Bio Factsheet

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Answering Exam Questions on the Kidney

This Factsheet is aimed at those students who want to get full marks on kidney questions. If you are unsure of basic kidney structure or function, please read Factsheet No. 1 first!

When answering exam questions on the kidney you must know the basic anatomy of the kidney, the mechanics of urine formation and the control of urine formation. When you know and understand the basic knowledge, you will be able to interpret and analyse more complicated data interpretation questions.

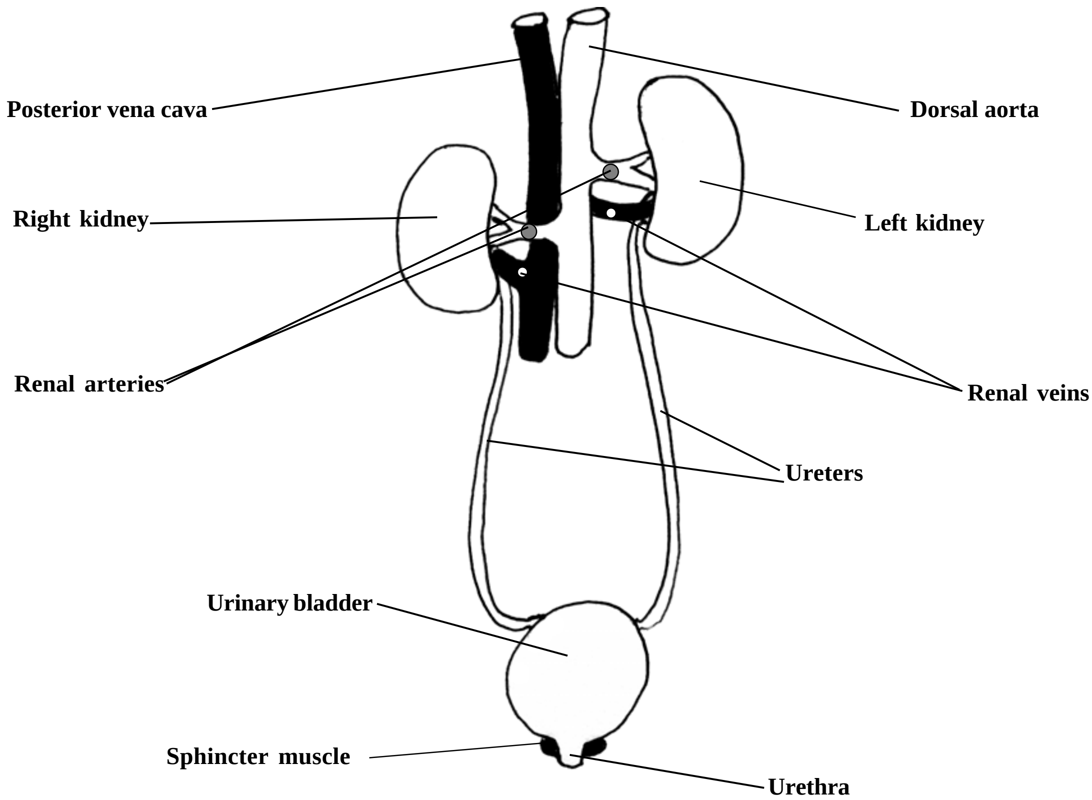
Students are often asked to 'state the functions of the kidneys'. A common answer is 'the kidneys produce urine which is excreted from the body'. This is not an adequate answer, because, although the kidneys produce urine, this is not their function but a consequence of their functions.

The functions of the kidneys are to:

- remove toxic metabolic waste products (for example, urea, uric acid, ammonia, H^+, HCO_3^-) from the blood, for excretion
- regulate the blood pH, blood water and salt content, blood osmotic pressure, blood pressure and blood volume. This is homeostasis.

Urine is produced as an incidental result of these activities.

Fig 1. Ventral view of the urinary system

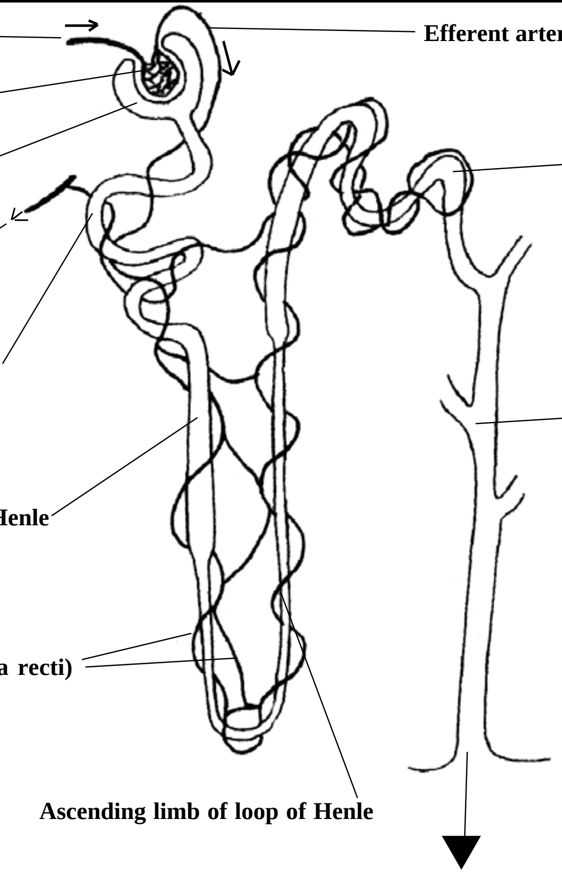


When labelling diagrams of the urinary system, several errors frequently occur. For example:-

- When labelling the kidneys, left and right get mixed up – always note whether the diagram is a dorsal or a ventral view. If it is ventral, the right kidney will be on your right when you are facing the diagram. Note that the right kidney is a bit above the left kidney (which is displaced backwards by the liver). If dorsal or ventral are not specified, assume the view is ventral – this is a standard biological convention.
- The posterior vena cava and aorta are frequently labelled the wrong way round - as a consequence so are the renal arteries and veins. Remember, in a ventral view the aorta is on the right of the diagram.
- Ureters and urethra are frequently confused. The urethra drains the bladder to the outside, ureters drain the kidneys to the bladder. 'Ureter' and 'urethra' should not be confused with the term 'uterus'.

Remember that each kidney contains thousands of nephrons. A nephron is a single working unit of the kidney.

Diagram of a nephron



When labelling diagrams of the nephron certain errors are often made. For example:-

- Do not label the afferent arteriole as the renal artery, or the efferent arteriole/efferent venule as the renal vein. As soon as the renal artery enters the kidney it divides, ultimately into afferent arterioles. The efferent venules join to form larger venules, ultimately forming the renal vein, which leaves the kidney.
- The afferent and efferent **arterioles** are often mixed up. The afferent arteriole goes to the glomerulus. The efferent arteriole leaves the glomerulus leading to the capillary network (vasa recti) which surround the nephron tubules.
- The efferent arteriole and efferent **venule** are often mixed up. The efferent arteriole leaves the glomerulus. The efferent venule leaves the nephron, having drained the vasa recti.
- Do not just label the loop of Henle but distinguish the descending limb and the ascending limb. This is particularly important when the question is about tubular functions. These regions have different histology, different properties and different functions.
- Do not just label 'convoluted tubule' but distinguish 'first/proximal' and 'second/distal'. Again, this is very important if the question is linked to tubular functions, - the regions have different histology, properties and functions.
- If you draw a nephron, remember that the vasa recti cover the convoluted tubules and loop of Henle, but do not cover the collecting duct.

Production of urine

To organise your thoughts, particularly if answering essay questions, think of urine formation in three categories:-

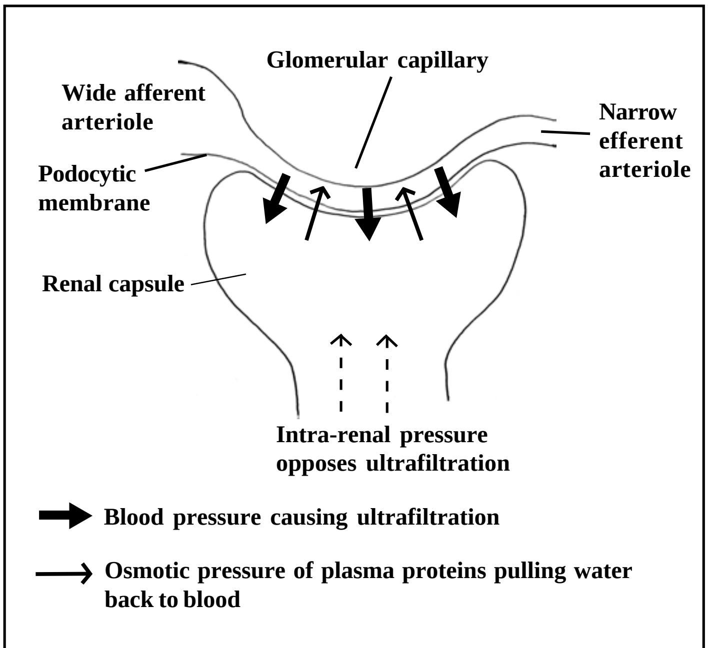
1. Formation of glomerular filtrate, from glomerular blood to renal capsule.
2. Modification of glomerular filtrate into urine. During this process the kidney is carrying out the functions of blood homeostasis and excretion.
3. Control of kidney function, including antidiuretic hormone (ADH) and its roles.

Formation of glomerular filtrate

Always refer to the nature of the renal capsule and glomerular membranes, and to three pressures – the glomerular blood pressure, the plasma protein osmotic pressure and the intra-renal (intra-capsule) pressure:-

- When referring to the membranes of glomerular capillaries and renal capsule, which separate the blood from the glomerular filtrate, point out:-
  - * The membranes are **differentially permeable**. They allow small molecules (for example, water, salts, glucose, amino acids, urea) to pass freely from blood to capsule, but will not allow large molecules of plasma protein to pass, so proteins are kept in the blood.
  - * Pavement cells in both of these membranes are modified into **podocytes** (foot cells).
    These have cytoplasmic projections which lift them off their basement membranes. This makes the membranes many times more permeable than other epithelial membranes, without sacrificing the selective permeability.
- When referring to the glomerular blood pressure point out:-
  - * Blood pressure in the glomerular capillaries is twice as high as capillary blood pressure elsewhere in the body. The efferent arteriole is narrower than the afferent arteriole and exerts a 'damming up' effect causing the rise in blood pressure.
  - * The raised glomerular blood pressure causes **ultrafiltration**. This is 'filtration under pressure' and forces water and small molecules dissolved in the water of the blood plasma into the capsule, forming **glomerular filtrate**.
- When referring to plasma protein osmotic pressure point out:-
  - * Because plasma proteins cannot leave the blood glomerular filtrate will not contain protein.
  - * High concentration of protein in blood plasma and absence of protein in glomerular filtrate causes an osmotic pressure to be exerted across the differentially permeable membranes, drawing water from the capsule back to blood. This concentrates the glomerular filtrate.
- When referring to intrarenal pressure point out:-
  - * It is the pressure of fluid already in the capsule and tubules of the nephron,
  - * It tends to oppose glomerular blood pressure and so opposes ultrafiltration.

Glomerular filtration



Keep the three opposing pressures in context. Express them as an equation:

Effective filtration pressure forming glomerular filtrate	=	**glomerular blood pressure**	–	**osmotic pressure of plasma proteins**	–	**intra-renal pressure**

Glomerular blood pressure averages 8 kPa, plasma protein osmotic pressure averages 4 kPa and intra-renal pressure averages 2.7 kPa.
Thus, Effective filtration pressure = 8 - 4 – 2.7 = 1.3 kPa

You will not have to remember these figures, but you may be given values to comment on, in particular situations. For example, in kidney disease (nephritis) the membranes are damaged so protein leaks from blood to glomerular filtrate. You may be asked what effect this has on the osmotic gradient, (it reduces), and to use the equation to assess the effect on the rate of filtrate formation (it increases the effective filtration pressure and so a much larger volume of filtrate is formed).

Modification of the glomerular filtrate into urine.

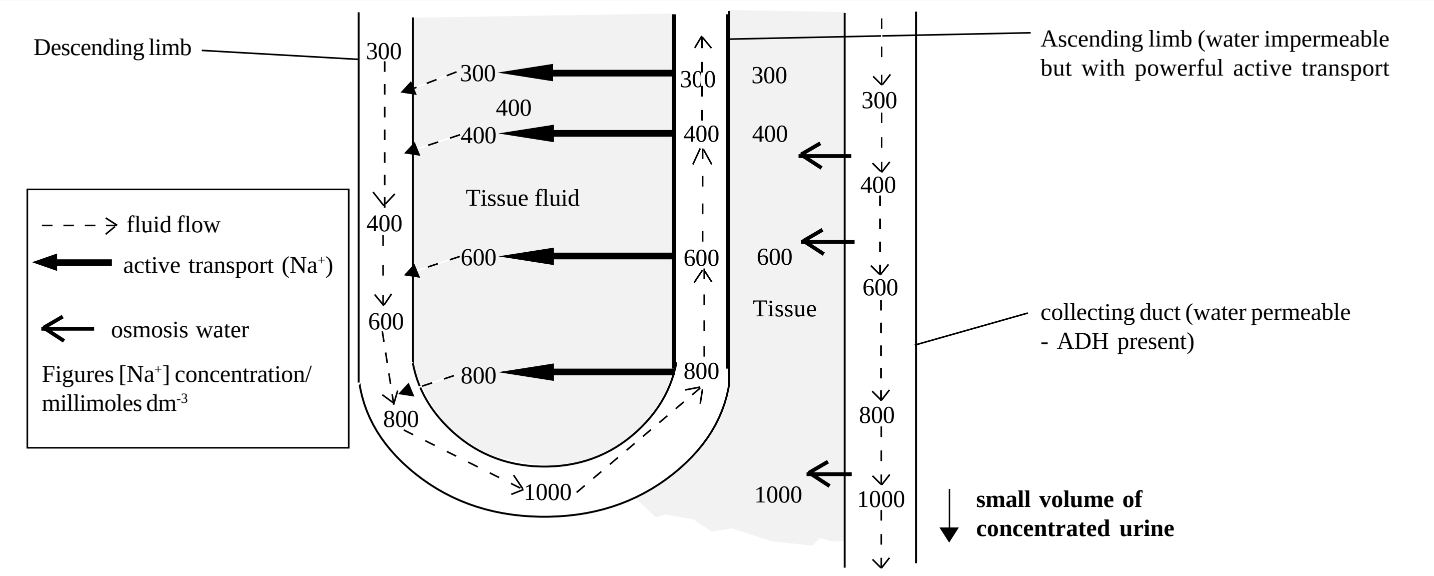
Be careful to refer to the various fluids correctly:-

- In the renal capsule the fluid is **glomerular filtrate**.
- From the start of the first convoluted tubule to the end of the second convoluted tubule the fluid is **tubular fluid**.
- In the collecting duct the fluid is **urine**.
- In some texts the tissue fluid surrounding the tubules is referred to as 'interstitial fluid'.

Know the water permeabilities of the various tubules of the nephron so you do not make errors about where water is reabsorbed from glomerular filtrate (now called tubular fluid) back to the surrounding tissue fluid and then blood. A very common candidates' statement is the 'loop of Henle is involved with water reabsorption'. This is true but candidates then make the error of thinking that the loop of Henle itself reabsorbs the water. **It does not**.

- The proximal convoluted tubule is very permeable to water and osmotically reabsorbs about 80% of the filtrate water.
- The descending limb of the loop of Henle is fairly permeable to water but passively absorbs sodium and chloride ions from surrounding tissue fluid. Because of this, its osmotic gradients may alter, so it could draw water from tissue fluid into filtrate or pass water from filtrate to tissue fluid.
- The ascending limb **is always totally impermeable to water** but has very powerful active transport mechanisms for pumping sodium and chloride ions from filtrate into surrounding tissue fluid, which thus becomes very concentrated in this area. (These sodium and chloride ions can then diffuse into the descending limb, resulting in a circulation of Na^+ and Cl^-, which is the counter-current mechanism of the loop of Henle). (Its functions are outlined below). Candidates often write incorrect accounts because they have not learnt the basic fact that '**the ascending limb is <u>always totally impermeable to water</u>'**.
- The collecting duct (and distal convoluted tubule) is impermeable to water in the absence of anti-diuretic hormone (ADH) but is permeable to water in the presence of ADH. (Candidates often get this the wrong way around). The counter-current mechanism causes a high concentration of Na^+ and Cl^- to be maintained in the tissue fluid surrounding the collecting ducts and loop of Henle. Because of this, if ADH is present, water can be reabsorbed osmotically from the collecting ducts to the tissue fluid and into the blood. This results in a small volume of concentrated urine being produced. If ADH is absent, no water can be reabsorbed and a large volume of dilute urine is produced.

Counter current in the loop of Henle



In the system shown in the above diagram, if ADH was absent so that water was not reabsorbed via the collecting duct, what would be the final concentration of the large volume of urine produced?

Answer: 300 millimole dm^{-3}

- The composition of tubular fluid at the top of the descending limb is a result of glomerular filtration and reabsorption processes which have occurred in the first convoluted tubule. As far as Na^+ is concerned, it is basically similar to the blood concentration, 300 millimoles dm^{-3}. Remember that the Na^+ concentration in the tissue fluid around the top of the ascending limb is in equilibrium with the blood concentration, also 300 millimoles dm^{-3}. The counter-current mechanism thus enables the blood concentration of Na^+ (and Cl^-) to be maintained, (homeostasis). It also maintains a high concentration of salt in the tissue fluid surrounding the collecting ducts. This enables water reabsorption, when necessary, so regulating blood water content, blood volume and blood (hydrostatic) pressure. The regulation of the blood salt concentration also regulates the blood osmotic pressure.

__Exam Hint:__ the counter-current principle in the kidney is a difficult concept which frequently confuses candidates. Carefully assess the wording of questions to decide whether it is the mechanism of the counter-current system that is wanted, or the functions of the counter-current system, namely, regulation of blood water and salt concentration, blood volume, blood hydrostatic pressure and blood osmotic pressure.

- You may be asked about the use of active transport in modification of glomerular filtrate into urine, (other than the active transport of the counter-current system). Refer to both **active reabsorption** and **active secretion** and remember that they occur across the tubule walls between the tubular fluid and the tissue fluid. Exchange between the tissue fluid and blood is by simple diffusion. Candidates often make a mistake by writing 'active transport occurs between the blood and tubular fluid'.
  - * Active reabsorption takes place in the first convoluted tubule. Normally all the glucose is actively reabsorbed from the tubular fluid, nearly all the amino acids, some of the salts (Na^+, K^+, Mg^{2+}, Ca^{2+}, Cl^-, HCO_3^-) and small quantities of urea (even though the aim is to excrete urea).
  - * Active secretion takes place in the second convoluted tubule, pumping extra substances into the tubular fluid from the tissue fluid. Substances that may be pumped into the tubular fluid include H^+, K^+, HCO_3^-, ammonia, creatinine and drugs such as penicillin.

Control of kidney function: ADH

Question: State the functions of ADH.

Answer: It makes the collecting duct walls permeable to water which enables regulation of the volume and concentration of urine.

This is a very common answer given by students but unfortunately it is not correct.

Remember – production/regulation of urine is an incidental result of kidney functions in homeostasis and excretion. Making collecting duct walls permeable to water is how ADH **acts** to carry out its functions.

The answer should have been: **ADH regulates the volume/water content of the blood and so regulates the blood pressure.** (The alternative name of ADH is '**vasopressin**', and this name reflects its function of raising blood pressure, by reducing blood water loss via the urine. Vasopressin can also raise blood pressure by stimulating constriction of arterioles).

The other aspect of ADH, which may be tested in examinations, is its control by negative feedback. Remember the following points:-

- ADH is secreted via the **posterior** pituitary. ('pituitary' alone will probably not score a mark, and anterior pituitary is wrong).
- Receptors called **osmoreceptors** in the **hypothalamus** are stimulated when the blood osmotic pressure is **too high** – due to too much water loss and a resultant increase in the proportion of Na^+ content to water content.
- The stimulated osmoreceptors induce **neurosecretory cells** in the hypothalamus to synthesize ADH. This ADH is transported to the posterior pituitary and released into the general blood stream.
- The ADH targets receptors on cells lining the kidney collecting ducts, changing the wall permeability so that water can be reabsorbed. Thus, the blood volume is increased and so is the blood pressure.
- The increase in blood water content lowers the proportion of Na^+ content to water content, which allows the osmoreceptors to switch off. This curtails (damps) ADH production, and returns the collecting ducts to water impermeability.

Commonly occurring errors/deficiencies in candidates' answers include:-

- Reference to 'brain' as the site of osmoreceptors. 'Hypothalamus' should be specifically stated.
- Stating that the 'posterior pituitary secretes ADH'. It does not – the hypothalamus secretes ADH but the posterior pituitary releases it to the blood.
- Getting the action of ADH on collecting ducts the wrong way round by stating that 'presence of ADH reduces the permeability of collecting ducts to water'. Remember, ADH presence makes collecting ducts more permeable to water.

Acknowledgements:
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