# The Urinary System Physiology

The urinary system is the main excretory system in the human body. It comprises the following structures: Two kidneys, two ureters, the urinary bladder and the urethra.

This system plays a vital part in maintaining the body's homeostasis of water and electrolytes. The kidneys produce urine that contains metabolic waste products, including the nitrogenous compounds urea and uric acid, excess ions and some drugs.

**Functions of the Kidney**

The kidneys filter 200 litres of blood daily, allowing toxins, metabolic wastes, and excess ions to leave the body in the urine

It regulated the volume and chemical makeup of the blood

It also maintains the proper balance between water and salts, and acids and bases

**Other Renal Functions**

-Gluconeogenesis during prolonged fasting

-Production of rennin to help regulate blood pressure and erythropoietin to stimulate RBC production

-Activation of vitamin D

**Other Urinary System Organs**

Urinary bladder – provides a temporary storage reservoir for urine

Paired ureters – transport urine from the kidneys to the bladder

Urethra – transports urine from the bladder out of the body

## Urinary System Organs

**Kidney Location and External Anatomy**

The bean-shaped kidneys lie in a retroperitoneal position in the superior lumbar region and extend from the twelfth thoracic to the third lumbar vertebrae.

The right kidney is lower than the left because it is crowded by the liver

The lateral surface is convex and the medial surface is concave, with a vertical cleft called the renal hilus leading to the renal sinus

Ureters, renal blood vessels, lymphatics, and nerves enter and exit at the hilus

**Layers of Tissue Supporting the Kidney**

Renal capsule – a fibrous capsule that prevents kidney infection

Adipose capsule – fatty mass that cushions the kidney and helps attach it to the body wall

Renal fascia – outer layer of dense fibrous connective tissue that anchors the kidney

**Internal Anatomy**

A frontal section shows three distinct regions

Cortex – the light-colored, granular superficial region

Medulla – exhibits cone-shaped medullary (renal) pyramids

Pyramids are made up of parallel bundles of urine-collecting tubules

Renal columns are inward extensions of cortical tissue that separate the pyramids

The medullary pyramid and its surrounding capsule constitute a lobe

Renal pelvis – flat, funnel-shaped tube lateral to the hilus within the renal sinus

Major calyces – large branches of the renal pelvis

Collect urine draining from papillae

Empty urine into the pelvis

Urine flows through the pelvis and ureters to the bladder

**Blood and Nerve Supply**

Approximately one-fourth (1200 ml) of systemic cardiac output flows through the kidneys each minute.

Arterial flow into and venous flow out of the kidneys follow similar paths

The nerve supply is via the renal plexus

**The Nephron**

Nephrons are the structural and functional units that form urine, consisting of:

Glomerulus – a tuft of capillaries associated with a renal tubule

Glomerular (Bowman's) capsule – blind, cup-shaped end of a renal tubule that completely surrounds the glomerulus

**The Nephron**

Renal corpuscle – the glomerulus and its Bowman's capsule

Glomerular endothelium – fenestrated epithelium that allows solute-rich, virtually protein-free filtrate to pass from the blood into the glomerular capsule

**Anatomy of the Glomerular Capsule**

The external parietal layer is a structural layer

The visceral layer consists of modified, branching epithelial podocytes

Extensions of the octopus-like podocytes terminate in foot processes

Filtration slits – openings between the foot processes that allow filtrate to pass into the capsular space

**Renal Tubule**

Proximal convoluted tubule (PCT) – composed of cuboidal cells with numerous microvilli and mitochondria

Reabsorbs water and solutes from the filtrate and secretes substances into it

Loop of Henle – a hairpin-shaped loop of the renal tubule

The proximal part is similar to the proximal convoluted tubule

The proximal part is followed by the thin segment (simple squamous cells) and the thick segment (cuboidal to columnar cells)

Distal convoluted tubule (DCT) – cuboidal cells without microvilli that function more in secretion than reabsorption

**Connecting Tubules**

The distal portion of the distal convoluted tubule nearer to the collecting ducts

Two important cell types are found here

Intercalated cells - Cuboidal cells with microvilli which have a function in maintaining the acid-base balance of the body

Principal cells - Cuboidal cells without microvilli that help maintain the body's water and salt balance

**Nephrons**

Cortical nephrons – 85% of nephrons; are located in the cortex

Juxtamedullary nephrons:

Are located at the cortex-medulla junction

Have loops of Henle that deeply invade the medulla

Have extensive thin segments

Are involved in the production of concentrated urine

**Capillary Beds of the Nephron**

Every nephron has two capillary beds

Glomerulus

Peritubular capillaries

Each glomerulus is:

Fed by an afferent arteriole

Drained by an efferent arteriole

**Capillary Beds of the Nephron**

Blood pressure in the glomerulus is high because:

Arterioles are high-resistance vessels

Afferent arterioles have larger diameters than efferent arterioles

Fluids and solutes are forced out of the blood throughout the entire length of the glomerulus

**Capillary Beds**

Peritubular beds are low-pressure, porous capillaries adapted for absorption that:

Arise from efferent arterioles

Cling to adjacent renal tubules

Empty into the renal venous system

Vasa recta – long, straight efferent arterioles of juxtamedullary nephrons

**Vascular Resistance in Microcirculation**

Afferent and efferent arterioles offer high resistance to blood flow

Blood pressure declines from 95mm Hg in renal arteries to 8 mm Hg in renal veins

**Vascular Resistance in Microcirculation**

Resistance in afferent arterioles:

Protects glomeruli from fluctuations in systemic blood pressure

Resistance in efferent arterioles:

Reinforces high glomerular pressure

Reduces hydrostatic pressure in peritubular capillaries

**Juxtaglomerular Apparatus (JGA)**
Where the distal tubule lies against the afferent (sometimes efferent) arteriole

Arteriole walls have juxtaglomerular (JG) cells

Enlarged, smooth muscle cells

Have secretory granules containing renin

Act as mechanoreceptors

**Juxtaglomerular Apparatus (JGA)**

Macula densa

Tall, closely packed distal tubule cells

Lie adjacent to JG cells

Function as chemoreceptors or osmoreceptors

Mesangial cells:

Have phagocytic and contractile properties Influence capillary filtration

**Filtration Membrane**

Filter that lies between the blood and the interior of the glomerular capsule

It is composed of three layers

Fenestrated endothelium of the glomerular capillaries

Visceral membrane of the glomerular capsule (podocytes)

The basement membrane is composed of fused basal laminae of the other layers

**Mechanisms of Urine Formation**

The kidneys filter the body's entire plasma volume 60 times each day

The filtrate:

Contains all plasma components except protein

Loses water, nutrients, and essential ions to become urine

The urine contains metabolic wastes and unneeded substances

**Mechanisms of Urine Formation**

Urine formation and adjustment of blood composition involves three major processes

1. Glomerular filtration
2. Tubular reabsorption
3. Secretion

**Glomerular Filtration**

Principles of fluid dynamics that account for tissue fluid in all capillary beds apply to the glomerulus as well

The glomerulus is more efficient than other capillary beds because:

Its filtration membrane is significantly more permeable

Glomerular blood pressure is higher

It has a higher net filtration pressure

Plasma proteins are not filtered and are used to maintain the oncotic pressure of the blood

**Net Filtration Pressure (NFP)**

The pressure responsible for filtrate formation NFP equals the glomerular hydrostatic pressure (hpg) minus the oncotic pressure of glomerular blood (opg) combined with the capsular hydrostatic pressure (hpc) NFP = HP g – (opg + hpc)

**Glomerular Filtration Rate (GFR)**

The total amount of filtrate formed per minute by the kidneys

Factors governing filtration rate at the capillary bed are:

Total surface area available for filtration

Filtration membrane permeability

Net filtration pressure

**Glomerular Filtration Rate (GFR)**

GFR is directly proportional to the NFP

Changes in GFR normally result from changes in glomerular blood pressure

**Regulation of Glomerular Filtration**

If the GFR is too high:

Needed substances cannot be reabsorbed quickly enough and are lost in the urine

If the GFR is too low:

Everything is reabsorbed, including wastes that are normally disposed of

Three mechanisms control the GFR

Renal autoregulation (intrinsic system)

Neural controls

Hormonal mechanism (the renin-angiotensin system)

**Intrinsic Controls**

Under normal conditions, renal autoregulation maintains a nearly constant glomerular filtration rate

Autoregulation entails two types of control

Myogenic – responds to changes in pressure in the renal blood vessels

Flow-dependent tubuloglomerular feedback – senses changes in the juxtaglomerular apparatus

**Extrinsic Controls**

When the sympathetic nervous system is at rest:

Renal blood vessels are maximally dilated

Autoregulation mechanisms prevail

**Extrinsic Controls**

Under stress:

Norepinephrine is released by the sympathetic nervous system

Epinephrine is released by the adrenal medulla

Afferent arterioles constrict and filtration is inhibited

The sympathetic nervous system also stimulates the renin-angiotensin mechanism

The **renin-angiotensin-aldosterone system (RAAS)** is a crucial hormonal mechanism that regulates **blood pressure, fluid balance, and electrolyte homeostasis**. It is activated primarily in response to **hypovolemia**, **hypotension**, or **sodium depletion**.

## Activation of RAAS

The system is initiated when **juxtaglomerular (JG) cells** of the afferent arterioles in the kidney secrete **renin**, an enzyme that catalyzes the cascade.

Renin Release: Triggers

Renin is secreted in response to three main stimuli:

1. **Reduced renal perfusion pressure** (hypotension) sensed as **decreased stretch of JG cells** (intrarenal baroreceptor mechanism)
2. **Decreased sodium chloride concentration** at the macula densa of the distal tubule, which stimulates JG cells via tubuloglomerular feedback
3. **Sympathetic nervous system activation**, specifically **?1-adrenergic receptor stimulation** on JG cells by renal sympathetic nerves

## Biochemical Cascade

1. **Renin** converts **angiotensinogen** (produced by the liver) into **angiotensin I**
2. **Angiotensin I** is then converted into **angiotensin II** by **angiotensin-converting enzyme (ACE)**, primarily in the pulmonary endothelium

## Actions of Angiotensin II

Angiotensin II is a **potent vasoconstrictor** and has several critical physiological effects:

- **Increases systemic vascular resistance (SVR)** ? elevates **mean arterial pressure (MAP)**
- **Stimulates the adrenal cortex (zona glomerulosa)** to secrete **aldosterone**, which:
  - Increases sodium and water reabsorption in the distal nephron
  - Promotes potassium and hydrogen ion excretion

- **Enhances proximal tubular sodium reabsorption**
- **Stimulates thirst** via the hypothalamus and promotes **antidiuretic hormone (ADH)** release from the posterior pituitary
- **Constriction of efferent arterioles** of the glomerulus ? increases **glomerular capillary hydrostatic pressure** and helps maintain **glomerular filtration rate (GFR)** despite low renal perfusion

## Net Effects of RAAS Activation

- **Increased blood volume and blood pressure**
- **Restoration of renal perfusion**
- **Homeostasis of sodium and potassium levels**