the blood through from the blood capillaries into the renal capsule. This process is called **ultrafiltration**.

The blood flowing through the afferent arteriole is at a high pressure, and due to the small width of the efferent arteriole, a burst of pressure forces molecules within the blood with a relative molecular mass (RMM) of below 69,000 through the glomerular capillaries and into the Bowman's capsule. This pressure is called **filtration pressure**.



The materials which are passed through this way during ultrafiltration pass through pores in the **endothelium**. The endothelial cells line the **basement membrane** of the Bowman's capsule. The basement membrane is made up of collagen and various other glycoproteins and fibres. The inner lining of the capsule, just beyond this basement membrane consists of **podocytes**, the epithelial cells of the capsule. Podocyte cells have specialised finger-like projections called **major processes** ensuring there are gaps between the cells. Fluid can flow between these cells into the renal capsule.

Each layer (the endothelium, basement membrane and epithelium) are adapted to allow the passage of these substances:

- the endothelial cells have small gaps between them that blood, and the substances dissolved in it, can pass through
- the basement membrane consists of a fine mesh of collagen fibres which act as a filter, preventing molecules larger than 69,000 RMM from passing through the membrane
- the podocytes have major processes which keep gaps between the cells so substances can pass between them

Not all substances are removed from the blood plasma and into the glomerular filtrate. Those which are must clearly have a relative molecular mass of below 69,000. Therefore, molecules of water, glucose and urea, as well as amino acids and ions are all removed from the blood plasma and filtered into the nephron. A minority of proteins (the small ones) may be filtered through, but the vast majority of proteins are too big to fit through the gaps in the basement membrane, and so remain in the blood. Similarly, all blood cells do not enter the glomerular filtrate.

Selective reabsorption

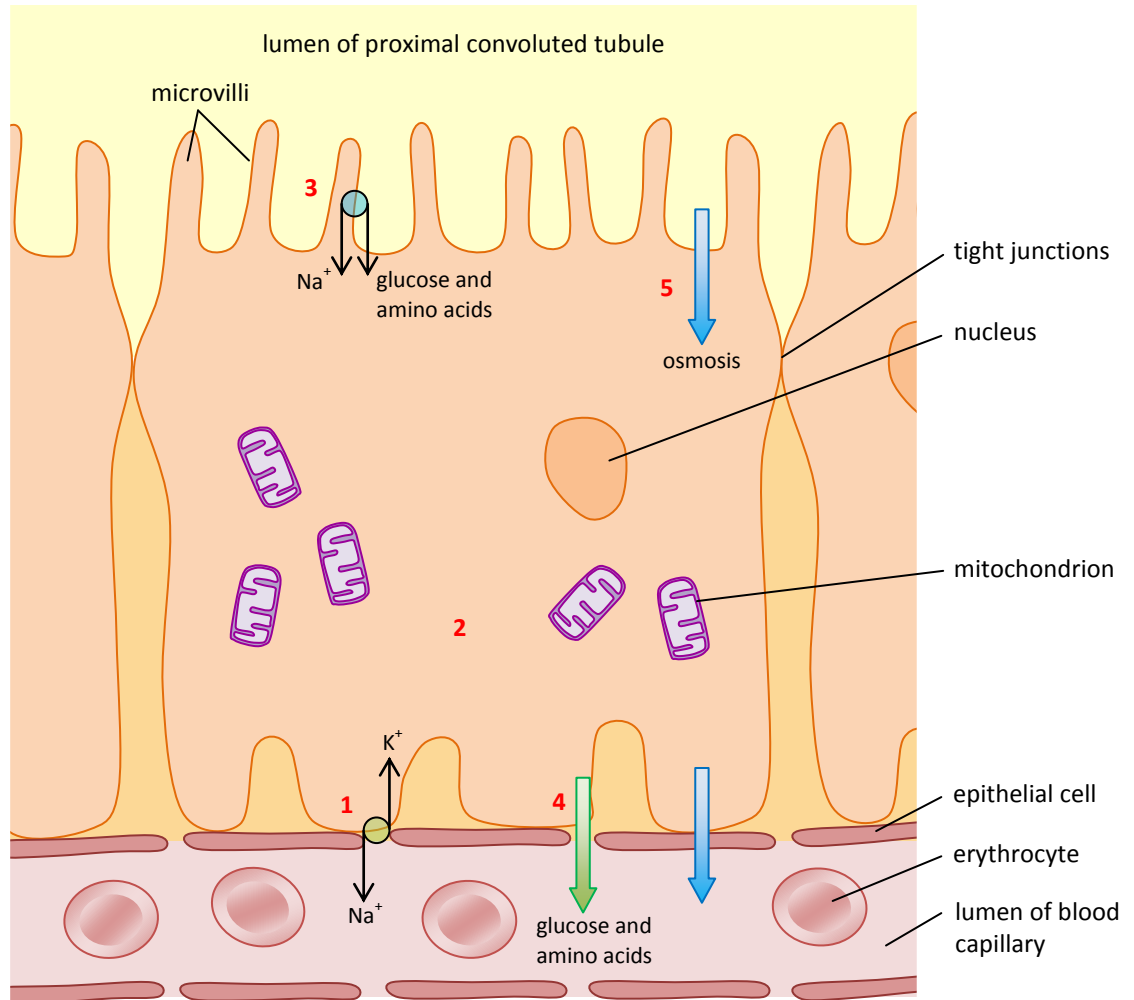
The filtrate which results in the Bowman's capsule flows along the nephron, and it is at the **proximal convoluted tubule** that the majority of substances to be reabsorbed are so. Approximately 85% of the nephron filtrate is reabsorbed back into the blood along the proximal convoluted tubule. This process is known as **selective reabsorption**.

During this stage, all of the glucose and amino acids are reabsorbed back into the blood. Some ions are also reabsorbed, namely sodium ions, as well as a small amount of water. Selective reabsorption occurs in a several staged process:

- 1 On the cell surface membrane closest to the blood capillary, there are **sodium-potassium pumps** which actively transport sodium ions out of the cell and potassium ions into the cell (the primary function is to transport Na^+)
- 2 As sodium ions are pumped out of the cell, the concentration of sodium ions inside the cell drops
- 3 This allows the transport of sodium ions back into the cell from the surface membrane in contact with the proximal convoluted tubule – the ions flow in through specialised **co-transporter proteins** which couple the movement of sodium ions into the cell with the movement of glucose and amino acids (this is facilitated diffusion)

- 4 As sodium moves into the cell, taking glucose and amino acids in with it, the concentration of glucose and amino acids within the cell lining the convoluted tubule increases, and so these substances diffuse out of the cell and into the blood capillary via facilitated diffusion, using transport proteins
- 5 The movement of ions, glucose and amino acids from the convoluted tubule into the cells leads to an increased **water potential** (Ψ) inside the convoluted tubule, and so water diffuses, by **osmosis**, into the cells lining the tubule, which in turn increases the water potential of those cells, and so water diffuses into the blood capillary

The cells which line the walls of the proximal convoluted tubule have several adaptations which make them particularly good at their function. Firstly, there are **tight junctions** between each cell which prevent substances from moving between cells (instead they have to go through them). Also, there are many mitochondria to provide energy for the active processes. The plasma membrane in contact with the convoluted tubule is also folded to give many **microvilli** which increase the surface area for the movement of substances into the cell and ultimately into the blood capillary.



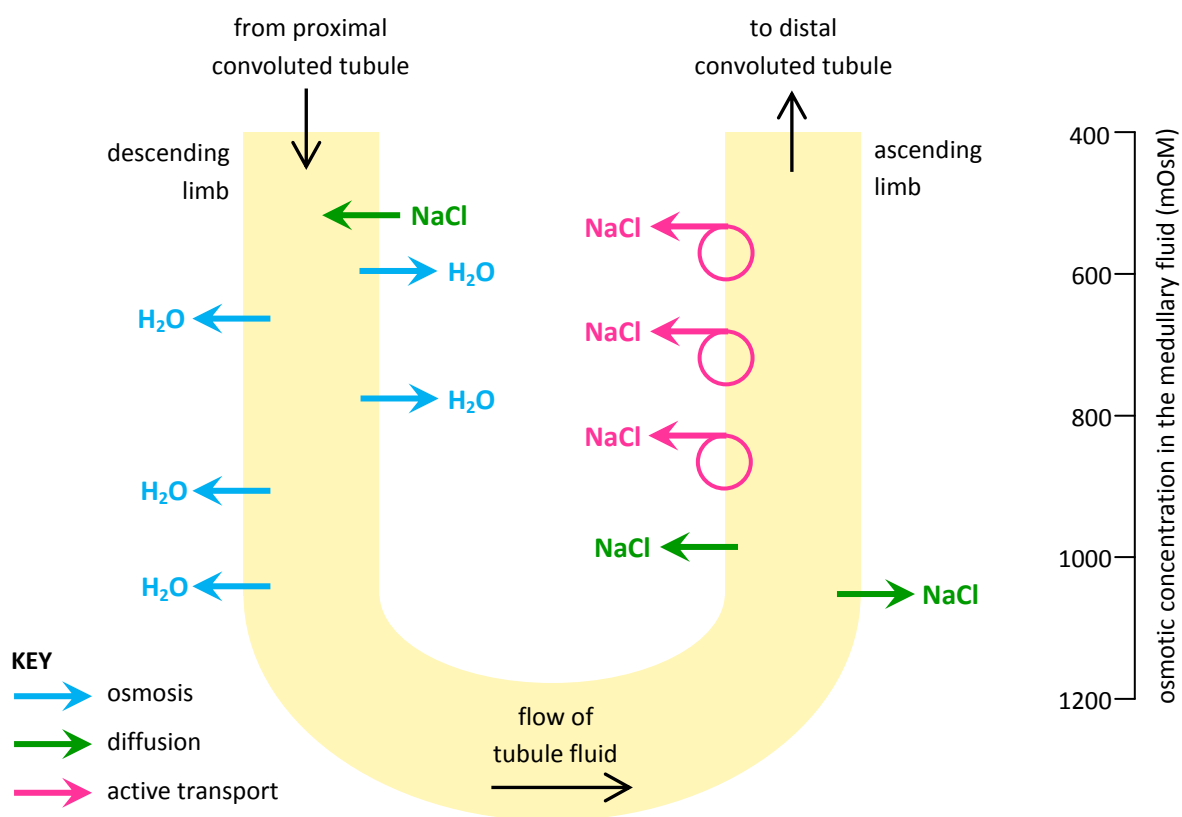
There may also be some **endocytosis** of the smaller proteins which were not too big to pass through the basement membrane and so ended up in the glomerular filtrate. This allows them to be transported back into the blood, alongside the other useful substances (the glucose, amino acids, ions and water).

Creating a water potential gradient

During selective reabsorption, approximately two thirds of the water from the nephron filtrate is reabsorbed back into the blood. It is the role of the **loop of Henle** to establish a low water potential, to ensure that even more of the remaining water can be reabsorbed from the fluid in the collecting duct.

The loop of Henle consists of two sections: the **descending limb** and the **ascending limb**. Needless to say, the descending limb (which begins from the proximal convoluted tubule) heads 'downwards' into the medulla, and the ascending limb (which ends at the distal convoluted tubule) head back 'upwards' through to the cortex. The way that the loop of Henle is arranged allows sodium and chloride ions to flow out of the ascending limb and into the descending limb. This creates a high concentration gradient of salts (the sodium and chloride ions) in the tubule fluid (the fluid inside the loop of Henle), which causes the salts to move out of the ascending limb and into the surrounding tissue, of the medulla, which of course decreases the water potential. The descending limb is the only limb to not actively extrude sodium and chloride ions into the medullary fluid.

- 1 The descending limb is highly permeable to water, and so water is lost to the surrounding medullary fluid by osmosis more and more as the fluid flows down the limb, and the water which is lost is reabsorbed back into the blood by surrounding capillaries – this concentrates the tubule fluid
- 2 This descending limb does not actively lose any sodium or chloride ions
- 3 At the bottom section of the ascending limb, sodium chloride diffuses from the ascending limb into the medullary interstitial fluid, lowering the solute concentration of the filtrate and adding to the solute concentration of the surrounding fluid
- 4 Near the top of the ascending limb, sodium chloride is actively transported out into the medullary fluid. As the walls of the ascending limb are impermeable to water, the movement of salts out of the tubule does not cause water to osmotically follow along
- 5 Some of these salts may diffuse back into the top of the descending limb, as this is where the concentration of salts is highest in the medullary fluid (remember, salts cannot leave the descending limb, but they can diffuse in here)
- 6 As the tubule fluid moves along the loop of Henle, the transport of sodium chloride out of the ascending limb, coupled with the osmosis of water out of the descending limb, establishes an osmotic concentration in the medullary interstitial fluid which becomes increasingly hypertonic as the loop drops in towards the medulla



The arrangement of the loop of Henle results in what is known as the **countercurrent multiplier**. This is because of the gradient of osmotic concentration that the above processes produce up and down each limb of the loop. The purpose of this system is to increase the efficiency of salt transfer across from the ascending limb to the descending limb, which causes a build-up of salts in the surrounding medullary fluid.

The collecting duct

After the loop of Henle, the fluid flows along the **distal convoluted tubule**, where various transport proteins fine tune the appropriate levels of salts for the fluid. The fluid, however, still contains a lot of water, even after selective reabsorption and the reabsorption of water (above). After the distal convoluted tubule, the fluid flows into and down the **collecting duct** which heads through to the pelvis. As the water potential of the fluid is very high, since it contains a lot of water, where the osmotic concentration in the surrounding tissue (in the cortex and some of the medulla) is quite low, water moves out of the collecting duct and into the interstitial fluid by osmosis. It will then be reabsorbed, again by osmosis, by the various blood capillaries surrounding the nephron. This maintains an appropriate concentration of water in the urine.