How kidneys produce urine

The kidneys are responsible for maintaining the volume and chemical composition of bodily fluids. They do this by filtering impurities from the blood and excreting excess water and metabolic by-products as urine.

The kidneys are the major excretory organs of the body, and are situated towards the back of the abdomen, below the diaphragm. They are responsible for maintaining the constancy of body fluids by filtering toxins, metabolic waste products and excess ions from the blood. The end result of this process is the excretory fluid urine.

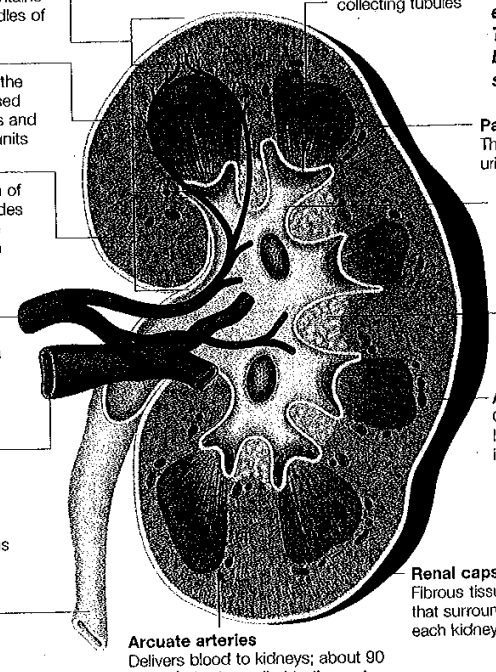
At the same time, the kidneys also maintain blood volume (the correct balance of water and salts) and the correct acidity of body fluids. This complex process is called homeostasis.

INSIDE THE KIDNEY

There are three distinct zones within the kidney: the renal cortex (outermost zone), the renal pelvis (inner zone) and the renal medulla (middle zone). The cortex is granular and pale in appearance, and contains a network of arteries, veins and capillaries. The medulla is a darker, striped area divided into conical structures known as renal pyramids. At the apex of each pyramid are papillae, nipple-shaped projections that extend into the renal pelvis via cavities known as calyces.

There are over one million blood processing units within the kidney that are called nephrons. Urine produced by the nephrons drains into the pelvis via calyces. In turn, the pelvis is linked to the ureter, the tubes that channel the urine to the bladder.

Internal structure of the kidney



Renal cortex
The outermost region of the kidney; contains the capillary bundles of the nephrons

Renal medulla
Middle region of the kidneys, composed of renal pyramids and urine-collecting units

Renal pelvis
Innermost region of the kidneys; divides into two or three branches known as calyces

Renal artery
Supplies blood to the kidney via artery directly connected to the aorta

Renal vein
Drains blood from the kidney directly into the vena cava (one of the main veins to the heart)

Ureter
30 cm-long tubes that channel urine from the renal pelvis to the bladder

Renal pyramid
Formed of parallel bundles of urine-collecting tubules

The kidneys process about 180 litres of blood every day, but less than one per cent (1.5 litres) is excreted from the body as urine. This waste is carried directly to the bladder, via the ureter, where it is stored until excreted from the body.

Papilla
The tip of the renal pyramid; drains urine into the pelvis via the calyces

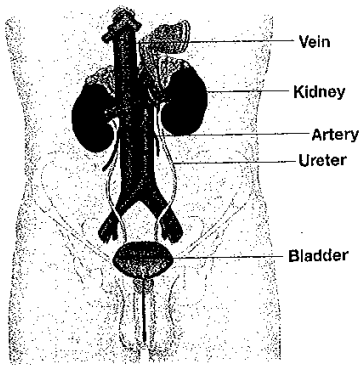
Calyx
Major and minor cavities that cup the apexes of the renal pyramids; urine is collected here before being drained into the pelvis

Adipose tissue
A soft, fatty tissue that cushions the calyces

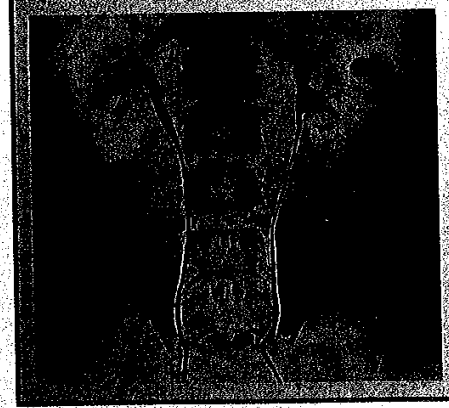
Arcuate veins
Channels blood leaving the kidney into the renal vein

Renal capsule
Fibrous tissue that surrounds each kidney

Arcuate arteries
Delivers blood to kidneys; about 90 per cent is channelled to the cortex



The kidneys are paired organs situated on either side of the spine at the back of the abdomen. They only weigh about one per cent of the overall body weight, but receive 20 per cent of the blood pumped by the heart.



This contrast medium X-ray clearly shows the kidneys (green) and the ureters (red – the vessels connecting the ureters to the kidneys). The bladder is the dark red circular mass at the bottom of the X-ray.

The production of urine is a three-step process: filtration, reabsorption and secretion. Once the required water and essential nutrients have been reabsorbed, the fluid remaining in the tubule is urine, which empties into the collecting ducts and then to the ureters to be excreted from the body via the bladder.

The walls of the ureter are muscular. Regular waves of contraction (peristalsis) move the urine from the renal pelvis towards the bladder every 10–30 seconds. The ureters pass obliquely through the bladder wall, tending to close the ureteric opening except during a peristaltic contraction. This prevents the backflow of urine.

The bladder muscle is controlled by involuntary nerve action. The bladder fills without increasing internal pressure until it is near capacity. When the bladder is full, the pressure within rises dramatically, triggering a spinal nerve reflex which acts to cause the bladder muscle to contract and empty its contents via the urethra. This is the process of micturition (urination). The first urge to micturate is felt when the bladder volume is about 150 ml. This increases to a sense of urgency at 400 ml.

Urine production

Approximately one litre of blood flows into an adult kidney every minute. There are over one million urine-producing units within the kidney, and from all of these, one millilitre of urine is produced every minute.

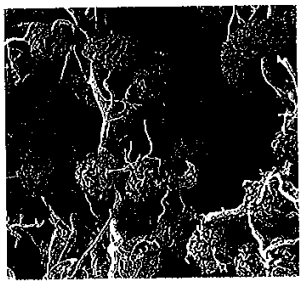
The nephron is the functional, structural unit of the kidney which filters blood and is responsible for urine production. There are over a million nephrons in each kidney, as well as thousands of collecting ducts into which the urine drains.

The nephron is formed from two main units: a glomerulus and its associated renal tubule. The glomerulus is a tight ball of capillaries situated in the renal cortex, and its tubules, through which water and chemicals absorb into the blood, extend down into the medulla.

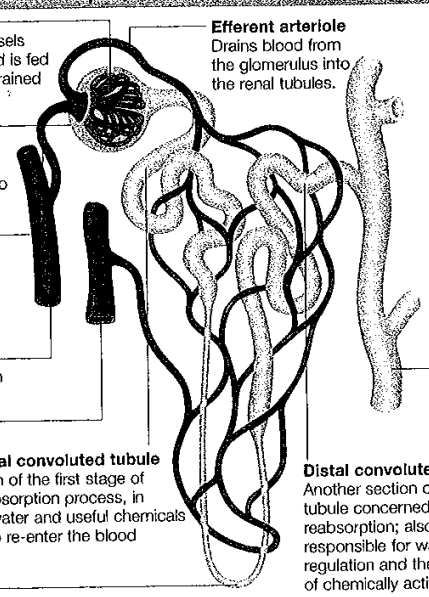
BOWMAN'S CAPSULE

At one end of the renal tubule, completely encasing the glomerulus, is a closed unit called the Bowman's capsule. Together, the Bowman's capsule and its glomerulus are called a renal corpuscle, and are responsible for filtering waste products into the renal tubule.

The other end of the renal tubule connects to a urine-collecting tubule. The specific nature and function of the cells within the renal tubule are essential to the excretory and homeostatic function of the nephron as a whole.



The nephron and its blood supply



Glomerulus
Tight knot of capillary blood vessels located in the renal cortex; blood is fed into this capillary network and drained out via two arterioles

Bowman's capsule
Cup-shaped end of a nephron which encloses the glomerulus; it is the site of blood filtration into the kidney tubule

Afferent arteriole
Arteriole (blood vessel linking capillaries to arteries) that feeds blood into the glomerulus from the interlobular artery

Interlobular artery
Branch of the renal artery, which delivers blood to the kidney

Arcuate vein
Branch of the renal vein, which empties blood into the heart

Loop of Henle
Hairpin bend in the renal tubule; nutrient reabsorption can also take place here

Efferent arteriole
Drains blood from the glomerulus into the renal tubules.

Proximal convoluted tubule
Location of the first stage of the reabsorption process, in which water and useful chemicals begin to re-enter the blood

Distal convoluted tubule
Another section of the renal tubule concerned with reabsorption; also largely responsible for water regulation and the balance of chemically active solutions

Urine collecting tubule
Drains urine into the ureter, for removal to the bladder

The nephron is the active unit of filtration within the kidneys. It is composed of two main elements: the glomerulus, which filters blood, and the renal tubule, which re-absorbs the useful substances back into the blood and extracts the waste material. The tubule is divided into distinct segments: the proximal tubule, the loop of Henle and the distal tubule.

EXCRETION OF METABOLIC WASTE PRODUCTS

The waste products of metabolism are eliminated by the kidneys via the nephrons. They also excrete toxins ingested or produced by the body. The principle waste products in urine are urea (from protein metabolism), creatinine (from muscle), uric acid (from metabolism of nucleic acids), bilirubin (from haemoglobin metabolism) and the broken down products of hormones.

Glomeruli are tight knots of blood capillaries (seen here in blue) in the kidneys. Each glomerulus forms part of a tiny filtration unit that removes toxic waste from the blood.

The nephron works by a process of secretion followed by reabsorption. Nutrients and waste products flow freely out of the blood in the glomerulus into the Bowman's capsule. These chemicals are accompanied by water and many essential nutrients, which must be reclaimed by the body.

This reabsorption occurs in the remaining parts of the nephron and renal tubules. The waste eventually drains into the collecting ducts to be eliminated from the body.

Most of this reabsorption takes place in a section of the renal tubules called the distal convoluted tubule (see diagram above). The reabsorption and some secretion that takes place here, and in another section known as the loop of Henle, is dependent upon the body's requirements at the time.

Closely associated with the capillary bed of the glomerulus and the renal tubules are the peritubular capillaries. These are another vital element to the reabsorption process. The pressure in these capillaries is much lower than that of the glomerulus and allows water and nutrients to flow freely into them, re-absorbing them back into the blood.

Capillary networks

On entering the kidney, the renal artery divides into several branches, each radiating towards the cortex. In the cortex, the branches subdivide repeatedly into smaller and smaller vessels. The final sub-branch is called an arteriole. Each arteriole supplies blood to one nephron.

The anatomy of the arterial blood supply to the kidney nephrons is unique, in that each nephron is supplied by two, rather than one, capillary beds. The arteriole supplying the nephron is known as the efferent arteriole. It is the tight knotting of the resulting capillaries that forms the glomerulus.

On leaving the capillary tuft, the microvessels join together to form the outgoing arteriole, known as the afferent arteriole. This arteriole then redivides into the peritubular capillaries – a second network of microvessels surrounding the urine collecting tubule further down its length. These capillaries empty into the vessels of the venous system, eventually draining into the renal vein.

The pressure in the glomerulus is high, forcing fluid, nutrients and waste products out of the blood into the nephron capsule. The pressure in the peritubular capillaries is low, allowing fluid reabsorption. Adjustments to the pressure differences between the two capillary beds control the excretion and reabsorption of water and chemicals within the blood.

A cast of a normal kidney shows the complex capillary networks within the organ. There are approximately one million arterioles in each kidney.

How the kidneys control blood pressure

The kidneys play a fundamental role in the long-term regulation of blood pressure. The blood pressure must be kept stable so that organs receive an adequate supply of blood and oxygen.

The kidneys are two bean-shaped organs located on either side of the pelvis. They have two main roles:

- Regulating the salt and water balance in the body
- Excreting waste substances such as urea, excess salt and other minerals, in the form of urine.

FILTRATION SYSTEM

The kidneys contain millions of microscopic filtering units, called nephrons, which are the working components of the kidneys. Certain substances in the blood (such as glucose) are filtered but reabsorbed back into the bloodstream, while harmful wastes and excess water are excreted in the form of urine.

BLOOD PRESSURE

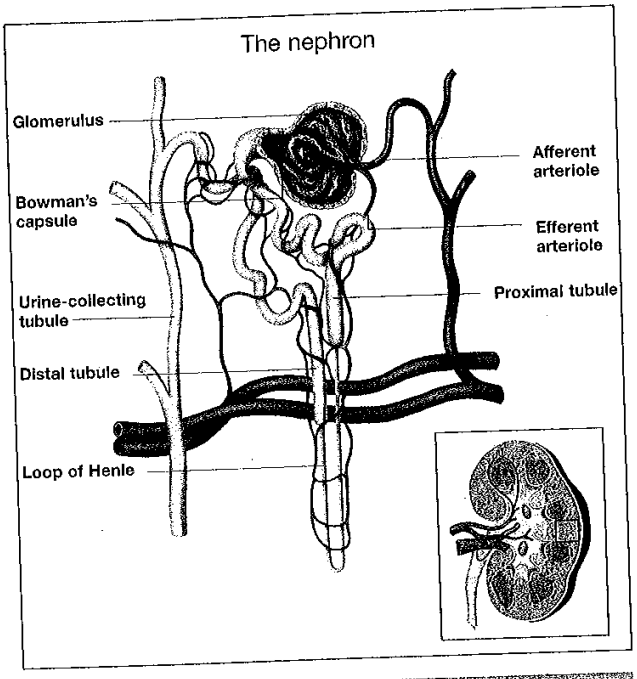
The kidneys play an extremely important role in the long-term regulation of blood pressure. Blood pressure is defined as the pressure of blood against the walls of the main arteries and is an indication of the efficiency of a person's circulation.

REGULATION

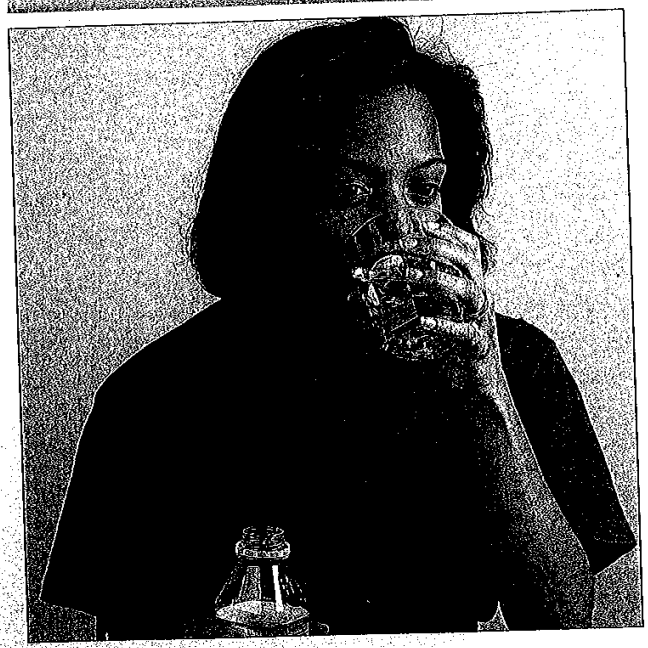
Blood pressure must be regulated in order to provide an adequate supply of blood and oxygen to the organs.

- Hypotension (low blood pressure) may indicate that there is insufficient blood in the circulation. This can result in vital organs being deprived of oxygen rich blood and result in shock
- Hypertension (abnormally high blood pressure) means that the heart has to work harder to pump blood against a greater resistance within the arterial circulation, putting great strain on the heart.

Blood is filtered through the kidneys. Some substances are reabsorbed into the blood, while others, such as excess water and waste, are excreted as urine.



Blood volume



A number of mechanisms within the body act to ensure that blood pressure is kept within normal limits, on both a short- and long-term basis. The kidneys play an important part in this long-term regulation of blood pressure.

BLOOD VOLUME

The kidneys help to maintain homeostasis (equilibrium) in the circulation by regulating blood volume. Although the volume of blood varies with age and gender, the kidneys usually maintain total circulating volume at around five litres.

Any significant alteration in this level will affect blood pressure:

- An increase in blood volume leads to an increase in blood pressure. For example, an excessive intake of salt with resulting water retention can lead to a higher blood pressure
- A decrease in blood volume causes a decrease in blood pressure. Severe blood loss or dehydration are common causes. A sudden drop in blood pressure may indicate internal bleeding.

Drinking water is an important way of maintaining blood volume. The kidneys use water levels and salt concentration to control blood pressure.

FEEDBACK SYSTEM

The role of the kidneys is to detect any changes in blood volume or pressure via a feedback system and to react accordingly.

- When blood volume increases, the kidneys remove more water from the blood, reducing the blood volume and restoring normal blood pressure
- When blood volume decreases, due to dehydration for example, the kidneys absorb less water, thus restoring blood pressure.

Renal hormones

Blood volume is a direct indicator of blood pressure. The kidneys continually monitor blood absorption and sodium levels to maintain an even pressure.

The kidneys regulate blood pressure by altering the amount of urine passed, thereby regulating blood volume. When blood pressure is low, the kidneys conserve water in the circulation and when it is raised, they ensure that greater volumes of water are passed as urine.

FILTRATION RATE

Within each nephron (functional unit of the kidney) is a bundle of arterioles (blood vessels) called the glomerulus. Water and solutes are 'pushed' out of the blood into the collecting tubules by the higher blood pressure in the glomerulus. An average person filters about 125 mls of filtrate per minute. If the blood pressure is too low, water will remain in the circulation to help boost the blood pressure. If the blood pressure is high, more water is forced into the tubules and passed as urine.

FEED-BACK MECHANISM

The walls of the blood vessels supplying the nephrons contain specialized cells that are able to detect blood pressure. It is these cells that set into motion additional processes needed to rectify abnormal pressure.

- The blood pressure falls below normal limits and the specialized cells detect this change
- A hormone called renin is secreted into the blood stream
- Renin converts a substance called angiotensin into angiotensin I, which then becomes angiotensin II as it passes through the lungs in the blood
- Angiotensin II stimulates the adrenal glands (located on the top of the kidneys) to produce aldosterone
- Aldosterone acts directly on the nephrons in the kidneys so that more salt and water are reabsorbed back into the blood circulation. This results in an increase in blood pressure

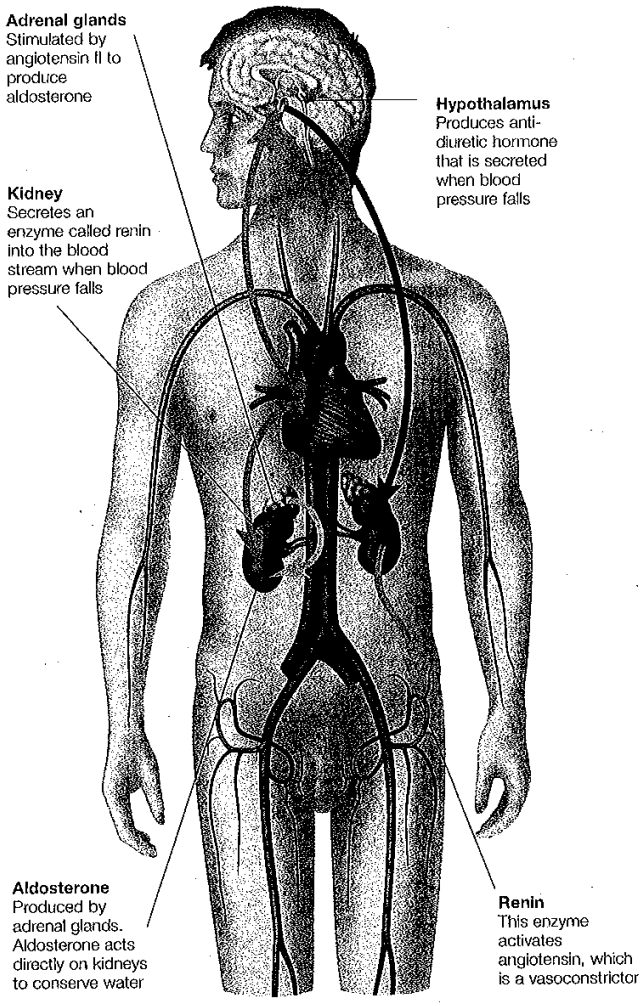
In addition to this mechanism, angiotensin II constricts blood vessels, thus increasing the pressure within them.

ANTI-DIURETIC HORMONE

The hypothalamus in the brain also has a role to play. When the water concentration in the blood is low, potentially leading to a drop in blood pressure, the hypothalamus secretes anti-diuretic hormone (ADH). This acts on the tubules in the nephrons, making them more permeable so that more water is reabsorbed into the blood.

The kidneys help to control blood pressure using a feedback mechanism. This diagram shows the sequence of events following a change in pressure.

Control of blood pressure



The normal blood pressure of a resting adult is usually about 120/80 mmHg, but this can be influenced by a wide range of factors:

- Age. Blood pressure naturally increases throughout life. This is because the arteries lose the elasticity that, in younger people, absorbs the force of heart contractions
- Gender. Men generally experience higher blood pressure than women or children
- Lifestyle choices. Being overweight, consuming high levels of alcohol or enduring a long period of stress can all contribute to high blood pressure.

Blood pressure is influenced by a number of factors, such as age and stress. Regular monitoring and life-style advice are vital in those at risk.

Hypertension
Abnormally high blood pressure (hypertension) may be caused by a number of factors but is commonly caused by atherosclerosis, a disease that causes narrowing of the blood vessels.

When the disease affects the arteries of the kidney (renal arteries) it may cause long-term problems with blood pressure regulation.

Hypotension
Abnormally low blood pressure (hypotension) is usually due to reduced blood volume or increased blood-vessel capacity. This can happen in the case of severe burns or dehydration, which both lower blood volume, or through an infection such as septicaemia which causes a widening of the blood vessels.