1. Details of Module and its structure

Module Detail	
Subject Name	Biology
Course Name	Biology 02 (Class XI, Semester - 2)
Module Name/Title	Excretory Products and their Elimination: Part – 2
Module Id	Kebo_21902
Pre-requisites	Knowledge about excretory organs and human excretory system
Objectives	After going through this lesson, the learners will be able to understand the following: • Excretion • Need of removal of excretory products • Excretory products in animals • Ammonotelism, Ureotelism and Uricotelism • Excretory organs in different animals • Excretion in human beings
Keywords	Glomerular filtration rate (GFR), Juxta glomerular apparatus (JGA), glomerular filtration, Renin-Angiotensin mechanism, Atrial Natriuretic Factor, Micturition, haemodialysis.

2. Development Team

Role	Name	Affiliation
National MOOC Coordinator (NMC)	Prof. Amarendra P. Behera	CIET, NCERT, New Delhi
Program Coordinator	Dr. Mohd. Mamur Ali	CIET, NCERT, New Delhi
Course Coordinator (CC) / PI	Dr. Sunita Farkya	DESM, NCERT, New Delhi
Course Co-Coordinator / Co-PI	Dr. Yash Paul Sharma	CIET, NCERT, New Delhi
Subject Matter Expert (SME)	Mr. V. S. Malik	R. P. V. V. Civil Lines, Delhi
Review Team	Dr. Aruna Mohan (Retd.)	Gargi College, University of Delhi

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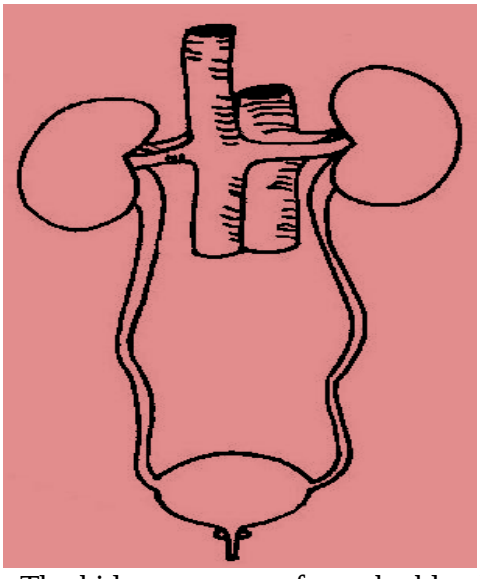
1. Introduction

The **excretory system** is a passive biological system that removes excess, unnecessary materials from the body fluids of an organism, so as to help maintain internal chemical homeostasis and prevent damage to the body. The dual function of excretory systems is the elimination of the waste products of metabolism and to drain the body of used up and broken down components in a liquid and gaseous state. In humans and other amniotes (mammals, birds and reptiles) most of these substances leave the body as urine. Only the organs specifically used for the excretion are considered a part of the excretory system. Kidneys are bean-shaped organs which are present on each side of the vertebral column in the abdominal cavity.



Humans have two kidneys. The kidneys remove from the blood, the nitrogenous wastes such as urea, as well as salts and excess water, and excrete them in the form of urine. This is done with the help of millions of nephrons present in the kidney. The urine from the kidney is collected by the ureter, one from each kidney, and is passed to the urinary bladder. The urinary bladder collects and stores the urine until urination. The urine collected in the bladder is passed into the external environment from the body through an opening called the urethra.

2. Mechanism of urine formation

Urine formation involves three main processes namely:

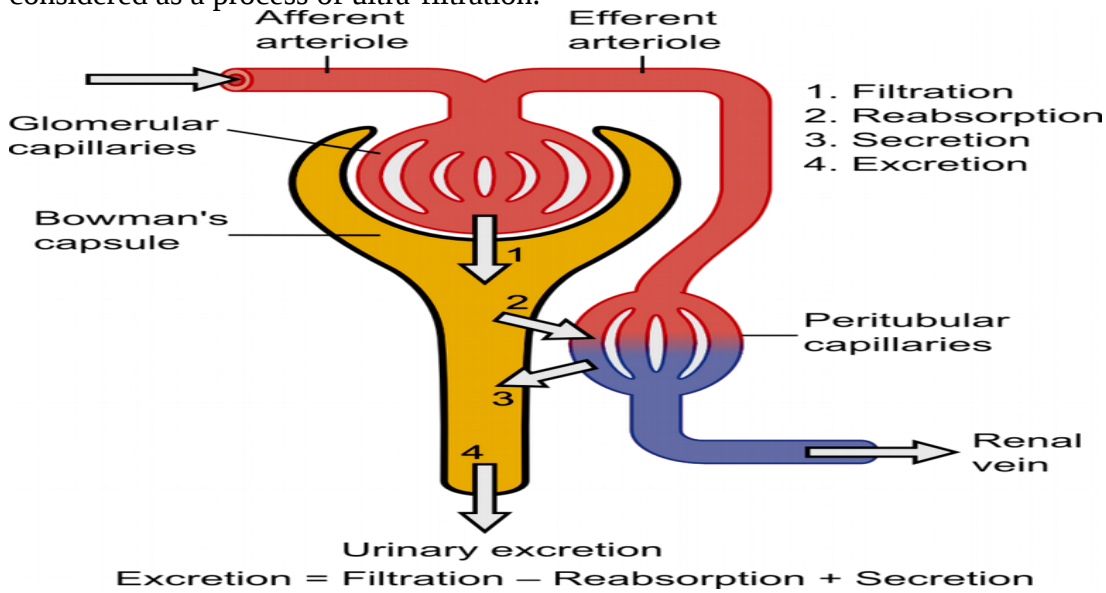
(i) **Glomerular Filtration,**

(ii) **Re-absorption and**

(iii) **Secretion.**

Glomerular Filtration:

The glomerular capillary blood pressure causes filtration of blood through 3 layers, i.e., the endothelium of glomerular blood vessels, the epithelium of Bowman's capsule and a basement membrane between these two layers. The epithelial cells of Bowman's capsule called podocytes are arranged in an intricate manner so as to leave some minute spaces called filtration slits or slit pores. The diameter of efferent arteriole (arteriole bringing blood out of the glomerulus) is less than the diameter of afferent arteriole (arteriole taking blood inside the glomerulus). This difference in diameters creates a pressure which facilitates the filtration. Blood is filtered so finely through these membranes that almost all the constituents of the plasma, except the proteins pass onto the lumen of the Bowman's capsule. Therefore, it is considered as a process of ultra-filtration.

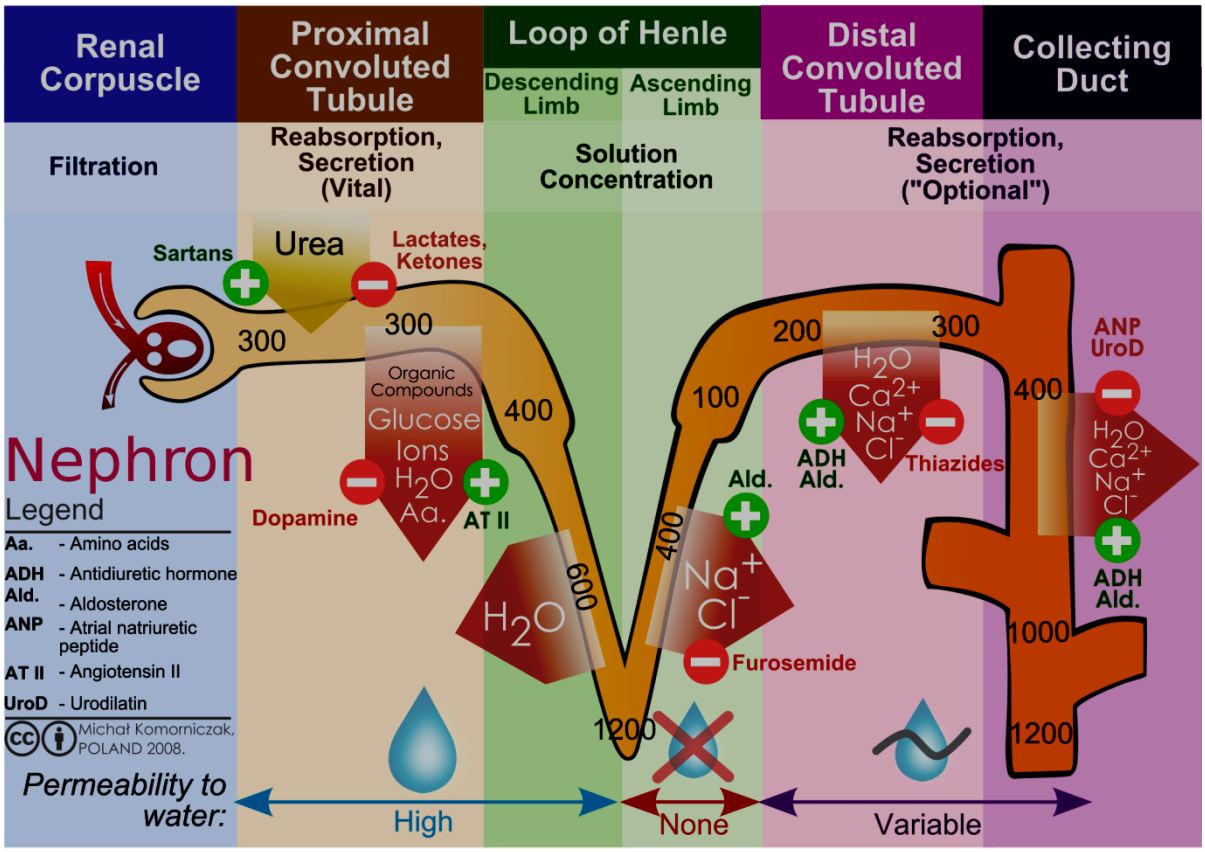


Glomerular Filtration Rate (GFR): The amount of the filtrate formed by the kidneys per minute is called glomerular filtration rate (GFR). GFR in a healthy individual is approximately 125 ml/minute, i.e., 180 litres per day. On an average, 1100-1200 ml of blood is filtered by the kidneys per minute which constitute roughly 1/5th of the blood pumped out by each ventricle of the heart in a minute.

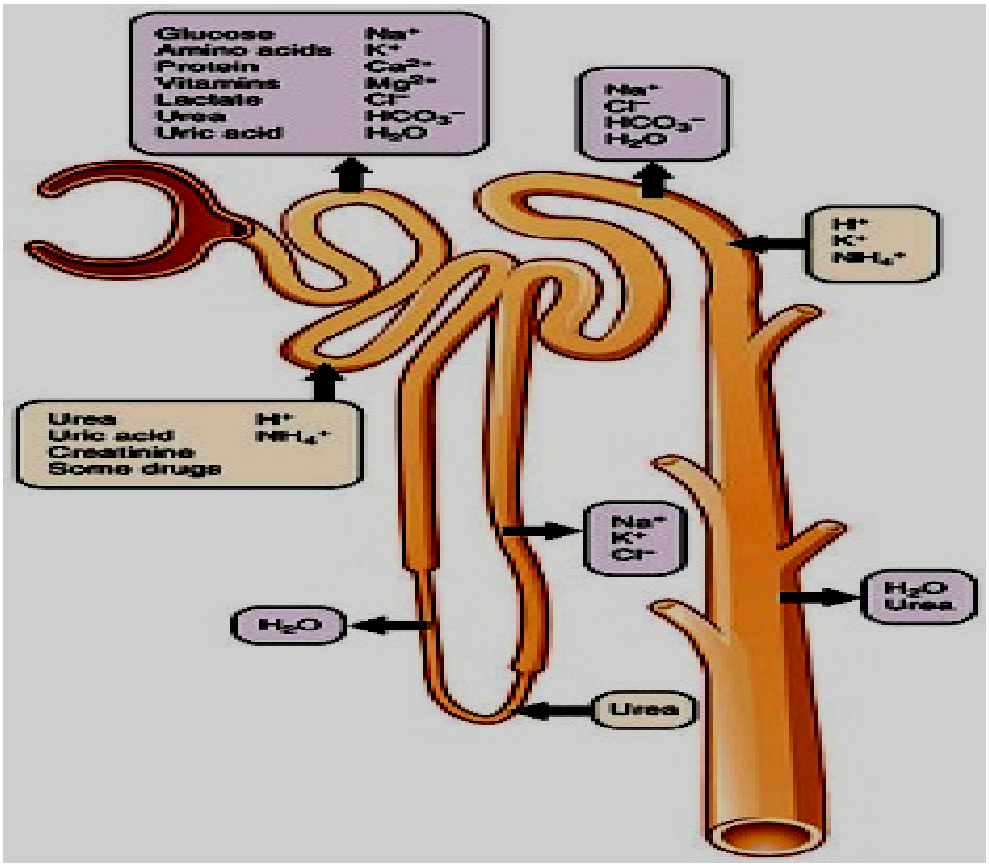
Regulation of GFR: The kidneys have built-in mechanisms for the regulation of glomerular filtration rate. One such efficient mechanism is carried out by juxta glomerular apparatus (JGA).

JGA is a special sensitive region formed by cellular modifications in the distal convoluted tubule and the afferent arteriole at the location of their contact. A fall in GFR can activate the JG cells to release renin which can stimulate the glomerular blood flow and thereby the GFR back to normal.

Reabsorption:



A comparison of the volume of the filtrate formed per day (180 litres per day) with that of the urine released (1.5 litres), suggest that nearly 99 per cent of the filtrate has to be reabsorbed by the renal tubules. This process is called reabsorption. The tubular epithelial cells in different segments of nephron perform this either by active or passive mechanisms. For example, substances like glucose, amino acids, Na^+, etc., in the filtrate are reabsorbed actively whereas the nitrogenous wastes are absorbed by passive transport. Reabsorption of water also occurs passively in the initial segments of the nephron. During urine formation, the tubular cells secrete substances like H^+, K^+ and ammonia into the filtrate. Tubular secretion is also an important step in urine formation as it helps in the maintenance of ionic and acid base balance of body fluid



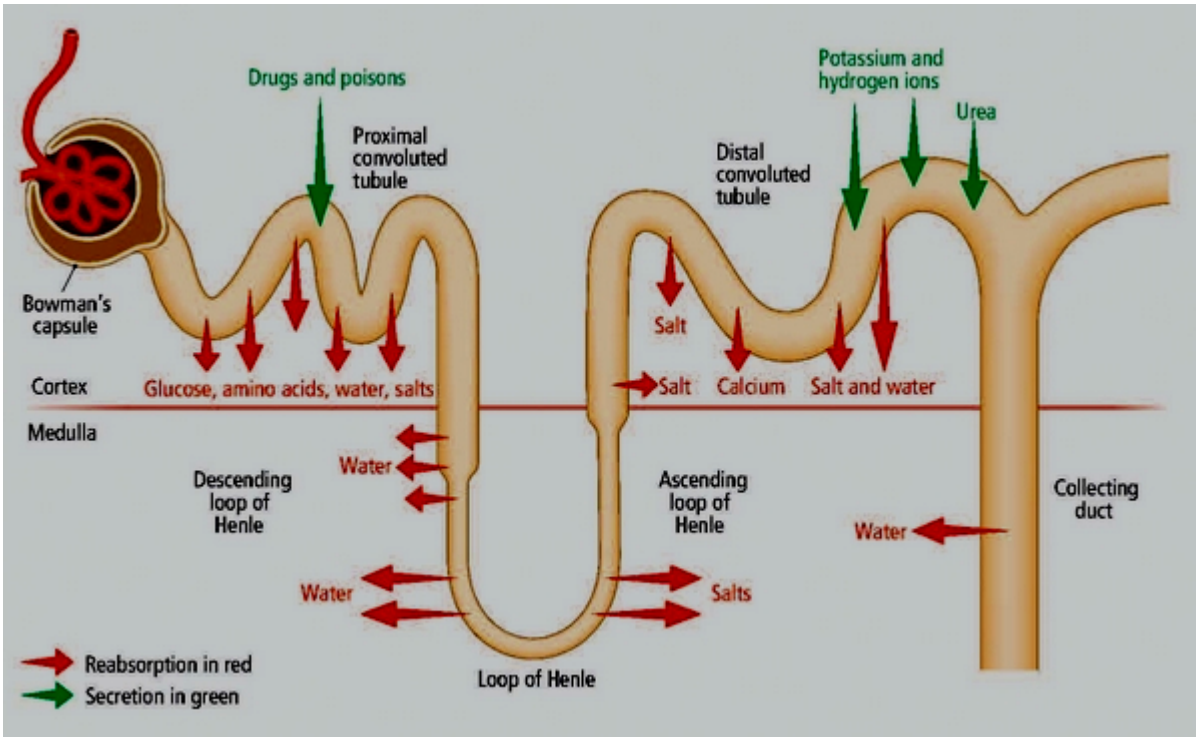
Secretion

Nitrogenous waste products like creatinin and some other substances like potassium ions, Hydrogen ions and ammonia are removed from the blood by the distal convoluted tubule, and are then added to the urine. This is called tubular secretion. This is the last step of urine formation. It maintains the ionic and acid balance of the body fluids.

3. Mechanism of concentration of urine

Henle's loop and vasa recta play a significant role in this. The flow of filtrate in the two limbs of Henle's loop is in opposite directions and thus forms a counter current. The flow of blood through the two limbs of vasa recta is also in a counter current pattern. The proximity between the Henle's loop and vasa recta, as well as the counter current in them help in maintaining an increasing osmolarity towards the inner medullary interstitium, i.e., from 300 $mOsmolL^{-1}$ in the cortex to about 1200 $mOsmolL^{-1}$ in the inner medulla. This gradient is mainly caused by NaCl and urea. NaCl is transported by the ascending limb of Henle's loop which is exchanged with the descending limb of vasa recta. NaCl is returned to the interstitium by the ascending portion of vasa recta.

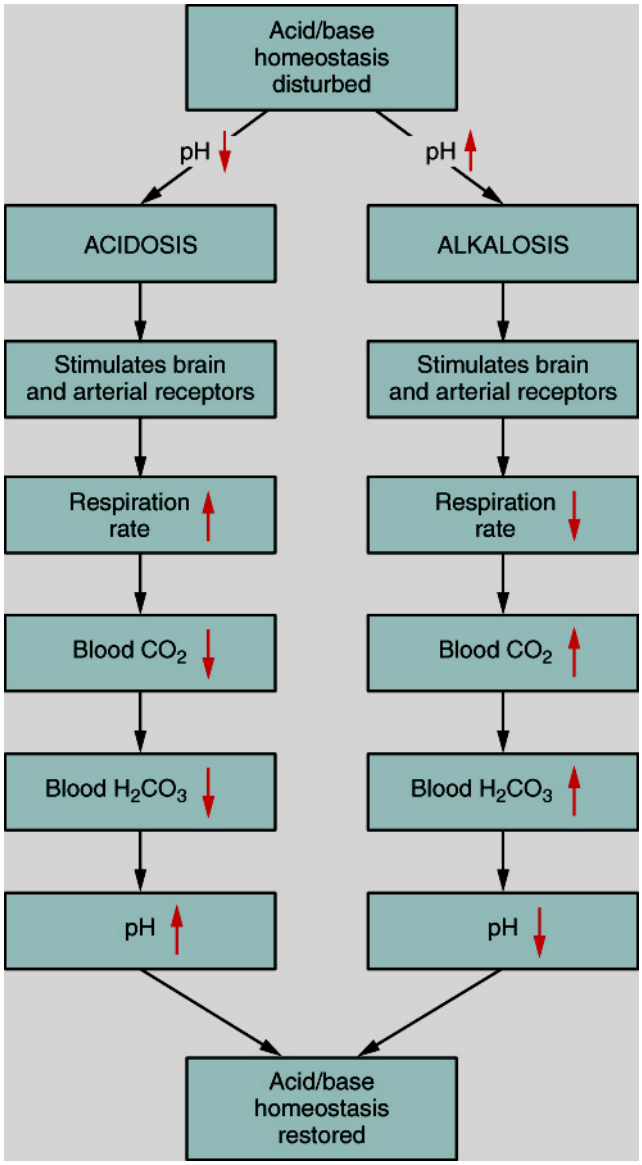
Similarly, small amounts of urea enter the thin segment of the ascending limb of Henle's loop which is transported back to the interstitium by the collecting tubule.



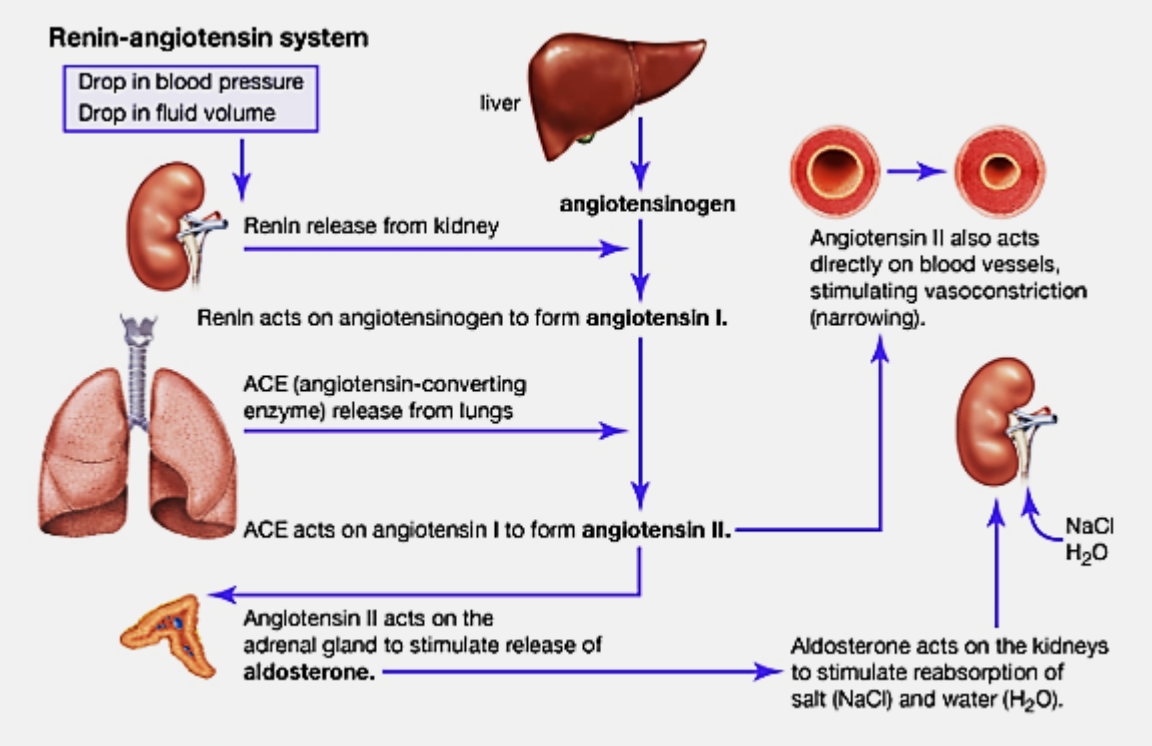
The above described transport of substances facilitated by the special arrangement of Henle's loop and vasa recta is called the counter current mechanism. This mechanism helps to maintain a concentration gradient in the medullary interstitium. Presence of such interstitial gradient helps in an easy passage of water from the collecting tubule thereby concentrating the filtrate (urine). Human kidneys can produce urine nearly four times concentrated than the initial filtrate formed.

4. Regulation of kidney function

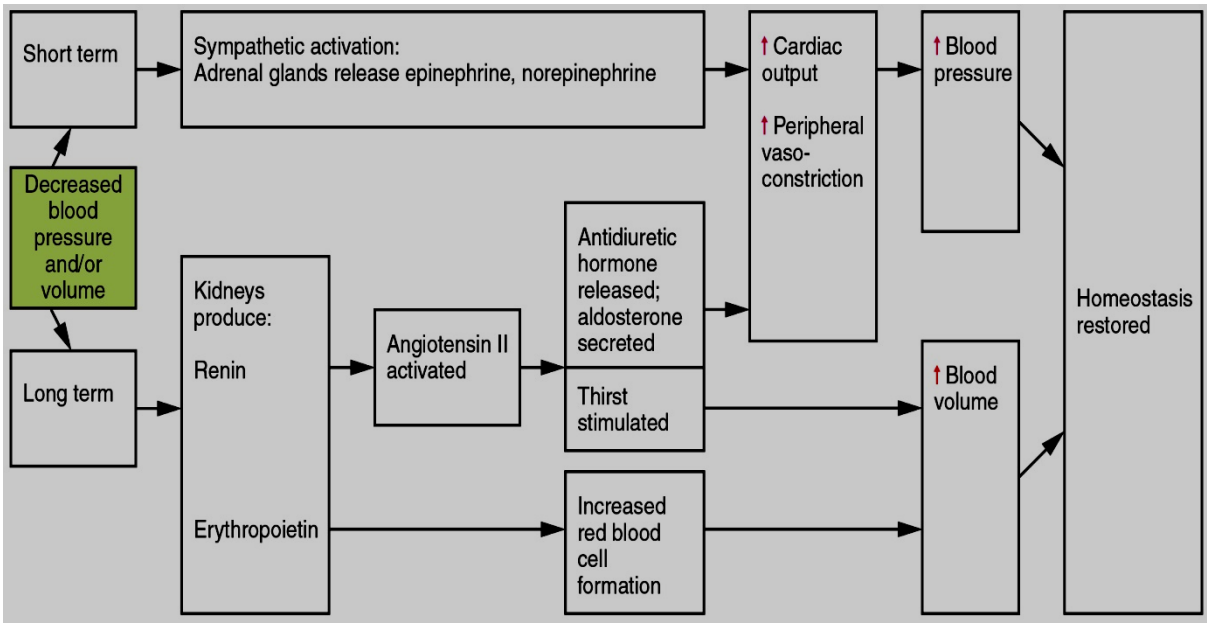
The functioning of the kidneys is efficiently monitored and regulated by hormonal feedback mechanisms involving the hypothalamus, JGA and to a certain extent, the heart. Osmoreceptors in the body are activated by changes in blood volume, body fluid volume and ionic concentration. An excessive loss of fluid from the body can activate these receptors which stimulate the hypothalamus to release antidiuretic hormone (ADH) or vasopressin from the neurohypophysis. ADH facilitates water reabsorption from latter parts of the tubule, thereby preventing diuresis. An increase in body fluid volume can switch off the osmoreceptors and suppress the ADH release to complete the feedback. ADH can also affect the kidney function by its constrictor effects on blood vessels. This causes an increase in blood pressure. An increase in blood pressure can increase the glomerular blood flow and
thereby the GFR.



The JGA plays a complex regulatory role. A fall in glomerular blood flow/glomerular blood pressure/GFR can activate the JG cells to release **renin** which converts angiotensinogen in blood to angiotensin I and further to angiotensin II. Angiotensin II, being a powerful vasoconstrictor, increases the glomerular blood pressure and thereby GFR. Angiotensin II also activates the adrenal cortex to release Aldosterone. Aldosterone causes reabsorption of Na+ and water from the distal parts of the tubule. This also leads to an increase in blood pressure and GFR. This complex mechanism is generally known as the **Renin-Angiotensin** mechanism.



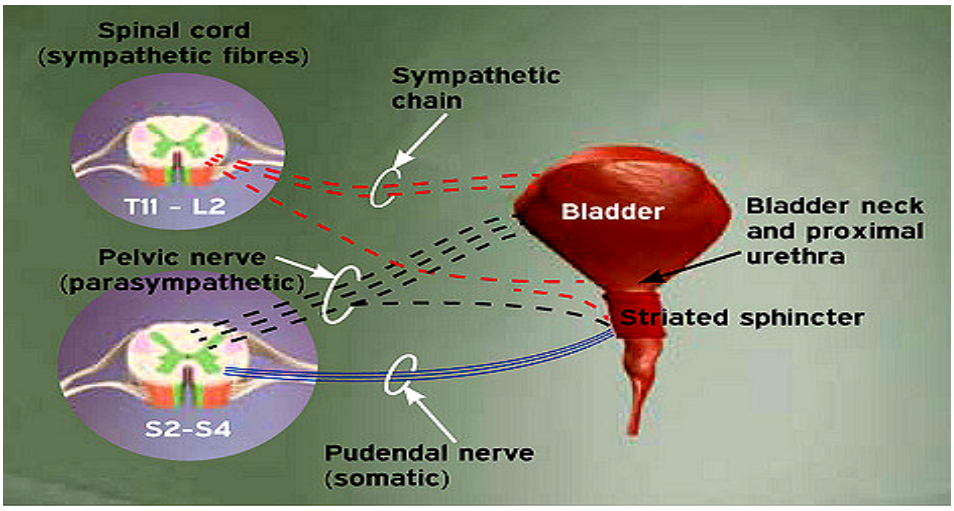
An increase in blood flow to the atria of the heart can cause the release of **Atrial Natriuretic Factor** (ANF). ANF can cause vasodilation (dilation of blood vessels) and thereby decrease the blood pressure. ANF mechanism, therefore, acts as a check on the renin-angiotensin mechanism.



5. Micturition

Urine formed by the nephrons is ultimately carried to the urinary bladder where it is stored till a voluntary signal is given by the central nervous system (CNS). This signal is initiated by the stretching of the urinary bladder as it gets filled with urine. In response, the stretch receptors on the walls of the bladder send signals to the CNS. The CNS passes on motor messages to initiate

the contraction of smooth muscles of the bladder and simultaneous relaxation of the urethral sphincter causing the release of urine. The process of release of urine is called micturition and the neural mechanisms causing it are called the micturition reflex. An adult human excretes, on an average, 1 to 1.5 litres of urine per day.

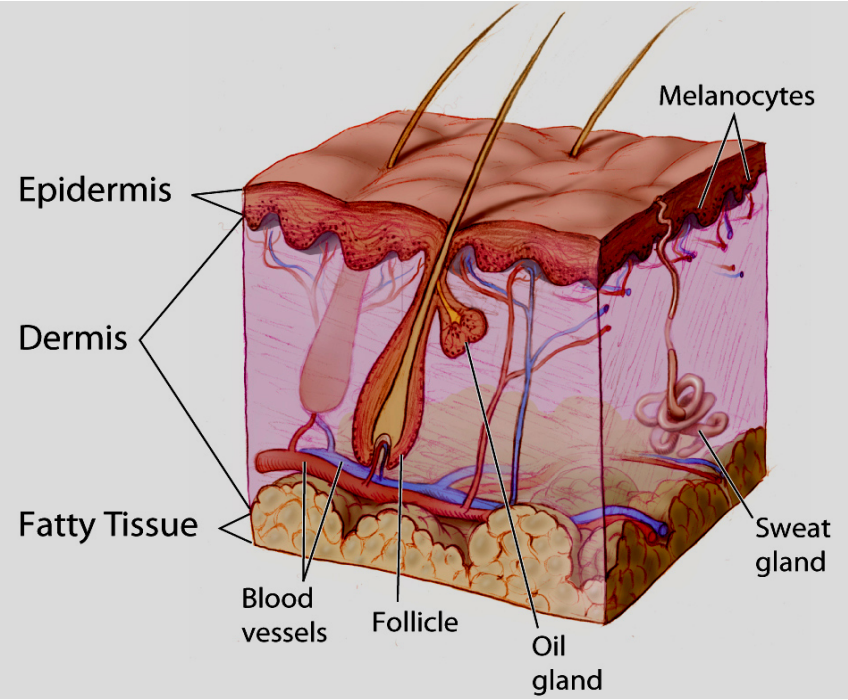


The urine formed is a light yellow coloured watery fluid which is slightly acidic (pH-6.0) and has a characteristic odour. On an average, 25-30 gm of urea is excreted out per day. Various conditions can affect the characteristics of urine. Analysis of urine helps in clinical diagnosis of many metabolic disorders as well as malfunctioning of the kidney. For example, presence of glucose (Glycosuria) and ketone bodies (Ketonuria) in urine are indicative of diabetes mellitus.

6. Role of other organs in excretion

Skin

The skin is the largest organ in our body. Its primary functions include regulation of body temperature, protects the body from harmful pathogens, protects the body from sunlight and harsh environmental conditions and provides the support to the mechanical framework of bones and muscles.

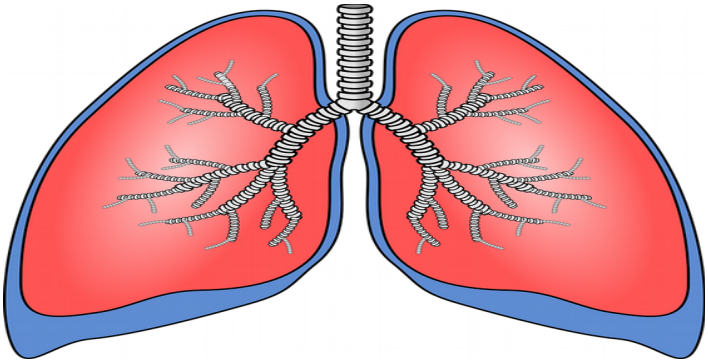


The skin contains multiple layers. These layers of the skin contain two types of glands: sweat glands and sebaceous glands. The sweat glands function to produce sweat. Also, sweat is a secretion of these glands which contains NaCl, water, amino acids, and glucose. The secretion of the sebaceous glands is known as sebum and it is a way to excrete excess fats such as sterols and waxes.

Lungs

Lungs are the primary organs of respiration in humans. They facilitate gaseous exchange where oxygen is taken in whereas carbon dioxide is given out. Therefore, lungs help in expelling or eliminating carbon dioxide which is a waste substance for the body. Along with carbon dioxide, the lungs also give out water in the form of water vapour. The lungs eliminate around 18L of carbon dioxide per hour and 400ml of water as vapour per day.

The amount of water eliminated as vapour through the lungs depends upon the temperature of the environment and condition of the body. In cases where the water levels in the body are less, the amount of water vapour eliminated is also reduced.

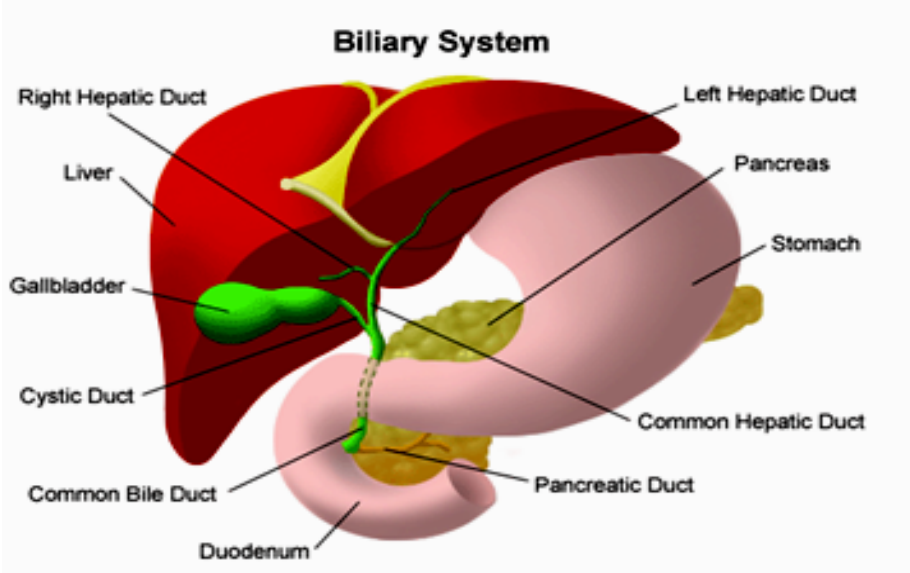


Intestines and the GI tract

Apart from urine, another waste that is eliminated from the body is faeces. Faeces is the solid waste that the body eliminates via the rectum. The digestive system and primarily the intestines are responsible for the formation of faeces. Excess fibre, salts, glucose and minerals like calcium and iron are eliminated through faeces.

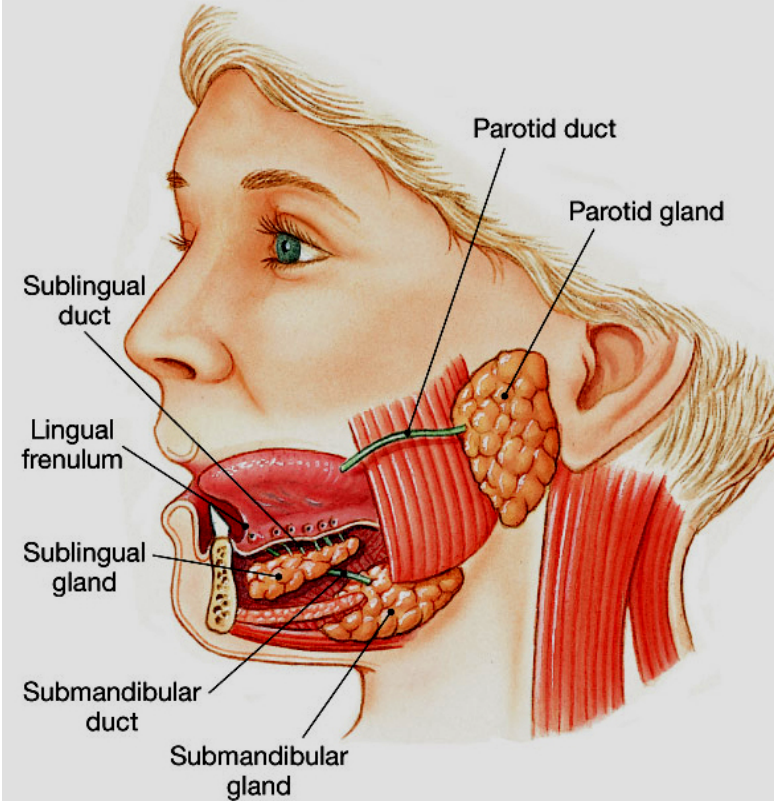
Liver

The liver plays a vital role in the formation and elimination of urea. This urea is then transported to the kidneys for elimination. The liver is known as the 'graveyard of RBCs' as it is here that they are destroyed. The by-products of RBC destruction, metabolized drug by-products, and hormonal metabolites are all synthesized in the liver and poured into the bile. Bile is then carried forward to the intestines which eliminate these wastes through faeces.



Salivary Glands

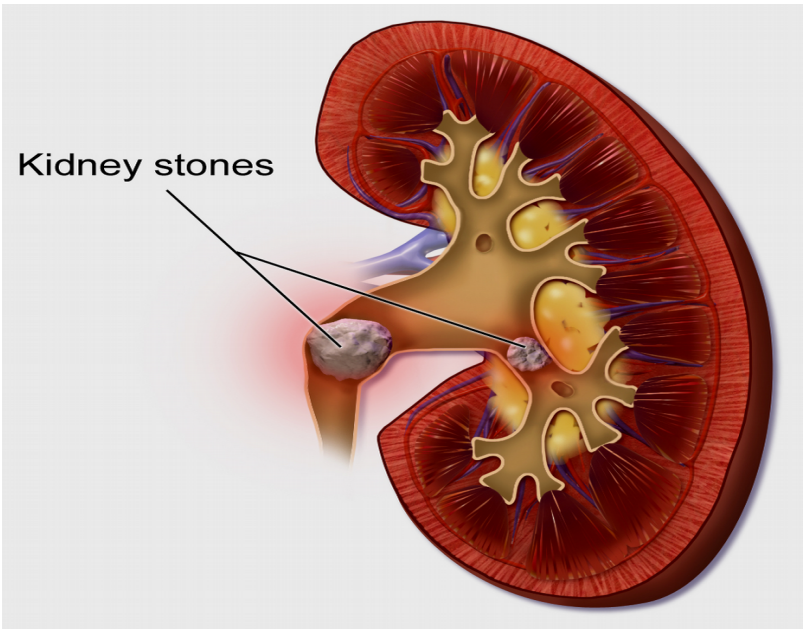
The main function of these glands is to secrete saliva. Saliva is a watery secretion that contains enzymes which help to digest the food as soon as it enters the oral cavity. Salivary glands are believed to take part in the excretion of heavy metal ions like mercury and lead.



7. Disorders of urinary system

Kidney Stones

It is called renal calculi also. These are formed by the accumulation of calcium, oxalate or uric acid crystals within the kidneys. They tend to separate out of the urine and remain within the kidneys.



There can be many causes of kidney stones, such as infections, excessive calcium consumption or reduced elimination, and reduced water intake. Kidney stones can cause many symptoms ranging from colic pain, back and abdominal cramps, nausea, and vomiting. Their
treatment ranges from electrolyte balance, medicines to surgery depending on their number and size.

Kidney Failure

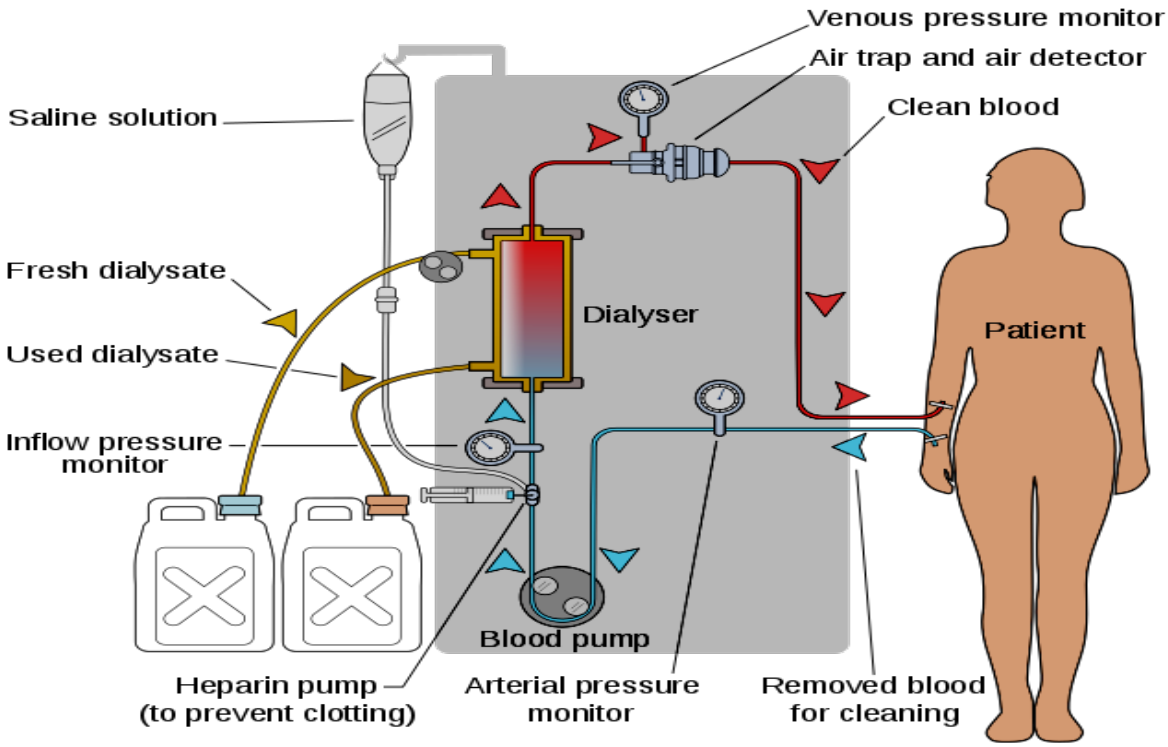
Kidney failure is termed as renal failure also. This is characterized by the cessation of functioning of one or both kidneys. This malfunctioning results in the accumulation of toxic wastes like urea (uremia), which can lead to death. There can be many reasons for kidney failure such as damaged tubules, diabetes that has cardiac effects, kidney stones, chronic drug intake to name a few. A damaged kidney cannot function efficiently to remove urea, ions, water, etc., from the blood. The kidneys are responsible for filtering the urine by a process called as glomerular filtration. Occasionally the nephrons of the kidney might not work properly and kidney failure may result. Patients with total kidney failure have to undergo dialysis. In the long term; kidney failure patients usually receive a kidney transplant.

Haemodialysis

One of the ways to treat kidney failure is to use a ‘dialysis machine’ that acts as an artificial kidney. It has a long tube like structure made of Cellophane suspended in a tank (dialyser) of a fresh dialysis fluid (dialysis). The Cellophane tube is partially permeable and therefore allows solutes to diffuse through. The dialysis fluid has the same concentration as normal tissue fluid, but nitrogenous wastes and excess salts are absent.

During dialysis, the blood of the patient is withdrawn from an artery and cooled at 0°C. It is maintained in a liquid state by adding an anticoagulant and by other special treatments. It is pumped through the dialysis machine. Here, the nitrogenous waste products from the blood diffuse into the dialysis fluid. The purified blood is then warmed to the body temperature and pumped back into the patient's body through a vein.

The dialyser is specific for each patient to avoid infections. Dialysis through an artificial kidney has to be carried out at frequent intervals. This process of purification of blood is called haemodialysis.
A dialysis machine works like a kidney except that no selective reabsorption takes place in the former.



An artificial kidney:
(1) Helps remove harmful wastes, extra salts and water;
(2) Controls blood pressure; and
(3) Maintains the balance of sodium and potassium salts in a patient whose kidneys have failed.

Urethritis

This is a condition characterized by the inflammation of the urethra. It is most commonly caused by bacteria either through sexual intercourse or from non- sexual sources.

Symptoms include burning sensation on passing urine, frequent urination, pain in the abdomen before and after passing urine. Treatment includes a course of antibiotics and alkaline syrups to neutralize the acidity of urine that causes the burning sensation.

Uremia

This condition is characterized by the increase in the blood urea levels. This occurs because the kidneys are unable to eliminate urea which leads to its accumulation and increased levels in the blood.

Anuria

This is a condition characterized by no passage of urine. There can be multiple treatment options but increasing the fluid and electrolyte intake is the primary one.

Polyuria

It is a term given to excessive or frequent passage of urine. This occurs when the kidneys are unable to filter and reabsorb the water from the urine. It is a symptom seen in many underlying body conditions such as diabetes mellitus and diabetes insipidus.

Summary

Urine formation involves three main processes, i.e., filtration, reabsorption and secretion. Filtration is a non-selective process performed by the glomerulus using the glomerular capillary blood pressure. About 1200 ml of blood is filtered by the glomerulus per minute to form 125 ml of filtrate in the Bowman's capsule per minute (GFR). JGA, a specialised portion of the nephrons, plays a significant role in the regulation of GFR. Nearly 99 per cent reabsorption of the filtrate takes place through different parts of the nephrons. PCT is the major site of reabsorption and selective secretion. HL primarily helps to maintain osmolar gradient (300 $mOsmolL^{-1}$ - 1200 $mOsmolL^{-1}$) within the kidney interstitium. DCT and
collecting duct allow extensive reabsorption of water and certain electrolytes, which help in osmoregulation: H^+, K^+ and NH_3 could be secreted into the filtrate by the tubules to maintain the ionic balance and pH of body fluids.

A counter current mechanism operates between the two limbs of the loop of Henle and those of *vasa recta* (capillary parallel to Henle's loop). The filtrate gets concentrated as it moves down the descending limb but is diluted by the ascending limb. Electrolytes and urea are retained in the

interstitium by this arrangement. DCT and collecting duct concentrate the filtrate about four times, i.e., from 300 mOsmolL^{-1} to 1200 mOsmolL^{-1}, an excellent mechanism of conservation of water. Urine is stored in the urinary bladder till a voluntary signal from CNS carries out its release through urethra, i.e., micturition. Skin, lungs and liver also assist in excretion.

All living organisms consume food to generate energy that allows them to perform their biological processes. At the same time, they have certain by-products that are generated during these processes and these need to be expelled. This is known as excretion. In the human body, a specialized system is present, known as the excretory system.

The excretory system in humans comprises of the kidneys, ureters, the urinary bladder, and urethra. These together are also called as the urinary system and they are responsible for elimination of the waste product urine. Let us understand more about disorders that can plague the excretory system.