Excretory System

Introduction

Metabolic reactions occurring in animal body produce certain materials which are of no use in the cells. These are called waste materials. They become toxic if allowed to accumulate in the body. Therefore these materials must be removed from the body for healthy life.

6.1 Definition of excretion

The process of removal of non-gaseous nitrogenous waste substances like ammonia, uric acid, urea etc. in the form of water, harmful substances, salts, pigments is known as excretion. It is mainly a process of removal of harmful substances from the body along with water balance.

6.2 Excretory orangs in various phyla

Protozoa – Plasma membrane (contractile vacuole).

Porifera – Absent-(All the cells contribute equally by water vascular system).

Coelenterata – Excretion of water substances through water canal system.

Platyhelminthes – Protonephridia, flame cells.

Nematoda – Excretory canal.

Annelida – Nephridia

Arthropoda

Crustacea – Green gland or Antennal gland.

Arachnida, Insecta myriapoda – Malpighian tubules.

Arachnida and Onychophora – Coxal gland.

Mollusca

Gastropoda – Organ of Bojanus or Kidney.

Pelecypoda – Organ of Bojanus and Keber's organ.

Cephalopoda – Renal sac.

Monoplacophora – Nephridia.

Echinodermata – Absent-Water vascular system.

Chordata

Urochordata – Neural gland.

Cephalochordata – Solenocyte.

Cyclostomes larva – Protonephric kidney.

Amphibia – Mesonephric kidney.

Reptiles, Birds and Mammals – Metanephric kidney

6.3 Classification of animals on the basis of excretory product

(i) **Ammonotelic :** They excrete ammonia *e.g.*, Helminthes, Molluscs, Echinoderms fishes, Protozoans, Poriferans, Annelid, Aquatic Arthropods, Tadpoles of Amphibia, Turtles, Crocodile etc.

(ii) **Ureotelic :** These organisms excrete urea *e.g.*, Cartilagenous fishes, Adult amphibia, Mammals etc.

(iii) **Uricotelic :** Excrete uric acid *e.g.*, Insects, Some gastropods, Lizards, Snakes, Birds etc.

6.4 Excretory products

(i) Amino acids – Molluscs (Unio, Limnea).

(ii) Urea – In Arginase enzyme containing animals.

(iii) Ammonia – All aquatic animals.

(iv) Uric acid – In animals which lack large quantity of water.

(v) Trimethylamine oxide – Marine elasmobranch, molluscs and arthropods.

6.5 Ureation or Urea cycle

Urea is main excretory product in mammals. There is less requirement of water for its excretion. Arginase enzyme is found in the liver of mammals which is essential for the excretion of urea. It was discovered by **Hans Kreb** and **Kurt Hensleit** in **1932**. This cycle is also known as Arginine-ornithine cycle.

(1) Ornithine cycle is the detoxification of ammonia.

(2) Urea cycle takes place in liver cells

(3) Urea cycle involves the union of two molecules of ammonia and a carbon dioxide.

(4) Ornithine cycle removes two waste products from the blood in liver. These are NH_3 and CO_2

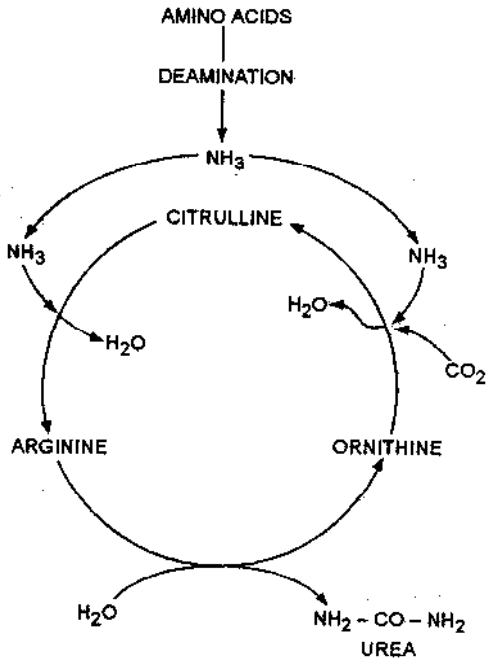
(5) Ornithine, a non-protein amino acid, reacts with one molecule of ammonia and carbon dioxide to give citrulline.

(6) Citrulline reacts with a second molecule of ammonia to give arginine.

(7) With the hydrolytic enzyme **arginase,** arginine is splitted into urea and ornithine with the elimination of a water molecule.

$$2(NH_3) + CO_2 \rightarrow H_2N - \underset{\underset{O}{\|}}{C} - NH_2 + H_2O$$

(8) Three participating amino acids in ornithine cycle are ornithine, citrulline and arginine.



Urea (ornithine) cycle in liver cells

(9) Two molecules of ammonia enter ornithine cycle.

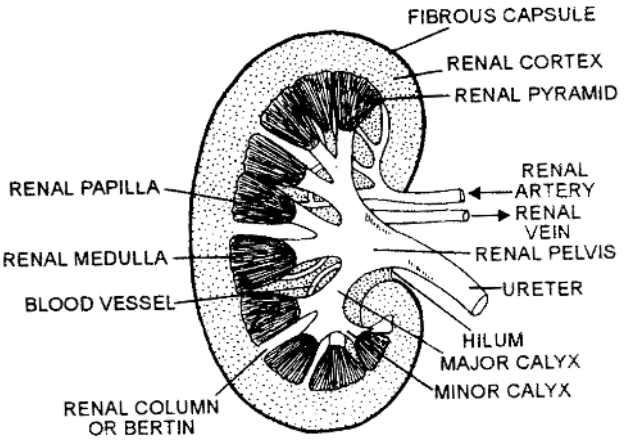
(10) The enzyme taking in ornithine cycle is arginase.

(11) Urea is produced by the enzyme arginase.

(12) **Clementi** was first to point out the presence of arginase in the liver of ureotelic animals.

6.6 Kidney

It is the main excretory organ. It is found in the dorsal side of abdomen. It is 12 ×6 × 3.5 *cm* in size, bean shaped and light brown in colour. Right kidney is situated little above (2.5 cm) from left kidney. In its L.V.S. kidney is seen to consist of much coiled **malpighian body (glomerulus + Bowman's capsule)**. Medulla is the inner part and urinary tubules are spread in a way giving medulla striated appearance. It (medulla) consists of **10, 12 conical renal pyramids,** basically, they are formed by the groups of loop of Henle's, and open towards hilus. Pyramids are related to calyces which opens in pelvis. Pelvis in a part of ureter, there a clear papilla seen in the middle of pyramid, there are stripes of medullary tubules between adjacent pyramids, which are known as renal column of Bertini. Hilus extends into ureter which supply urine to urinary bladder. Kidney is supplied with renal artery.

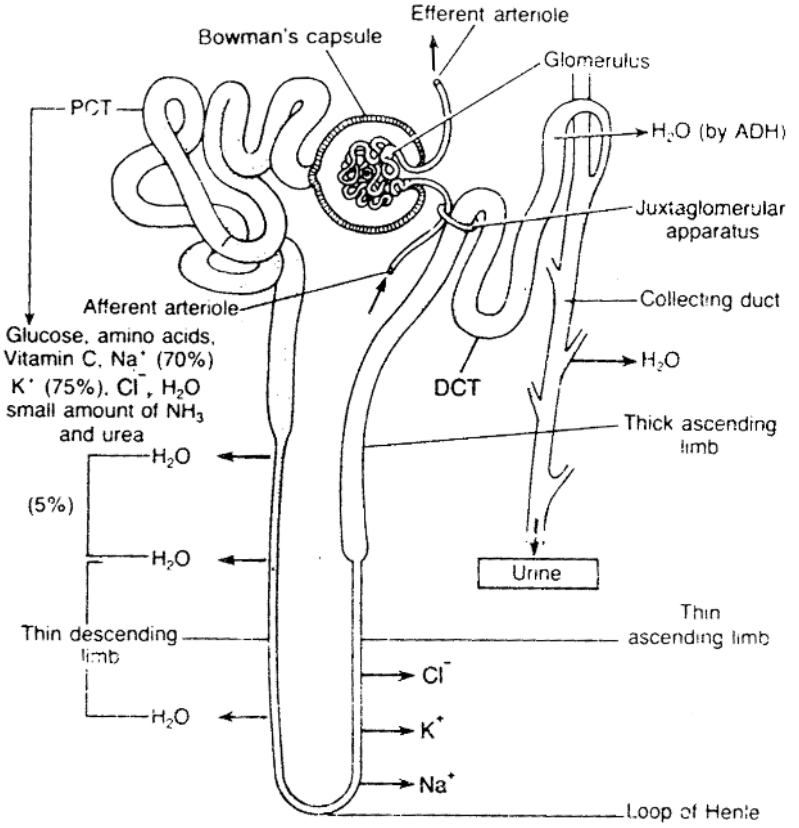


Longitudinal section of mammalian kidney

6.7 Nephron

Urine formation actually takes place in nephron. There are **1 to 1.2 million nephron** in a **single kidney of human** and 1 to 8 million in rabbit kidney. Nephron is also called unit of urine formation. It has following parts.

(i) **Bowman's capsule :** It is a cup shaped structure afferent renal artery of arcuate branch of renal artery enter Bowman's capsule and forms a bunch of blood capillaries called glomerulus. It is 10 nm (100Å) away from Bowman's capsule. Another end of glomerulus forms efferent renal artery, its diameter in less in comparison to A.R.A. Internal wall of Bowman's capsule is made up of squamous epithelium and Bowman's capsule is called malpighian corpuscle on the name of its discoverer Malpighi (1960).



A mammalian nephron

(ii) **Proximal convoluted tubule (PCT) :** It is also a convoluted tube in the cortex region. Having cilia at its anterior end. Recent discoveries have shown that these cilia are basically absorptive microvilli, which helps in selective reabsorption.

(iii) **Loop of Henle :** PCT opens into 'U' shaped loop of Henle. It is inserted in medulla which by pressure difference transports mineral, water and ions and thus forms urine. Wall of its descending and ascending loop is of squamous epithelium and cuboidal epithelium.

(iv) **Distal convoluted tubule (DCT) :** It is distal convoluted end of nephron. Its wall is covered with cuboidal epithelium while the mouth towards collecting tubule is covered with columnar epithelium.

(v) **Renal tubule :** Urine formed by nephron is transported to Duct of Bellini through collecting tubule (Renal tubule). Wall of renal tubule is of glandular epithelium. From Duct of Bellini urine is collected in pelvis which is then transported to urinary bladder through ureter.

6.8 Physiology of urination or Urine formation

Urination occurs in 3 stages.

(i) **Ultrafiltration**

(ii) **Selective reabsorption**

(iii) **Secretion**

(i) **Ultrafiltration :** Urine formation is a bio-physical process in which through kidney, inorganic salts, urea, creatine, harmful drugs, urobillin, heamatoporphyrin etc are excreted by the process of filtration. In this process, first of all blood enters into glomerulus, through renal arteriole, from here non-protein substances of blood enter Bowman's capsule due to glomerular hydrostatic pressure.

EFP = GHP – (BCOP + CHP)

(a) GHP = 75 mm Hg.
(due to narrower ERA)

(b) BCOP = 30 mm Hg.
(Blood colloidal osmotic pressure due to plasma protein)

(c) CHP = 20 mm Hg.
(Capsular hydrostatic pressure, due to fluid pre occupying the Bowman's capsule)

} Total exerted force in opposite direction
30+20 = 50 mm Hg.

EFP = GHP – (BCOP + CHP) = 75 – (30 + 20)

EFP = 25 mm *Hg*

(ii) **Selective reabsorption :** Many useful substances also enter Bowman's capsule (in the filtrate) which are essential for the body. They are reabsorbed by selective reabsorption. Among these **glucose, amino acid,** Na^+, K^+ etc. are absorbed actively, in presence of ATP by microvilli of proximal convoluted tubule. Here 80% filtrate is absorbed. About 80% of water is reabsorbed in PCT and loop of Henle. This is called obligatory water reabsorption. In DCT, Cl^- is reabsorbed by diffusion. Water reabsorption in DCT mediated by ADH is called facultative water reabsorption.

(iii) **Secretion :** Selective process involving both passive and active transport. Creatinine and foreign substances from interstitial fluid are secreted actively into the filtrate in PCT. Hydrogen, potassium, NH_4^+ & HCO_3^- are secreted into the filtrate in DCT by active transport. Urea enters the filtrate passively by diffusion in the ascending limb of Henle's loop.

Control of urination

(1) Vasopressin or ADH : Help to make concentrated urine.

(2) Aldosterone : It regulates the *Na –K* amount. It is also called salt retention hormone.

(3) Parathormone hormone : It regulates the absorption of Ca^{++} in nephron.

Other function of kidney

(1) Removal of non-volatile wastes.

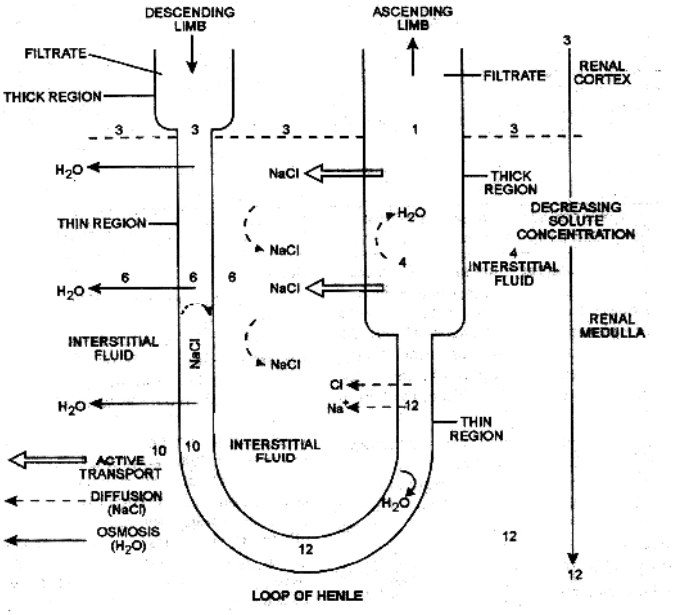
(2) Acid base balance.

(3) *pH* balance.

(4) Kidney secretes erythropoeitin hormone at the time of embryonic stage and chronic anaemia in adult. Blood capillaries surrounding Loop of Henle form juxta glomerulus which secretes renin hormone, which in turn excretes substances increasing blood pressure.

6.9 Counter current mechanism

The filtrate enters the descending tube of loop of Henle in medullary region. Here due to opposite flow of fluid in interstitial fluid and efferent renal arteriole, counter current mechanism is produced due to which Na^+ of filtrate is removed in interstitial fluid from descending tubule by active transportation. Here filtrate becomes hypotonic and enters ascending tube of loop of Henle. After reabsorption of Na^+ in this part filtrate becomes hypertonic and enters D.C.T. Atmospheric pressure of fluid increases from 400 mm Hg. to 1200 mm Hg since entering loop of Henle and then entering internal parts of medulla respectively. As a result there is removal of water and Na^+ in descending tube and reabsorption in ascending tube. The glomerular filtrate reaching the end of collecting duct, after being modified by reabsorption & secretion of some substances is called urine.



Countercurrent multiplier system. Numerals indicate relative concentrations of osmotically active solutes

Micturition : Urine is collected in urinary bladder via renal pelvis and ureters. On excessive collection of urine, sensory nerve endings in bladder wall get stimulated & this sets up reflexes. The inner sphincter valve gets open & then outer sphincter valve is opened by the will of the organism. Contraction of smooth muscles of bladder wall and relaxation of the urethral sphincters help in micturition.

Composition of human urine

Water – 95%, Salts – 2%, Urea 2.6%, Uric acid – 0.3%

Colour – Pale yellow, due to pigment urochrome.

pH – Ranges from 5.0 to 7.8, average *pH* 6.0, slightly acidic.

Odour – Aromatic, but become ammonia like upon standing.

Volume – 1 to 2 litres in 24 hours but varies to a considerable extent.

Traces of creatine, creatinine, ammonia etc. Many external factors affect urine formation, for instance: decrease in atm. temperature causes less synthesis of ADH in brain resulting in excessive urine formation.

6.10 Additional excretory organs

(i) **Skin :** Mammalian skin secretes two fluids: Sweat from sweat glands & sebum from sebaceous glands. Sweat consists of water, *NaCl*, urea & lactic acid. Sebum contains some lipids such as waxes, sterols, hydrocarbons & fatty acids.

(ii) **Lungs :** Remove CO_2 & some water as vapour in the expired air.

(iii) **Liver :** Excretes cholesterol, steroid hormones, bile pigments, certain vitamins & drugs via bile.

6.11 Disorder of kidney

(1) **Anuria :** The failure of kidney to secrete urine

(2) **Albuminuria :** Presence of albumin in urine

(3) **Bright's disease :** Inflammation of kidney (Glomerulo-nephritis)

(4) **Cystitis :** Inflammation of urinary bladder

(5) **Dysuria :** Painful urination

(6) **Enuresis :** Bed-wetting

(7) **Glycosuria :** Presence of sugar in urine. A pathological glycosuria results from diabetes mellitus

(8) **Haematuria :** Presence of RBCs in urine

(9) **Haemodialysis :** Removal of accumulated wastes like urea from blood by artificial kidney

(10) **Ketosis :** Presence of ketone or acetone bodies (aceto-acetic acid, β-hydroxybutyric acid and acetone) in urine (Acetonuria)

(11) **Kidney stone :** Crystallized chemicals like uric acid, calcium oxalate and calcium phosphate

(12) **Gout :** High level of uric acid in the blood

(13) **Polyuria :** Excessive urine

(14) **Pyuria :** WBCs or pus in the urine

(15) **Oliguria :** Scanty urine

(16) **Uremia :** High blood urea level due to kidney failure

Important tips

- The urine on standing gives a pungent smell. It is due to conversion of urea into ammonia by bacteria.
- The volume of urine produced per day will increase on cold damp day.
- The highest concentration of urea is found in hepatic vein. This is because urea is synthesized in liver.
- Least concentration of urea is found in renal vein. This is because urea is excreted through urine formed in kidney.
- Excretory products of mammalian embryo are eliminated out by placenta through maternal circulation.
- The term 'urine' can be first used for the content of collecting tubule.
- The substances necessary to the body which are reabsorbed very efficiently are high threshold substances, *e.g.*, Glucose, amino acids, keto acids, vitamin *C* and some salts.
- Renal threshold of a substance is its highest concentration in the blood upto which it is totally reabsorbed from the glomerular filtrate.
- The renal threshold of glucose, a high threshold substance, is about 180 mg per 100 ml.