Excretion and the Kidney

Define excretion

Excretion is the removal from the body of the waste products of metabolic pathways. Kidneys excrete nitrogenous waste products.

The Human Kidney

[Diagram of the human kidney with labeled parts: Aorta, inferior vena cava, renal artery, renal vein, left kidney, kidneys, ureters, bladder, sphincter muscle, urethra]

Draw and label a diagram of the kidney (include cortex, medulla, pelvis, ureter, renal blood vessels)
1. Nephrons

Annotate a diagram of a glomerulus and associated nephron to show the function of each part.

A section through a kidney shows it to be made up of thousands of tiny tubes called nephrons. One end of the tube forms a cup-shaped structure called a Bowman’s capsule (or renal capsule). This Bowman’s capsules of all nephrons are in the cortex of the kidney. From the Bowman capsule the tube runs towards the centre of the kidney, first forming a twisted region called the proximal convoluted tubule, and then a long hairpin loop in the medulla called the loop of Henle. The tubule then runs back upwards into the cortex where it forms another twisted region called the distal convoluted tubule, before finally joining a collecting duct which leads down through the medulla and into the pelvis of the kidney. Here all the collecting ducts join the ureter.

2. Function of the glomerulus

Explain the process of ultrafiltration, including blood pressure, fenestrated blood capillaries and basement membrane.

The function of the glomerulus is production of a filtrate from blood by a process called ultrafiltration. Part of the blood plasma escapes through the walls of all capillaries, but in the glomerulus 20% escapes, which is much greater than usual. There are two main reasons for this:

- The blood pressure is very high, because the vessel taking blood away from the glomerulus is narrower than the vessel bringing blood.
- The capillaries in the glomerulus are fenestrated – they have many pores through them.

These pores are large enough to allow any molecules through, but on the outside of the capillary wall is a basement membrane, composed of a gel of glycoproteins. The basement membrane acts as a filter as it only allows molecules under a particular molecular mass to pass through (protein layer between glomerulus and Bowman’s Capsule that prevents blood cells and large proteins from entering the Bowman’s Capsule). It lets all substances in blood plasma through except plasma proteins.

- Glucose
- Amino Acids
- Salts
- Water
- Urea

The fluid produced by ultrafiltration is collected by the Bowman’s Capsule and flows on into the proximal convoluted tubule.
3. Function of the proximal convoluted tubule

Explain the reabsorption of glucose, water and salts in the proximal convoluted tubule, including the roles of microvilli, osmosis and active transport.

Large volumes of glomerular filtrate are produced by the two kidneys. As well as waste products, the filtrate contains substances that the body needs, which must be re-absorbed into the blood. Most of this selective re-absorption happens in the proximal convoluted tubule. The wall of the nephron consists of a single layer of cells. In this proximal convoluted tubule the cells have microvilli projecting into the lumen, giving a large surface area for absorption. Pumps in the membrane re-absorb useful substances by active transport, using ATP produced by mitochondria in the cells. Selective reabsorbed are:

- **100% glucose** (*active transport + diffusion*)
- **amino acids**
- **vitamins**
- **hormones**
- **80% water** (osmosis)
- **salt (sodium, chloride)**
- **potassium**
- **40-50% urea** (diffusion)

Active transport of solutes makes the total solute concentration higher in the cells of the wall than in the filtrate in the tubule. Water therefore moves from the filtrate to the cells and on into the adjacent blood capillary by osmosis. About 80% of the water in the filtrate is re-absorbed, leaving 20% of the original volume to flow on into the loop of Henle.

4. Osmoregulation

Define osmoregulation

Osmoregulation is the control of the water balance of the blood, tissue or cytoplasm of a living organism.

a. The role of the loop of Henle:

Explain the roles of the loop of Henle, medulla, collecting duct and ADH (vasopressin) in maintaining the water balance of the blood.

Glomerular filtrate flows deep into the medulla in descending limbs of the loops of Henle and then back out to the cortex in ascending limbs.

Descending limbs and ascending limbs are **opposite in terms of permeability**. Descending limbs are **permeable to water** but not to sodium ions. Ascending limbs are **permeable to sodium ions** but not to water.

(2) Ascending limbs pump **sodium ions** from the filtrate into the medulla by active transport, creating a high solute concentration in the medulla.

(3) As the filtrate flows down the **descending limb** into this region of high solute concentration, some **water** is drawn out by osmosis. This dilutes the fluids in the medulla slightly.

However the filtrate that leaves the loop of Henle is more dilute than the fluid entering it, showing that the overall effect of the loop of Henle is to **increase the solute concentration of the medulla** (so water moves passively – through aquaporins – out in the collecting duct, down its concentration gradient to create concentrated urine).
b. Osmoregulation in the collecting duct

Osmoregulation is the control of water and solute levels. The collecting duct has an important role in osmoregulation.

too low water content in blood
- Pituitary gland secretes ADH (hormone)
- makes cells of collecting duct produce membrane channels ("aquaporins")
  = makes collecting duct permeable to water
Filtrate passes down the collecting duct through medulla, the high solute concentration of medulla causes most of the water in the filtrate to be reabsorbed by osmosis
- small volume of concentrated urine is produced

too high water content in blood
- no ADH is secreted
- aquaporins are broken down
- collecting duct becomes less permeable to water, little water is reabsorbed as filtrate passes down the collecting duct
- large volume of dilute urine is produced

In this way the water content of the blood is kept within narrow limits. The urine produced by the collecting ducts drains into the renal pelvis and down the ureter to the bladder.

c. Differences in concentrations

<table>
<thead>
<tr>
<th>Content (mg per 100 ml of blood)</th>
<th>Blood plasma (in renal artery)</th>
<th>Glomerular filtrate</th>
<th>Urine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glucose</td>
<td>90</td>
<td>90</td>
<td>0</td>
</tr>
<tr>
<td>Urea</td>
<td>30</td>
<td>30</td>
<td>2 000</td>
</tr>
<tr>
<td>Proteins</td>
<td>740</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

- (large) proteins in blood plasma but not in glomerular filtrate
- all other substances equal in concentration

d. Glucose in the urine of diabetics

Whereas no glucose is present in the urine of healthy people, glucose is present in the urine of untreated diabetic patients.

Rise in Blood glucose Level:

In **Type 1** diabetes, insulin-producing β-cells are destructed and the lack of insulin causes an increase of fasting blood glucose.

In **Type 2** diabetes, the cells do not respond to insulin and cannot make use of the glucose in the blood. Following, more insulin is produced and more glucose is released. Hence, tissues become resistant to insulin and blood glucose level starts to rise.

Hence, more Glucose from the blood diffuses from the glomerulus into the proximal convoluted tubule and causes an excess of glucose. As glucose is reabsorbed, there are not enough protein carriers (active transport) to get all the glucose back into blood. Glucose is left in the filtrate and appears in the urine.