CBCS THIRD SEM GENERAL

UNIT 4: EXCRETION;

STRUCTURE OF NEPHRON, MECHANISM OF URINE FORMATION, COUNTER-CURRENT MECHANISM

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Excretion is a process by which metabolic waste is eliminated from an organism. In vertebrates this is primarily carried out by the lungs, kidneys and skin.

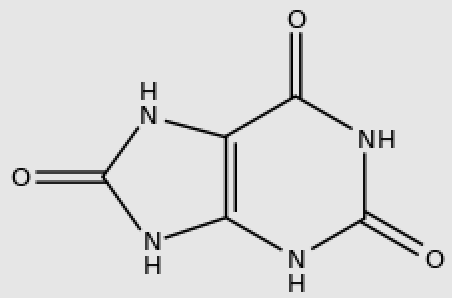
This is in contrast with secretion, where the substance may have specific tasks after leaving the cell.

Excretion is an essential process in all forms of life. For example, in mammals urine is expelled through the urethra, which is part of the excretory system.

In unicellular organisms, waste products are discharged directly through the surface of the cell.

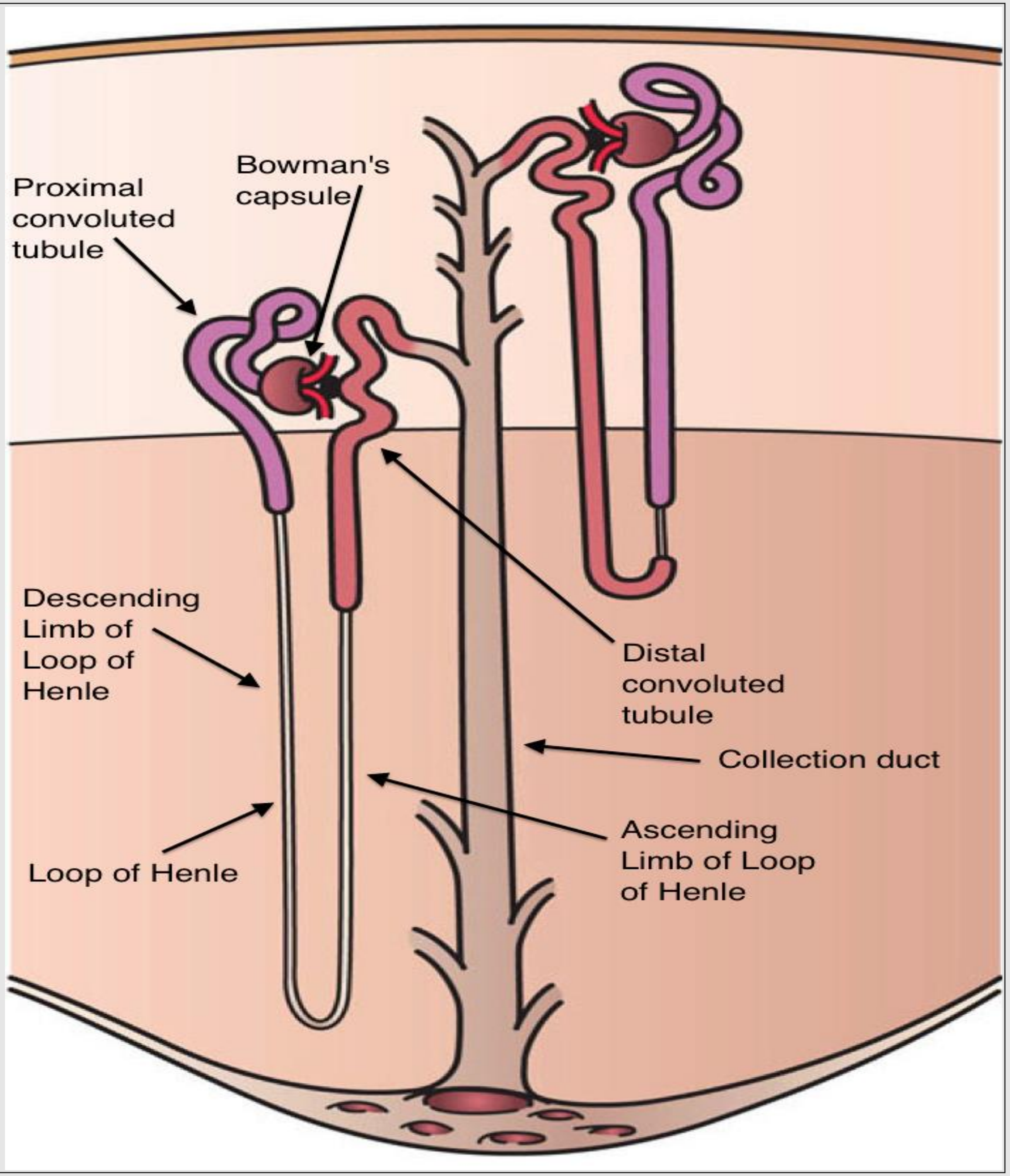
In animals, the main excretory products are carbon dioxide, ammonia (in ammoniotelics),

urea (in ureotelics), uric acid (in uricotelics), guanine (in Arachnida) and creatine.



The liver and kidneys clear many substances from the blood (for example, in renal excretion), and the cleared substances are then excreted from the body in the urine and feces.

Structure of Nephron,



The nephron is the functional unit of the kidney.

This means that each separate nephron is where the main work of the kidney is performed.

A nephron is made of two parts:

1.a renal corpuscle, which is the initial filtering component, and

The renal corpuscle consists of a tuft of capillaries called a glomerulus and an encompassing Bowman's capsule

2.a renal tubule that processes and carries away the filtered fluid.

Renal corpuscle

The renal corpuscle is the site of the filtration of blood plasma.

The renal corpuscle consists of the glomerulus, and the glomerular capsule or Bowman's capsule.

The renal corpuscle has two poles: a vascular pole and a tubular pole.

The arterioles from the renal circulation enter and leave the glomerulus at the vascular pole.

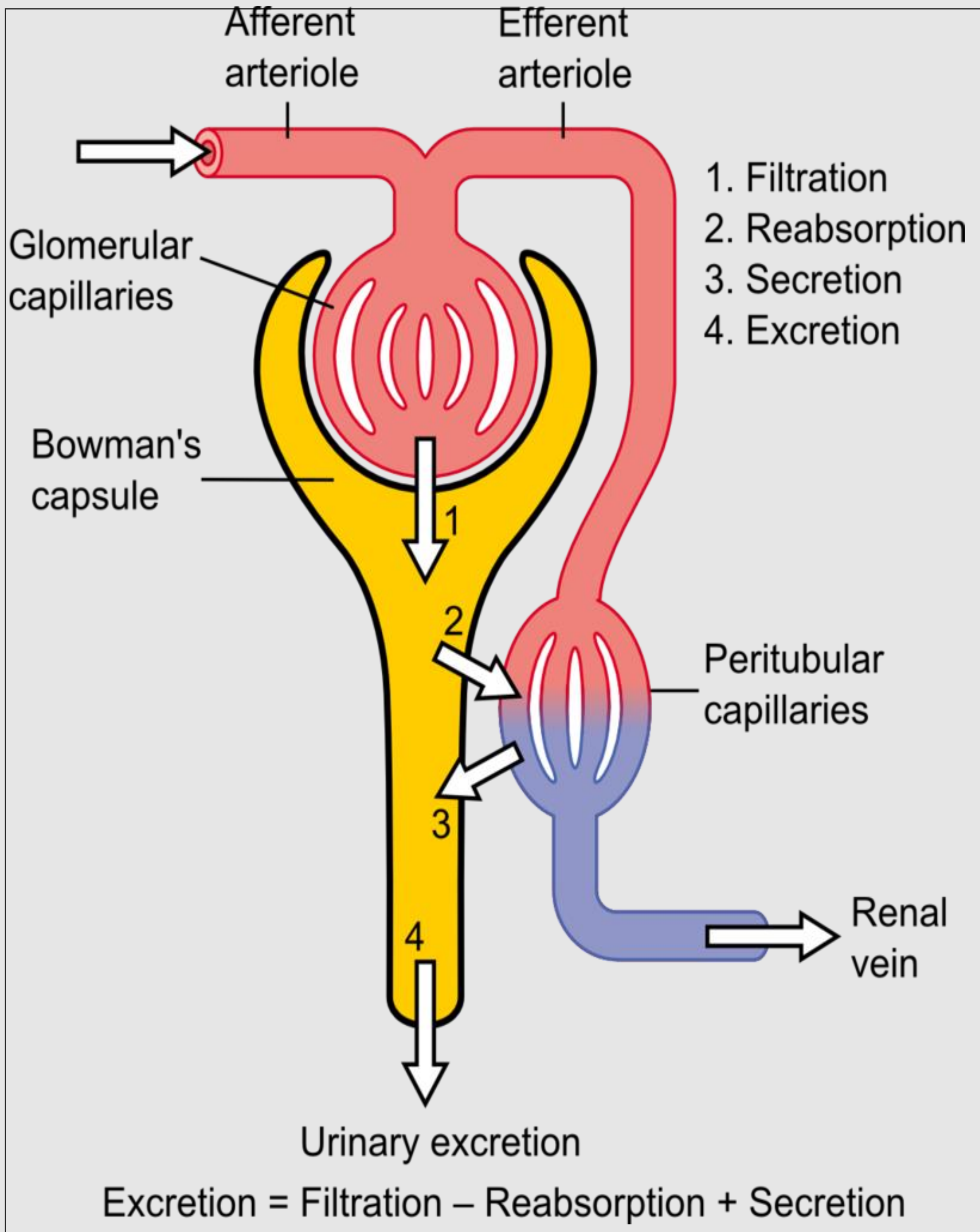


Fig.1) Schematic diagram of the nephron (yellow), relevant circulation (red/blue), and the four methods of altering the filtrate.

Glomerulus

The glomerulus is the network known as a tuft, of filtering capillaries located at the vascular pole of the renal corpuscle in Bowman's capsule. Each glomerulus receives its blood supply from an afferent arteriole of the renal circulation.

The glomerular blood pressure provides the driving force for water and solutes to be filtered out of the blood plasma, and into the interior of Bowman's capsule, called Bowman's space.

Only about a fifth of the plasma is filtered in the glomerulus. The rest passes into an efferent arteriole. The diameter of the efferent arteriole is smaller than that of the afferent, and this difference increases the hydrostatic pressure in the glomerulus.

Bowman's capsule

The Bowman's capsule, also called the glomerular capsule, surrounds the glomerulus. It is composed of a visceral inner layer formed by specialized cells called podocytes, and a parietal outer layer composed of simple squamous epithelium. Fluids from blood in the glomerulus are ultrafiltered through several layers, resulting in what is known as the filtrate.

The filtrate next moves to the renal tubule, where it is further processed to form urine. The different stages of this fluid are collectively known as the tubular fluid.

Renal tubule

The renal tubule is the portion of the nephron containing the tubular fluid filtered through the glomerulus.
After passing through the renal tubule, the filtrate continues to the collecting duct system.

The components of the renal tubule are:

Proximal convoluted tubule (lies in cortex and lined by simple cuboidal epithelium with brush borders which help to increase the area of absorption greatly.)
Loop of Henle (hair-pin like, i.e. U-shaped, and lies in medulla)
Descending limb of loop of Henle

Ascending limb of loop of Henle

The ascending limb of loop of Henle is divided into 2 segments:

Lower end of ascending limb is very thin and is lined by simple squamous epithelium.

The distal portion of ascending limb is thick and is lined by simple cuboidal epithelium.

Thin ascending limb of loop of Henle

Thick ascending limb of loop of Henle (enters cortex and becomes - distal convoluted tubule.)

Distal convoluted tubule

Connecting tubule

Blood from the efferent arteriole, containing everything that was not filtered out in the glomerulus, moves into the peritubular capillaries, tiny blood vessels that surround the loop of Henle and the proximal and distal tubules, where the tubular fluid flows.

Substances then reabsorb from the latter back to the blood stream.

The peritubular capillaries then recombine to form an efferent venule, which combines with efferent venules from other nephrons into the renal vein, and rejoins the main bloodstream

Proximal tubule

The proximal tubule as a part of the nephron can be divided into an initial convoluted portion and a following straight (descending) portion.

Fluid in the filtrate entering the proximal convoluted tubule is reabsorbed into the peritubular capillaries, including more than half of the filtered salt and water and all filtered organic solutes (primarily glucose and amino acids)

Distal convoluted tubule

The distal convoluted tubule has a different structure and function to that of the proximal convoluted tubule. Cells lining the tubule have numerous mitochondria to produce enough energy (ATP) for active transport to take place. Much of the ion transport taking place in the distal convoluted tubule is regulated by the endocrine system.

In the presence of parathyroid hormone, the distal convoluted tubule reabsorbs more calcium and secretes more phosphate. When aldosterone is present, more sodium is reabsorbed and more potassium secreted. Atrial natriuretic peptide causes the distal convoluted tubule to secrete more sodium.

Loop of Henle

The loop of Henle is a U-shaped tube that extends from the proximal tubule.

It consists of a descending limb and an ascending limb.

It begins in the cortex, receiving filtrate from the proximal convoluted tubule, extends into the medulla as the descending limb, and then returns to the cortex as the ascending limb to empty into the distal convoluted tubule.

The primary role of the loop of Henle is to enable an organism to produce concentrated urine, not by increasing the tubular concentration, but by rendering the interstitial fluid hypertonic.

The descending limb is permeable to water and noticeably less permeable to salt, and thus only indirectly contributes to the concentration of the interstitium.

As the filtrate descends deeper into the hypertonic interstitium of the renal medulla, water flows freely out of the descending limb by osmosis until the tonicity of the filtrate and interstitium equilibrate.

The hypertonicity of the medulla (and therefore concentration of urine) is determined in part by the size of the loops of Henle.

The thin ascending limb is impermeable to water, a critical feature of the countercurrent exchange mechanism employed by the loop.

The ascending limb actively pumps sodium out of the filtrate, generating the hypertonic interstitium that drives countercurrent exchange.

In passing through the ascending limb, the filtrate grows hypotonic since it has lost much of its sodium content.

This hypotonic filtrate is passed to the distal convoluted tubule in the renal cortex.

Mechanism of Urine formation, Counter-current mechanism

What is countercurrent multiplication?

Our kidneys have a remarkable mechanism for reabsorbing water from the tubular fluid, called countercurrent multiplication.

Countercurrent multiplication in the kidneys is the process of using energy to generate an osmotic gradient that enables you to reabsorb water from the tubular fluid and produce concentrated urine. This mechanism prevents you from producing litres and litres of dilute urine every day, and is the reason why you don’t need to be continually drinking in order to stay hydrated.

Where does it happen?

The kidneys contain two types of nephrons, superficial cortical nephrons (70-80%) and juxtamedullary nephrons (20-30%). These names refer to the location of the glomerular capsule, which is either in the outer cortex of the kidney, or near the corticomedullary border.

Nephrons can be thought of in sections, each with a different structure and function.

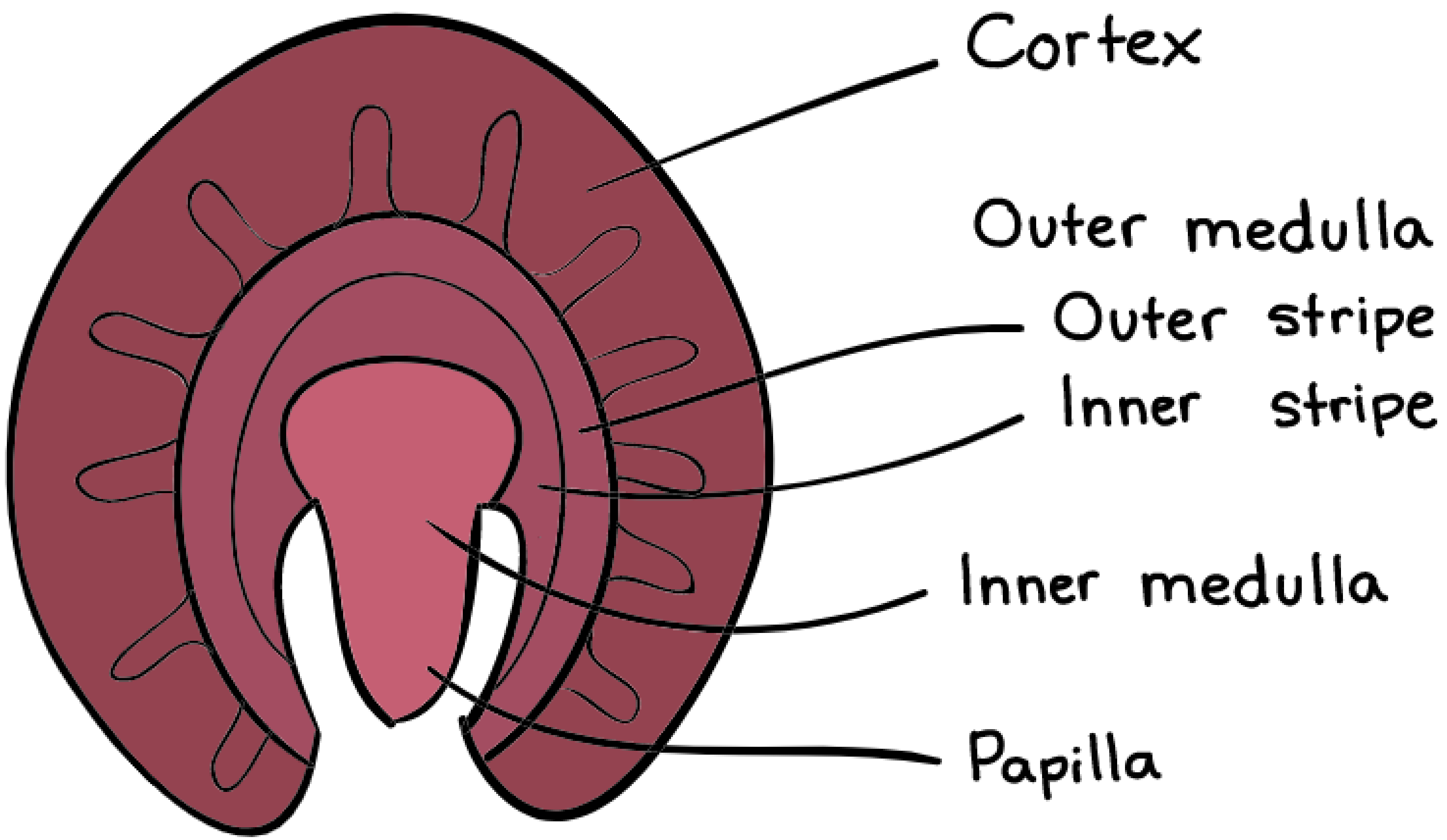
These are the glomerulus, the proximal tubule, the loop of Henle, the distal tubule, and the collecting duct. The loop of Henle is a hairpin-like structure comprised of a thin descending limb, a thin ascending limb and a thick ascending limb.

While the loops of Henle of cortical nephrons penetrate only as far as the outer medulla of the kidney, those of the juxtamedullary nephrons penetrate deeply within the inner medulla.

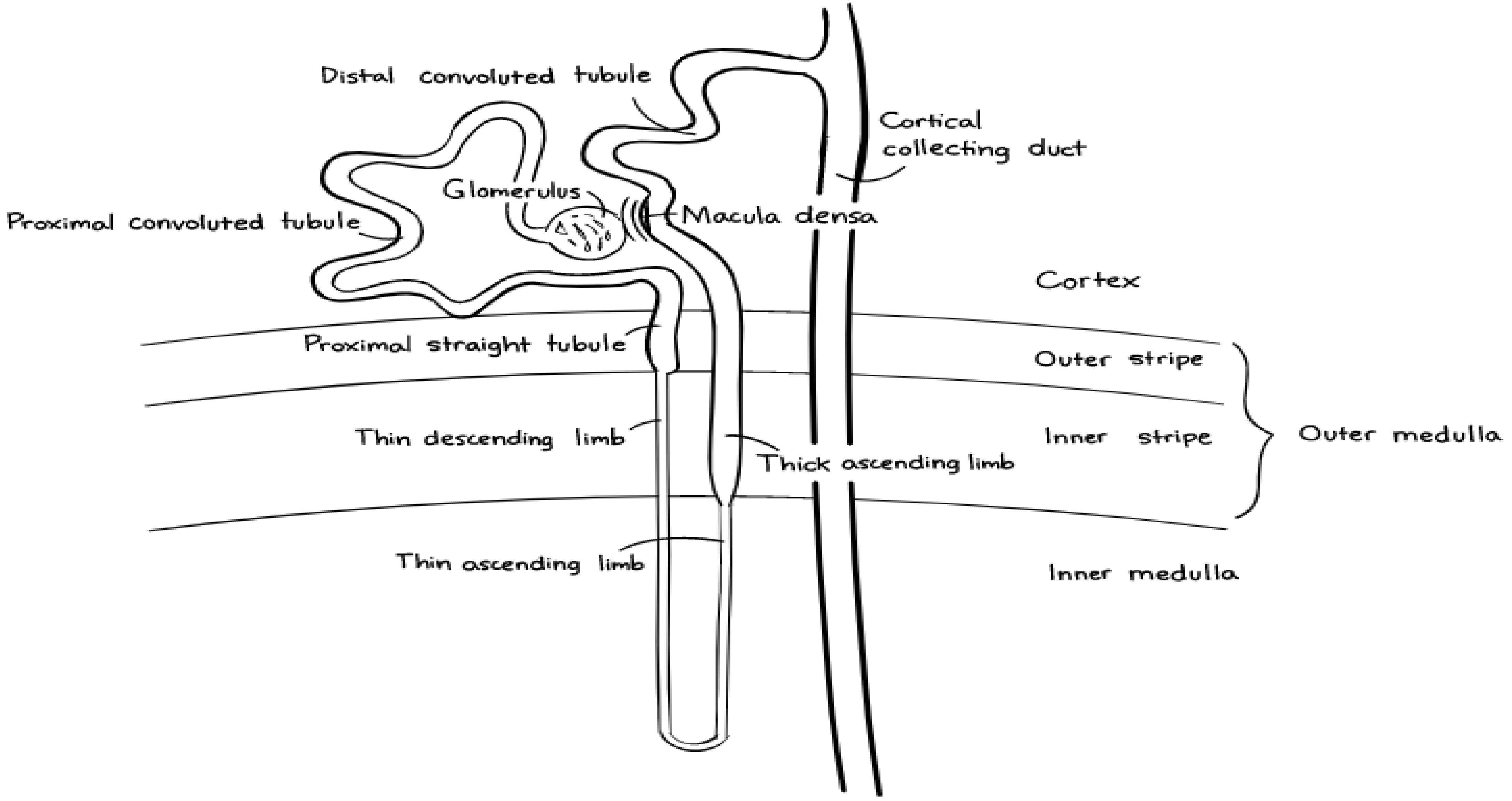
Although both cortical and juxtamedullary nephrons regulate the concentrations of solutes and water in the blood, countercurrent multiplication in the loops of Henle of juxtamedullary nephrons is largely responsible for developing the osmotic gradients that are needed to concentrate urine.

Fluid leaving the ascending limb of the loop of Henle enters the distal convoluted tubule, where its composition is further adjusted, and then drains into collecting tubules.

These tubules empty into collecting ducts that descend back through the medulla, and eventually connect to the ureter, which transports urine to the bladder.



Cortex
Outer medulla
Outer stripe
Inner stripe
Inner medulla
Papilla



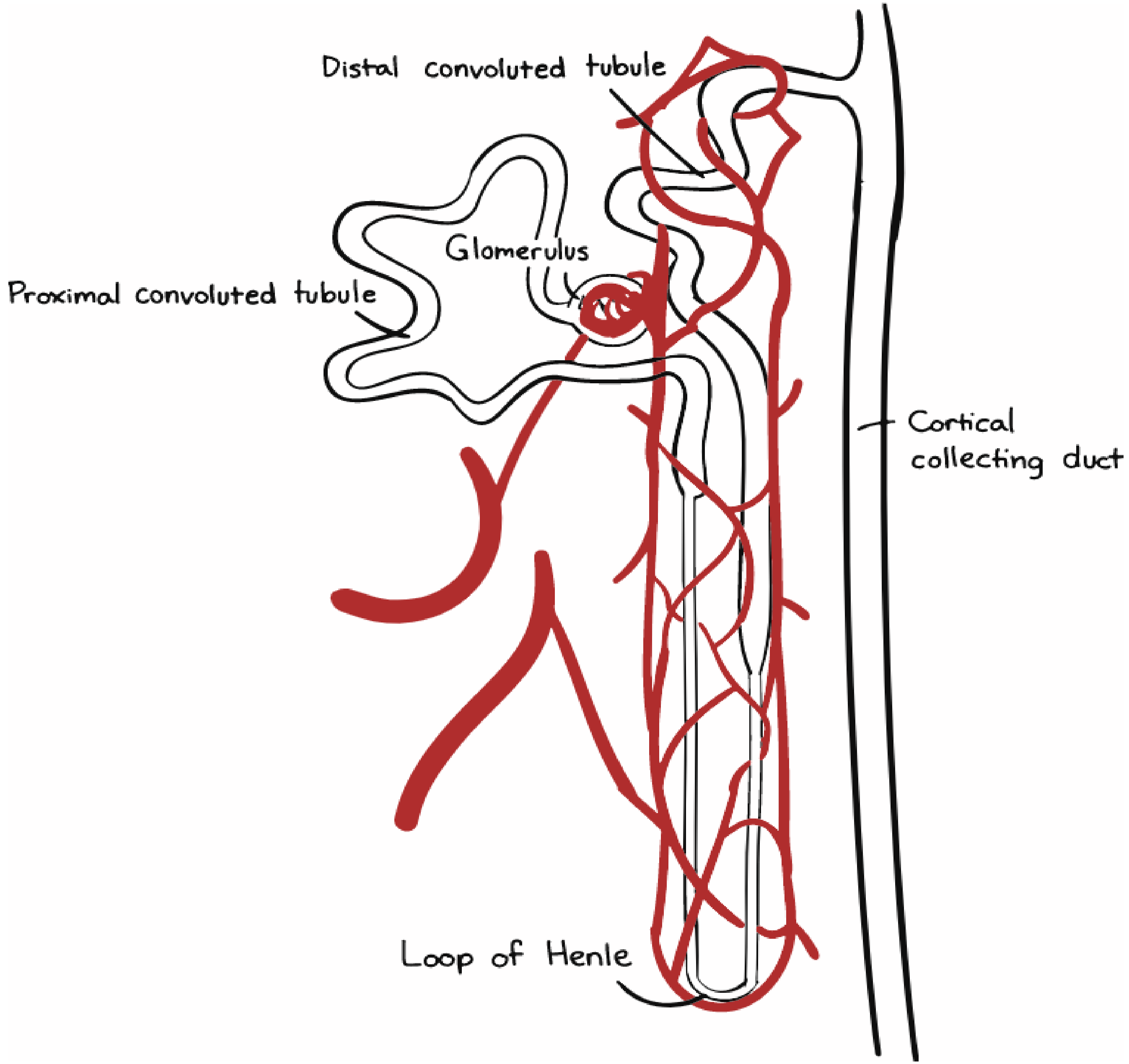
Distal convoluted tubule
Cortical collecting duct
Glomerulus
Macula densa
Proximal convoluted tubule
Cortex
Proximal straight tubule
Outer stripe
Thin descending limb
Inner stripe
Outer medulla
Thick ascending limb
Thin ascending limb
Inner medulla

Although the loops of Henle are essential for concentrating urine, they do not work alone.

The specialized blood capillary network (the vasa recta) that surrounds the loops are equally important.

The vasa recta capillaries are long, hairpin-shaped blood vessels that run parallel to the loops of Henle.

The hairpin turns slow the rate of blood flow, which helps maintain the osmotic gradient required for water reabsorption.


Distal convoluted tubule
Glomerulus
Proximal convoluted tubule
Cortical collecting duct
Loop of Henle

How does countercurrent multiplication work?

The three segments of the loops of Henle have different characteristics that enable countercurrent multiplication.
The thin descending limb is passively permeable to both water and small solutes such as sodium chloride and urea. As active reabsorption of solutes from the ascending limb of the loop of Henle increases the concentration of solutes within the interstitial space (space between cells), water and solutes move down their concentration gradients until their concentrations within the descending tubule and the interstitial space have equilibrated. As such, water moves out of the tubular fluid and solutes to move in. This means, the tubular fluid becomes steadily more concentrated or hyperosmotic (compared to blood) as it travels down the thin descending limb of the tubule.

The thin ascending limb is passively permeable to small solutes, but impermeable to water, which means water cannot escape from this part of the loop.
As a result, solutes move out of the tubular fluid, but water is retained and the tubular fluid becomes steadily more dilute or hyposmotic as it moves up the ascending limb of the tubule.

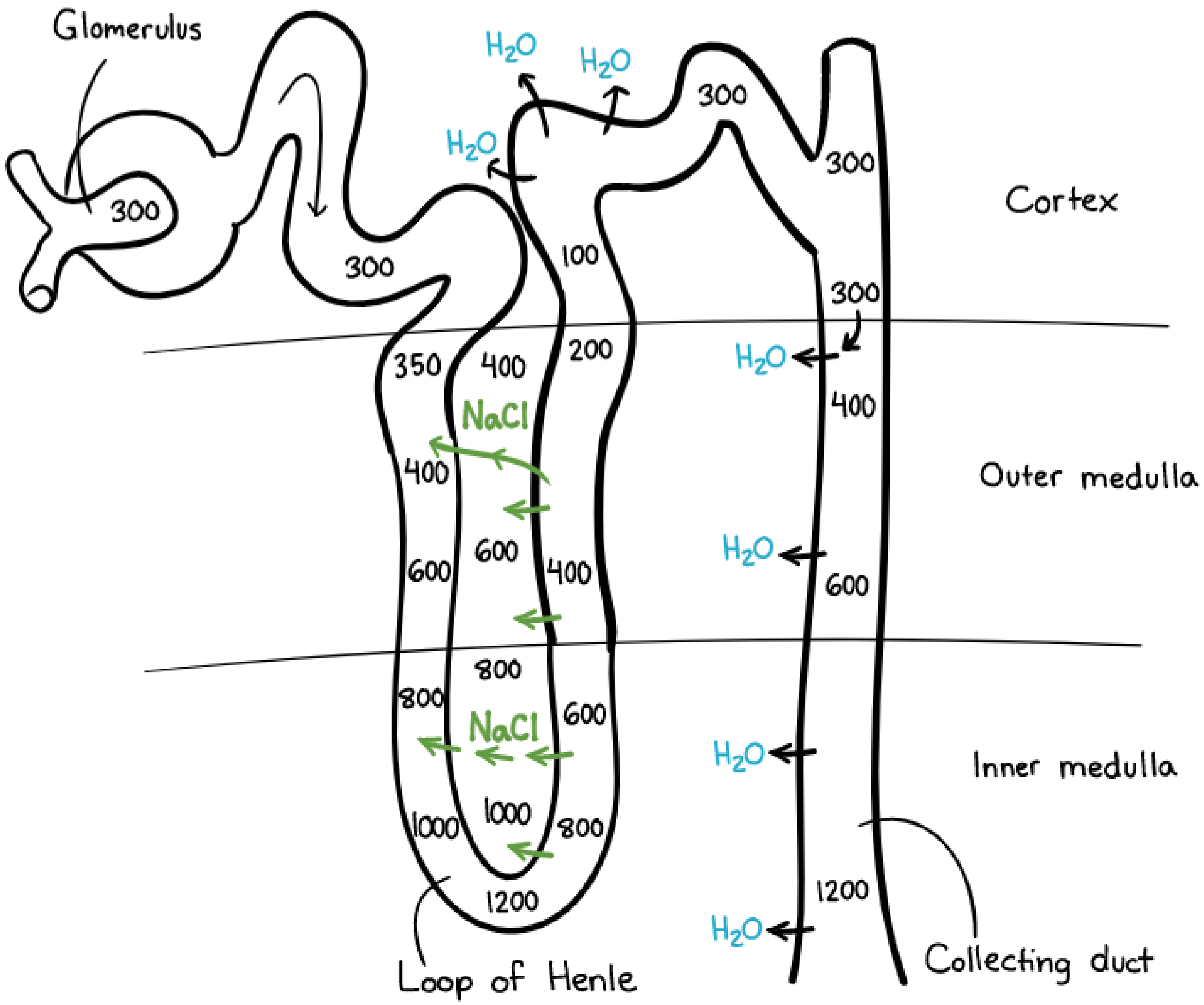
The thick ascending limb actively reabsorbs sodium, potassium and chloride. this segment is also impermeable to water, which again means that water cannot escape from this part of the loop. This segment is sometimes called the “diluting segment”.

Countercurrent multiplication moves sodium chloride from the tubular fluid into the interstitial space deep within the kidneys. Although in reality it is a continual process, the way the countercurrent multiplication process builds up an osmotic gradient in the interstitial fluid can be thought of in two steps:

The single effect. The single effect is driven by active transport of sodium chloride out of the tubular fluid in the thick ascending limb into the interstitial fluid, which becomes hyperosmotic. As a result, water moves passively down its concentration gradient out of the tubular fluid in the descending limb into the interstitial space, until it reaches equilibrium.

Fluid flow. As urine is continually being produced, new tubular fluid enters the descending limb, which pushes the fluid at higher osmolarity down the tube and an osmotic gradient begins to develop.

As the fluid continues to move through the loop of Henle, these two steps are repeated over and over, causing the osmotic gradient to steadily multiply until it reaches a steady state. The length of the loop of Henle determines the size of the gradient - the longer the loop, the greater the osmotic gradient.



Numbers indicate osmolarity in (mosm/L)

Absorbed water is returned to the circulatory system via the vasa recta, which surrounds the tips of the loops of Henle.

Because the blood flow through these capillaries is very slow, any solutes that are reabsorbed into the bloodstream have time to diffuse back into the interstitial fluid, which maintains the solute concentration gradient in the medulla.

This passive process is known as countercurrent exchange.

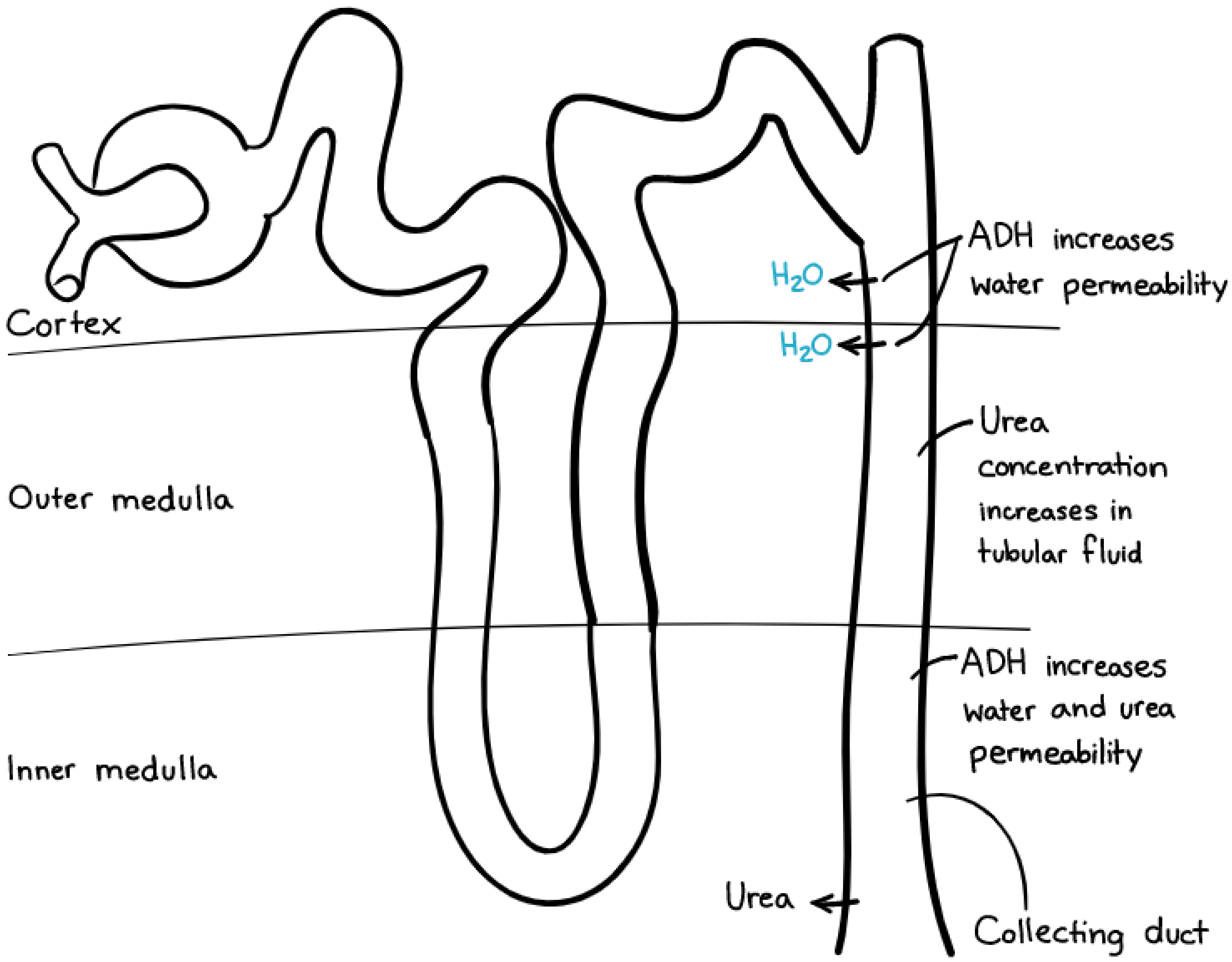
The concentration of urine is controlled by antidiuretic hormone, which helps the kidneys to conserve water. Its main effects in the renal tubules is to increase water permeability in the late distal tubule and collecting ducts, increase active transport of sodium chloride in the thick ascending limb of the loop of Henle, and enhance countercurrent multiplication and urea recycling, all of which increase the size of the osmotic gradient.

Urea recycling

Urea recycling in the inner medulla also contributes to the osmotic gradient generated by the loops of Henle.

Antidiuretic hormone increases water permeability, but not urea permeability in the cortical and outer medullary collecting ducts, causing urea to concentrate in the tubular fluid in this segment.

In the inner medullary collecting ducts it increases both water and urea permeability, which allows urea to flow passively down its concentration gradient into the interstitial fluid. This adds to the osmotic gradient and helps drive water reabsorption.



Cortex
Outer medulla
Inner medulla
H_2O
H_2O
ADH increases water permeability
Urea concentration increases in tubular fluid
ADH increases water and urea permeability
Urea
Collecting duct

Consider the following:

The kidneys are able to separate the reabsorption of water and solutes in the loop of Henle, distal nephron and collecting ducts. This means urine can be made more concentrated or more dilute than plasma, depending on how hydrated you are. This process is mainly controlled by antidiuretic hormone, a hormone that is made in the hypothalamus of the brain and stored in the pituitary gland. The release of antidiuretic hormone by the pituitary gland is controlled by sensors in your heart and blood vessels that detect drops in blood pressure, or increased concentrations of salt in your bloodstream that may occur when you are dehydrated. If you have ever felt dehydrated after having a few glasses of wine or beer, this is because alcohol inhibits the release of antidiuretic hormone, which increases urine production.

THANK YOU