EXCRETION

Types of Excretory Products in Animals

Human Excretory System

Urine Formation

Disorders of Excretory System
Excretion:

Animals accumulate ammonia, urea, uric acid, carbon dioxide, water and ions like Na+, K+, Cl−, phosphate, sulphate, etc., either by metabolic activities or by other means like excess ingestion. These substances have to be removed totally or partially. The process of removal of these harmful substances is called excretion.

Ammonotelism: Ammonia is the most toxic form and requires large amount of water for its elimination. The process of excreting ammonia is Ammonotelism. Many bony fishes, aquatic amphibians and aquatic insects are ammonotelic in nature. Ammonia, as it is readily soluble, is generally excreted by diffusion across body surfaces or through gill surfaces (in fish) as ammonium ions. Kidneys do not play any significant role in its removal.

Ureotelic: Terrestrial adaptation necessitated the production of lesser toxic nitrogenous wastes like urea nd uric acid for conservation of water. Mammals, many terrestrial amphibians and marine fishes mainly xcrete urea and are called ureotelic animals. Ammonia produced by metabolism is converted into urea in the liver of these animals and released into the blood which is filtered an excreted out by the kidneys. Some amount of urea may be retained in the kidney matrix of some of these animals to maintain a desired osmolarity.

Uricotelic: Reptiles, birds, land snails and insects excrete nitrogenous wastes as uric acid in the form of pellet or paste with a minimum loss of water and are called uricotelic animals.

Different Types of Excretory Organs in Animals:

- Protonephridia or flame cells are the excretory structures in Platyhelminthes (Flatworms, e.g., Planaria), rotifers, some annelids and the cephalochordate – Amphioxus. Protonephridia are primarily concerned with ionic and fluid volume regulation, i.e., osmoregulation.

- Nephridia are the tubular excretory structures of earthworms and other annelids. Nephridia help to remove nitrogenous wastes and maintain a fluid and ionic balance.

- Malpighian tubules are the excretory structures of most of the insects including cockroaches. Malpighian tubules help in the removal of nitrogenous wastes and osmoregulation.

- Antennal glands or green glands perform the excretory function in crustaceans like prawns.

www.excellup.com ©2009 send your queries to enquiry@excellup.com
HUMAN EXCRETORY SYSTEM

In humans, the excretory system consists of a pair of kidneys, one pair of ureters, a urinary bladder and a urethra.

Kidneys:

Shape & Size: Kidneys are reddish brown, bean shaped structures situated between the levels of last thoracic and third lumbar vertebra close to the dorsal inner wall of the abdominal cavity. Each kidney of an adult human measures 10-12 cm in length, 5-7 cm in width, 2-3 cm in thickness with an average weight of 120-170 g.

Structure: Towards the centre of the inner concave surface of the kidney is a notch called hilum through which ureter, blood vessels and nerves enter.

Inner Structure: Inner to the hilum is a broad funnel shaped space called the renal pelvis with projections called calyces. The outer layer of kidney is a tough capsule. Inside the kidney, there are two zones, an outer cortex and an inner medulla. The medulla is divided into a few conical masses (medullary pyramids) projecting into the calyces (sing.: calyx). The cortex extends in between the medullary pyramids as renal columns called Columns of Bertini.

Nephrons: Each kidney has nearly one million complex tubular structures called nephrons, which are the functional units. Each nephron has two parts – the glomerulus and the renal tubule.

Glomerulus: Glomerulus is a tuft of capillaries formed by the afferent arteriole – a fine branch of renal artery. Blood from the glomerulus is carried away by an efferent
arteriole. The renal tubule begins with a double walled cup-like structure called Bowman’s capsule, which encloses the glomerulus. Glomerulus alongwith Bowman’s capsule, is called the malpighian body or renal corpuscle.

**Tubules:** The tubule continues further to form a highly coiled network – proximal convoluted tubule (PCT). A hairpin shaped Henle’s loop is the next part of the tubule which has a descending and an ascending limb. The ascending limb continues as another highly coiled tubular region called distal convoluted tubule (DCT). The DCTs of many nephrons open into a straight tube called collecting duct, many of which converge and open into the renal pelvis through medullary pyramids in the calyces. The Malpighian corpuscle, PCT and DCT of the nephron are situated in the cortical region of the kidney whereas the loop of Henle dips into the medulla.

**Cortical Nephrons:** In majority of nephrons, the loop of Henle is too short and extends only very little into the medulla. Such nephrons are called cortical nephrons.

**Medullary Nephrons:** In some of the nephrons, the loop of Henle is very long and runs deep into the medulla. These nephrons are called juxta medullary nephrons.

**Vasa Recta:** The efferent arteriole emerging from the glomerulus forms a fine capillary network around the renal tubule called the peritubular capillaries. A minute vessel of this network runs parallel to the Henle’s loop forming a ‘U’ shaped vasa recta. Vasa recta is absent or highly reduced in cortical nephrons.
URINE FORMATION

Urine formation involves three main processes namely:

1. Glomerular Filtration,
2. Reabsorption and
3. 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 fluids.
FUNCTION OF THE TUBULES

Proximal Convoluted Tubule (PCT): PCT is lined by simple cuboidal brush border epithelium which increases the surface area for reabsorption. Nearly all of the essential nutrients, and 70-80 per cent of electrolytes and water are reabsorbed by this segment. PCT also helps to maintain the pH and ionic balance of the body fluids by selective secretion of hydrogen ions, ammonia and potassium ions into the filtrate and by absorption of HCO$_3^-$ from it.

Henle’s Loop: Reabsorption in this segment is minimum. However, this region plays a significant role in the maintenance of high osmolarity of medullary interstitial fluid. The descending limb of loop of Henle is permeable to water but almost impermeable to electrolytes. This concentrates the filtrate as it moves down. The ascending limb is impermeable to water but allows transport of electrolytes actively or passively. Therefore, as the concentrated filtrate pass upward, it gets diluted due to the passage of electrolytes to the medullary fluid.

Distal Convoluted Tubule (DCT): Conditional reabsorption of Na$^+$ and water takes place in this segment. DCT is also capable of reabsorption of HCO$_3^-$ and selective secretion of hydrogen and potassium ions and NH$_3$ to maintain the pH and sodium potassium balance in blood.

Collecting Duct: This long duct extends from the cortex of the kidney to the inner parts of the medulla. Large amounts of water could be reabsorbed from this region to produce concentrated urine. This segment allows passage of small amounts of urea into the medullary interstitium to keep up the osmolarity. It also plays a role in the maintenance of pH and ionic balance of blood by the selective secretion of H$^+$ and K$^+$ ions.

MECHANISM OF CONCENTRATION OF THE FILTRATE

The 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 mOsmol L$^{-1}$ in the cortex to about 1200 mOsmol L$^{-1}$ 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.

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 constrictory 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 vasoconstrctor, 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 rennin angiotensin mechanism.

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 is called the micturition reflex.

www.excellup.com ©2009 send your queries to enquiry@excellup.com
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.

ROLE OF OTHER ORGANS IN EXCRETION

**Lungs:** Lungs remove large amounts of CO$_2$ (18 litres/day) and also significant quantities of water every day.

**Liver:** Liver, the largest gland in our body, secretes bile containing substances like bilirubin, biliverdin, cholesterol, degraded steroid hormones, vitamins and drugs. Most of these substances ultimately pass out alongwith digestive wastes.

**Skin:** The sweat and sebaceous glands in the skin can eliminate certain substances through their secretions. Sweat produced by the sweat glands is a watery fluid containing NaCl, small amounts of urea, lactic acid, etc. Though the primary function of sweat is to facilitate a cooling effect on the body surface, it also helps in the removal of some of the wastes mentioned above. Sebaceous glands eliminate certain substances like sterols, hydrocarbons and waxes through sebum. This secretion provides a protective oily covering for the skin.

DISORDERS OF THE EXCRETORY SYSTEM

**Kidney Failure:** Malfunctioning of kidneys can lead to accumulation of urea in blood, a condition called uremia, which is highly harmful and may lead to kidney failure. In such patients, urea can be removed by a process called hemodialysis. Blood drained from a convenient artery is pumped into a dialysing unit after adding an anticoagulant like heparin. The unit contains a coiled cellophane tube surrounded by a fluid (dialyzing fluid) having the same composition as that of plasma except the nitrogenous wastes. The porous cellophane membrane of the tube allows the passage of molecules based on concentration gradient. As nitrogenous wastes are absent in the dialysis fluid, these substances freely move out, thereby clearing the blood. The blood is pumped back to the body through a vein after adding anti-heparin to it.

**Renal Calculi:** Stone or insoluble mass of crystallized salts (oxalates, etc.) formed within the kidney. These produce severe pain if they result in obstruction of urethra. Smaller sized calculi or stones are expelled by the body, while larger ones require surgical procedure to be expelled.