The Excretory System

Excretion and Its Importance

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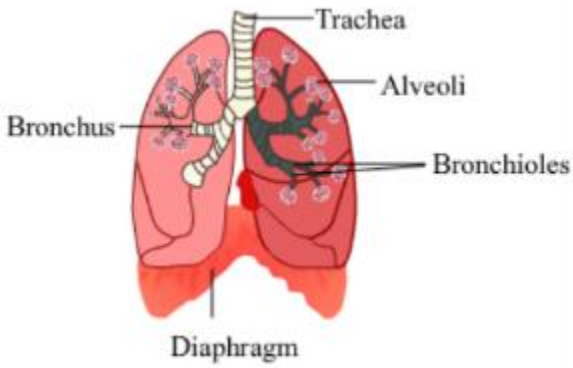
Excretory system consists of groups of organs that are responsible for excreting waste materials such as, harmful chemicals and other impurities from the body. The major excretory organ is kidney. However, there are some other organs also that perform the function of excretion.

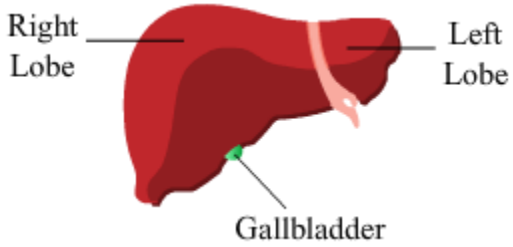
Let us understand the function of the following organs as excretory organs.

Lungs



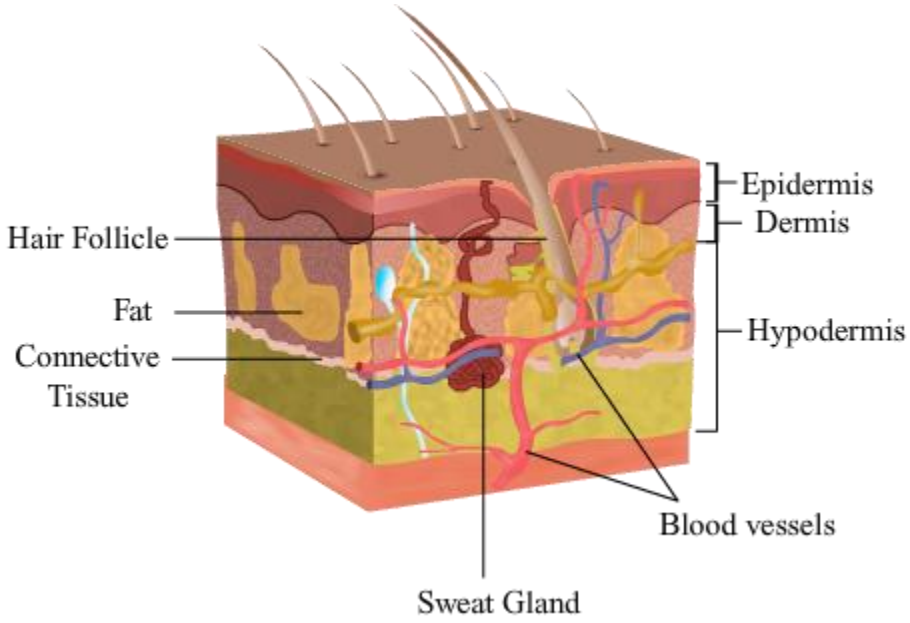
Respiration is a necessary process that provides energy for cellular activities. During respiration, carbon dioxide gets accumulated in the cells, from where it diffuses into the bloodstream and is finally transported to the lungs. From lungs, this carbon dioxide leaves the body every time we exhale.

Liver



Liver helps in the excretion of various unneeded substances in the body. It converts toxic ammonia into urea, a harmless fluid, by the process of deamination. This urea is then filtered by the kidney into urine. It does not directly eliminate excretory substances.

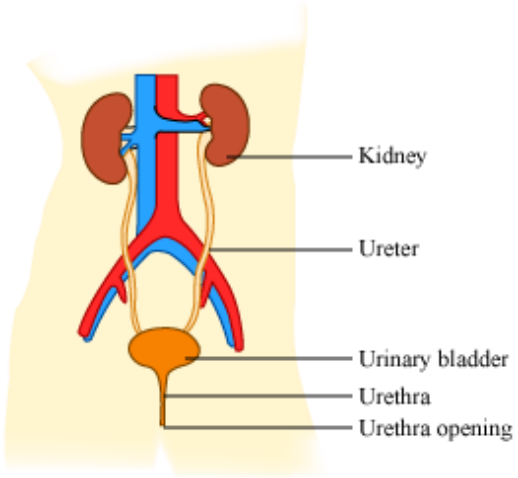
Skin



Skin also acts as an excretory organ. It possesses glands, namely, sweat glands and sebaceous glands. Sweat is a watery fluid that consists of metabolic wastes like water, sodium chloride, lactic acid, amino acids, urea, glucose, etc. Besides excreting metabolic wastes from the body, sweat also has a cooling effect on the body. On the other hand, sebaceous glands help in excretion of sebum which consists of lipids, fatty acids, etc.

How the other kinds of waste materials removed from the body? Is there a particular organ system that functions to remove waste materials from the body?

The organ system that performs the function of excretion is known as the **excretory system**. The excretory system removes the waste materials present in the blood.



Which organs are involved in this process? What mechanism is required for filtering blood?

The primary components of the excretory system are the kidneys, the ureter, the urinary bladder, and the urethra.

When blood reaches the kidneys, useful substances are absorbed back into blood, while the waste materials are dissolved in water and removed from the body in the form of **urine**.

The urine enters a long tube-like structure called the **ureter**. The ureter then passes the urine into the **urinary bladder**, which stores it until it is passed out of the body. Urine is passed out of the body through a muscular tube-like structure called the **urethra**.

Waste materials are also removed from the body through sweat. During sweating, water and salts are removed from the body.

Excretory System in Humans

Kidneys

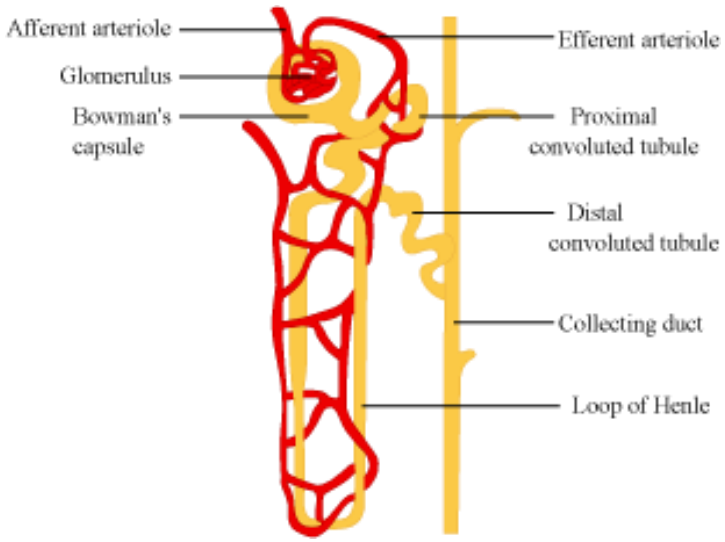
They eliminate nitrogenous wastes from the body and are helpful in maintaining the water balance of the body by removing excess fluids.

The various nitrogenous wastes such as urea, uric acid etc. are supplied from the blood to the kidneys (this is similar to the removal of CO_2 from the blood to the lungs). Thus, the basic filtration unit of the excretory system lies in the kidneys.

Structure of kidneys:

Kidneys are reddish brown bean shaped structures which are found in pairs. Each kidney is divided into two parts - an outer dark region called cortex and inner lighter region called medulla. Each kidney has several microscopic tubular structures called nephrons.

The kidneys consist of a cluster of very thin-walled capillaries. Each cluster is associated with a cup-shaped end of a tube, in which filtered urine is collected. These basic filtering units of the kidneys are called **nephrons**. Each kidney possesses a large number of nephrons (approximately 1- 1.5 million).



Structure of a nephron

The main components of a nephron are the **glomerulus**, **Bowman's capsule,** and a long **renal tube**. The blood enters the kidneys through the renal artery, which branches into many capillaries associated with the glomerulus. Water and solutes are transferred to the nephron at the Bowman's capsule.

In the proximal tubule, some substances such as amino acids, glucose, and salts are selectively reabsorbed and unwanted molecules are added in the urine. The filtrate then moves down into the loop of Henle, in which more water is reabsorbed. From here, the filtrate moves upwards into the distal tubule, and finally to the collecting duct. This duct collects urine from many nephrons.

The urine formed in each kidney then enters a long tube called the ureter. The ureters move the urine from the kidneys to the urinary bladder. The urinary bladder is under the control of the nervous system. This helps us to control the urge to urinate.

Some Interesting Facts:

- **Do you know that blood passes through the kidneys 300 times in a day?**
- **The urinary bladder can hold up to 600ml of urine!**

Artificial kidneys

Do you know what will happen if your kidneys fail?

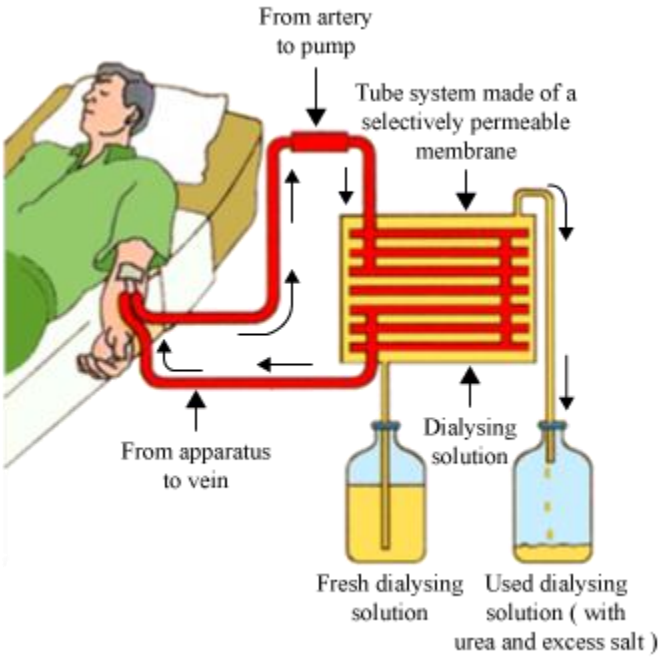
Healthy kidneys remove excess of fluid, wastes, and minerals from the body. They also make hormones that keep the bones strong and healthy. If the kidneys fail to function,

wastes may accumulate in the body, the body may retain excess fluid, and blood pressure may rise. This can even lead to death.

In such a case, an artificial kidney or hemodialysis is useful.

In hemodialysis, only a few drops of blood are allowed to flow, through a special filter that removes wastes and extra fluid. The detoxified blood is then returned to the body.

The special filter used in dialysis consists of a number of tubes with semi-permeable lining, suspended in a tank filled with the dialysis fluid.



Dialysis

What is dialysis? When is it performed? It performs the function of which organ?

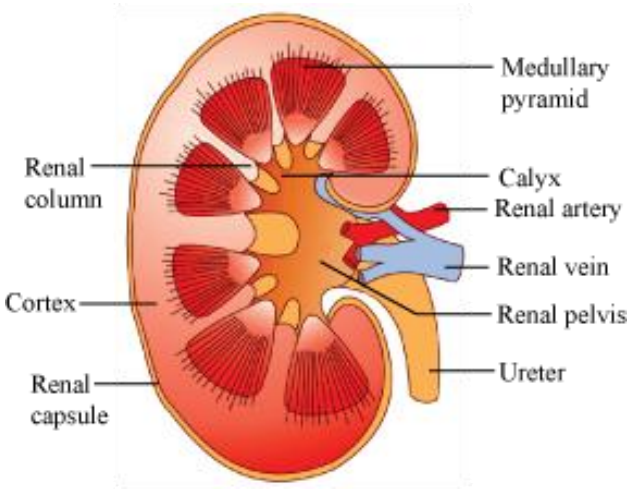
Sometimes, kidney(s) stops functioning because of an infection or an injury. This leads to the accumulation of harmful wastes in the body, which can even cause death. In such a condition, blood is filtered artificially. This process is known as **dialysis**. A dialysis machine performs the function of a normal kidney, and thus helps an individual to survive.

Do you know that the human bladder can stretch to hold up to 400 mL of urine?!

Kidney-Structure

- **Kidneys**

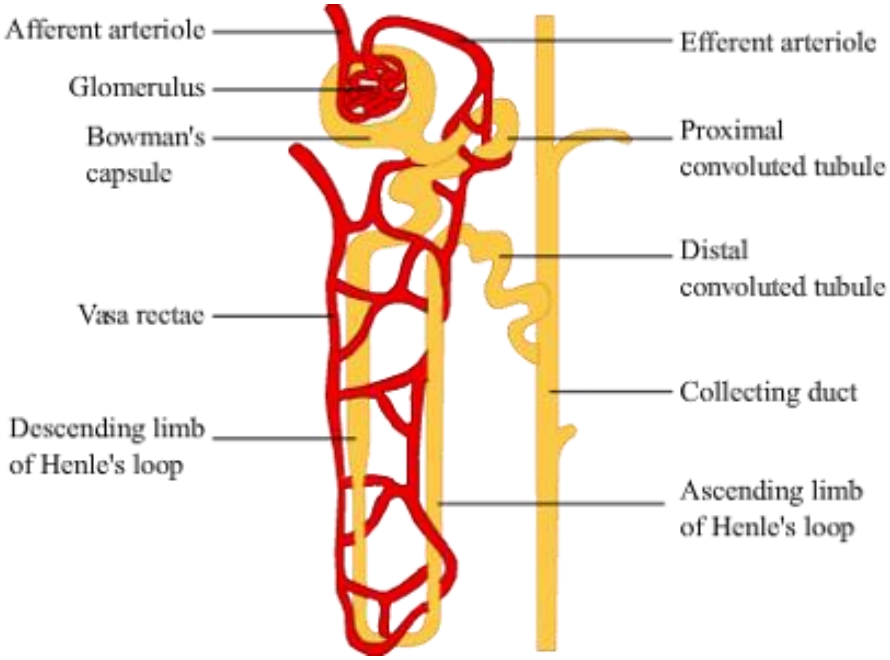
- Location: Between levels of the last thoracic and the third lumbar vertebra
- Measurement: 10−12 cm (length) × 5−7 cm (width) × 2−3 cm (thickness)
- Weight: 120−170 g
- Hilum: A notch present towards the centre of the inner concave surface of the kidney
- Through the hilum, the ureter, blood vessels and nerves enter the kidney.
- On the inside of the hilum, the renal pelvis is present. Renal pelvis has projections called calyces.
- 2 zones in the kidney: Cortex (outer)
  Medulla (inner)
- Medulla divides into medullary pyramids (cone-shaped). These medullary pyramids project into the calyces.
- Cortex is present in between the medullary pyramids as renal columns called the columns of Bertini.



- Each kidney consists of about 1 million nephrons. These are the structural and functional units of the kidneys.

Structure of Nephron

Nephrons



- A Nephron has two parts:
- Glomerulus
- Renal tubule
- Glomerulus
- Tuft of capillaries formed by the afferent arteriole
- Renal Tubule: Has many parts

  Bowman's capsule $\xrightarrow{\text{Continues into}}$ Proximal Convoluted Tubule (PCT) $\xrightarrow{\text{Continues into}}$

  Hairpin-shaped Loop of Henle $\xrightarrow{\text{Continues into}}$ Distal Convoluted Tubule (DCT) $\xrightarrow{\text{Opens into}}$

  Collecting duct $\xrightarrow{\text{Converges into}}$ Medullary pyramids → Renal pelvis

  Glomerulus + Bowman's Capsule = Malpighian body (Renal Corpuscle)

- **Afferent arteriole:** These are the arterioles that arise from renal arteries and break into numerous capillaries to form glomerulus present inside the Bowman's capsule
- **Efferent arteriole:** These are formed from the reunion of capillaries emerging from the Bowman's capsule. Once formed, they travel a short distance and then break up into the secondary capillary network called **vasa recta**, which surrounds the renal tubule.

- Nephrons are of 2 types:

- **Cortical nephrons**: Here, the loop of Henle is short and confined to the cortex only. Vasa rectae are absent. These nephrons are more common (85%).

- **Juxta medullary nephrons**: Here, the loop of Henle is long and extended to the medulla. Vasa rectae are present. These nephrons are less common (15%).

- Malpighian corpuscle, PCT and DCT are present in the corticle region only.

- Capillary network in a nephron:

- Peritubular capillaries: Emerging from the glomerulus, the efferent arteriole forms a capillary network around the renal tubule called the peritubular capillaries.

- Vasa Recta: A minute vessel of the capillary network present in a nephron runs parallel to Henle's loop to form the U-shaped Vasa Recta.

To test your knowledge of this concept, solve the following puzzle.

Urine Formation and Function of Nephron Tubules

Urine formation and Mechanism of Concentration of Filtrate

Urine Formation

Involves 3 basic steps:

- Glomerular filtration
- Re-absorption
- Secretion

Glomerular filtration

- Kidney filters 1100−1200 mL blood/min

- Filtration of blood occurs as it passes through three layers.

- Endothelium of glomerular blood vessels
- Epithelium of Bowman's capsule
- Basement membrane between these two layers
- Epithelial cells of Bowman's capsule are called podocytes. Arrangement of these podocytes leaves extremely minute spaces called filtration slits or slit pores.
- Ultrafiltration occurs through these slits pores, i.e., all plasma components (except proteins) get filtered into the lumen of the Bowman's capsule.

- Glomerular Filtration Rate (GFR): 125 mL/min or 180 L/day
- The glomerular filtration rate is regulated by the juxtaglomerular apparatus which releases the hormone renin.

Re-absorption

- GFR = 180 L/day; Urine released = 1.5 L/day. Thus, 99% of filtrate is re-absorbed by the renal tubules.
- Re-absorption occurs through the epithelial cells of the various segments of the nephrons.
- Active Re-absorption: Glucose, Na^+, amino acids
- Passive Re-absorption: Nitrogenous waste, water

Secretion

- Tubular cells secrete substances such as H^+, K^+ and ammonia into the filtrate.
- Importance: Maintenance of ionic and acid-base balance of body fluids

Constituents of Urine

Normal adult's urine consists of 95% water and 5% solid waste.

Organic Constituents in (g/L)	Inorganic Constituents in (g/L)
Urea: 2.3	Sodium chloride: 9.0
Creatinine: 1.5	Potassium chloride: 2.5
Uric acid: 0.7	Ammonia: 0.6
Others: 2.6	Others: 2.5

Abnormal constituents of urine:

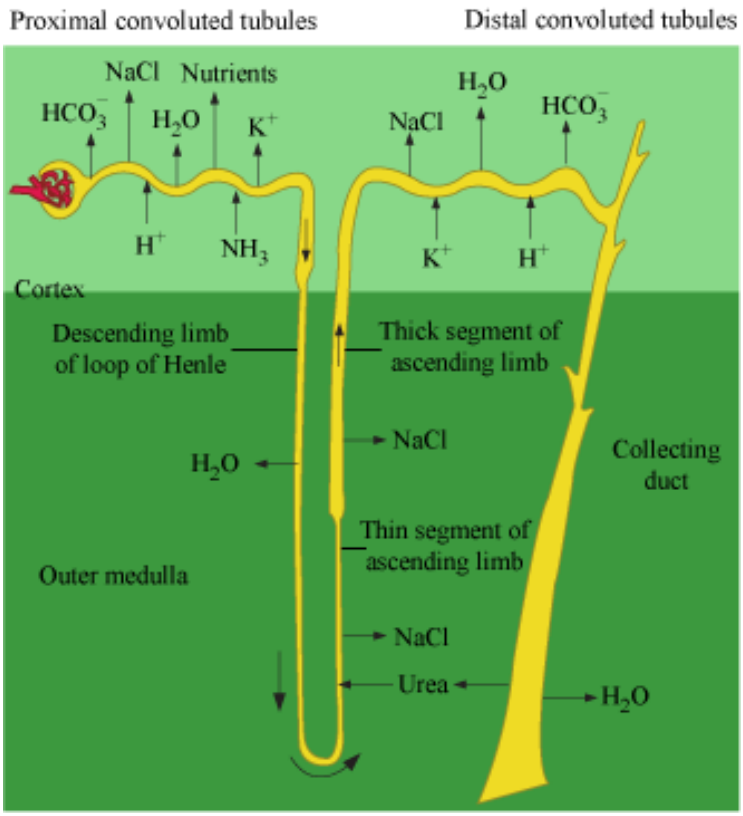
- **Blood cells:** Blood passes through urine due to infection in urinary tract, kidney stones, or tumour. This condition is known as haematuria.

- **Glucose:** Excess of glucose passes through urine. This condition is known as glycosuria and occurs in the case of diabetes mellitus.

- **Albumin:** Albumin is passed through urine due to high blood pressure or bacterial infection.
- **Bile pigments:** Bile pigments are passed through urine due to anaemia, hepatitis or liver cirrhosis.

Function of the Tubules

- **Proximal Convoluted Tubule**
- Specialised for re-absorption as it is lined by a simple cuboidal brush border epithelium which increases the surface area for absorption
- Re-absorbs all essential nutrients, electrolytes and water
- Secretes H^+, NH_4^+, K^+ ions and $HCO_3^{(-)}$ to maintain pH
- **Henle's Loop**
- Minimum re-absorption occurs here
- Helps in maintaining high osmolarity of the medullary fluid
- Descending loop of Henle: Permeable to water and impermeable to electrolytes; Concentrates the filtrate
- Ascending loop of Henle: Impermeable to water and permeable to electrolytes; Dilutes the filtrate
- **DCT**
- Conditional re-absorption of Na^+, water, HCO_3^-
- Selectively secretes H^+, K^+, NH_3
- Maintains pH and Na−K balance in blood
- **Collecting Duct**
- Concentrates the urine by absorbing large amounts of water
- Allows passage of urea into the medullary interstitial fluid to maintain osmolarity
- Secretes H^+ and K^+ ions; hence, maintains pH and ionic balance

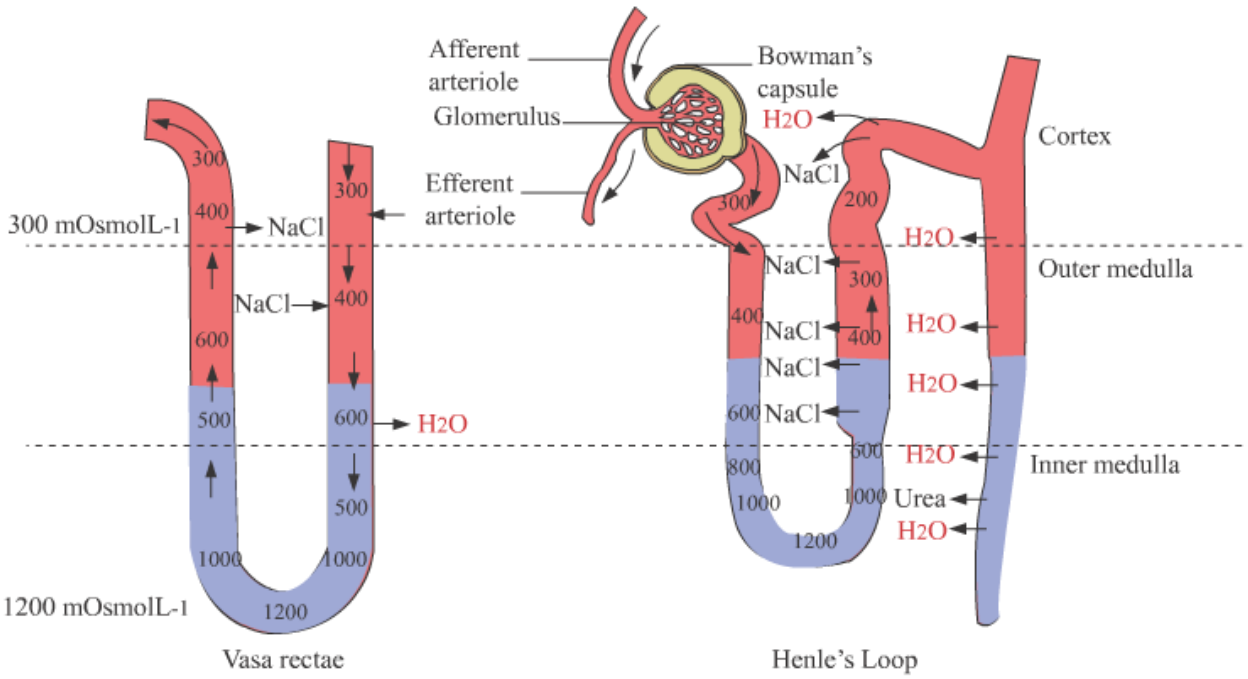


Micturition

- Passing of urine through the opening in the urinary bladder
- Urine is stored in urinary bladder. As the bladder gets filled with urine, it gets stretched.
- Stretch receptors on the walls of the bladder send signals to CNS.
- CNS sends counter signals to initiate contraction of the smooth muscles of the bladder, and relax the urethral sphincter to cause urine to be released (micturition).
- Neural mechanism: Micturition reflex
- Urine: 1−1.5 L/day; pH 6.0; Light yellow in colour
- On an average, 25−30 gm of urea is excreted everyday.
- Presence of glucose and ketone bodies in urine indicates diabetes mellitus.

Mechanism of concentration of filtrate

- Concentration of urine is achieved by the presence of a concentration gradient in the medullary interstitium.
- Such concentration gradient is maintained by a specialised mechanism called the counter-current mechanism.
- The flow of filtrate in the two limbs of Henle's loop is in the opposite direction. Flow of blood in vasa recta is also in the opposite direction. Both these flows form a counter-current.
- Close proximity of Henle's loop and vasa recta as well as the counter-current in them maintains an osmolarity that increases towards the medullary interstitium.
- NaCl and urea play a role in the maintenance of the gradient.
- NaCl: Transported by the ascending limb of Henle's loop and provided to the descending limb of vasa recta
- Urea: Enters the thin segment of the ascending limb of Henle's loop
- NaCl is transported back to the interstitium by the ascending portion of vasa recta and urea is transported back to the interstitium by the collecting tubule.



Regulation of Urine Output and Osmoregulation

Regulation of Urine Output

The volume and concentration of urine is regulated by **posterior lobe of pituitary gland** with the help of **antidiuretic hormone (ADH).**

- If ADH secretion is reduced, increased production of urine takes place (**Diuresis**).

- Some substances can increase the production of urine on consumption, such as liquid diet, tea, coffee etc. They are known as **diuretics**.

Some Facts to Know
Uric acid, one of the constituents of urine, has poor solubility in water. If not excreted from body efficiently, it may get crystallized and get deposited in the joints, causing acute pain in them. This medical condition is known as **gout**. Excessive uric acid and other salts may also be the source of kidney stones.

Osmoregulation
The process of regulation of water and salt content in blood by the kidneys is called osmoregulation. In other words, osmoregulation regulates osmotic pressure of the blood. To maintain kidney health and osmoregulation, we should ensure proper intake of water, either directly or through food.

Have you ever noticed that during summers the urine passed is usually thicker? Ever wondered why?

During summers, our body loses a considerable amount of water through sweating. To compensate this loss, our kidneys reabsorb more and more water from urine, thus making it more concentrated. Such conditions can have a negative impact on kidney health. That is why it is advised to drink a lot of water during summers.

In diseases like cholera and diarrhoea a lot of water is lost from the body. To replenish water and maintain osmoregulation, the patient should be given ORS from time to time.

Common disorders of the human excretory system:

- Presence of blood cells in urine, is an indication of any kind of infection.
- Presence of glucose in urine is the indication of diabetes mellitus. When the level of glucose is high in blood, it is excreted in the urine.
- Urinary tract infections are very common among the infections of excretory system. It occurs due to entry of any bacterium in the urinary tract.
- Formation of kidney stones is another common disorder of the human excretory system, where substances like calcium oxalate, calcium phosphate and uric acid form crystals in any part of the excretory system. This blocks the flow of urine and causes extreme pain.