Excretion and urinary system

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Excretion takes place by

- the skin (excess water and salts)
- respiratory system (CO_2)
- the release of bilirubin and biliverdin from liver into bile
- urinary system which has an essential role in removing waste products from the body.

- Urinary System
  It consists of two kidneys, two ureters, urinary bladder and urethra.

The human kidneys are two bean-shaped organs, one on each side of the backbone. Kidneys weight is about 300 g.
They represent about 0.4 - 0.5% of the total weight of the body, but receive 20–25% of the total arterial blood pumped by the heart. Each kidney contains one million nephrons which are the structural and functional units.
The kidneys are present in the dorsal region of the abdominal cavity on the two sides of the vertebral column just behind the liver. Each kidney consists of an outer thinner layer, the cortex and an inner layer, the medulla and pelvis.

ANATOMY OF THE KIDNEYS

- **paired organs that lie in the anterior dorsal region in the abdominal cavity just behind the liver on the two sides of the vertebral column.**

1. HILUM

- **medial portion of the kidneys which contain the renal blood vessels, nerves and the renal pelvis**

2. RENAL PELVIS

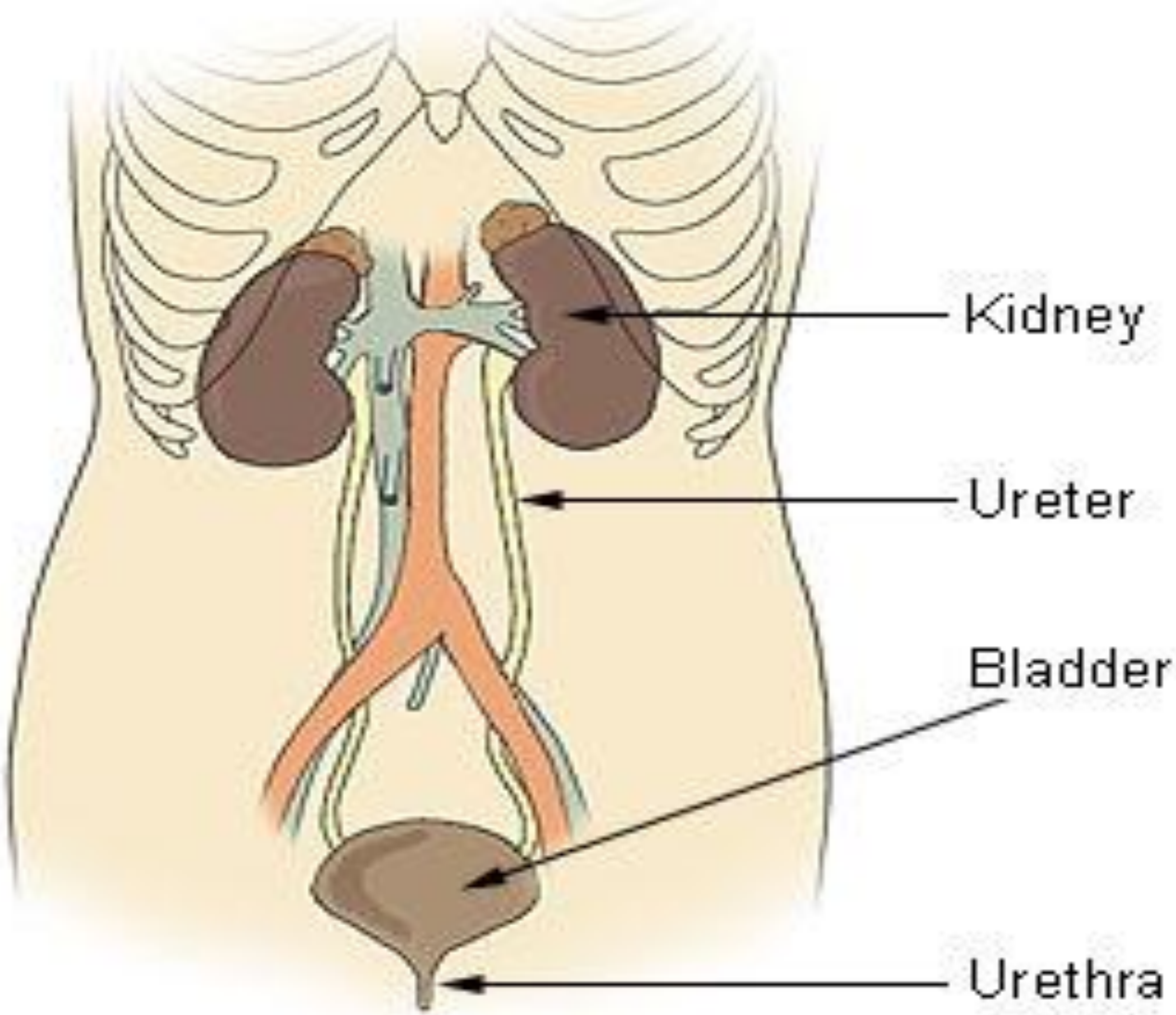
- **It is funnel shaped continuation of the upper ends of the ureters**
- **It is subdivided into the Major Calyx which in turn is subdivided further into the Minor Calyx which collects urine from the tubules of the papilla**
- **walls of pelvis, calices and ureters contain contractile elements that propel urine towards the bladder**

- Two ureters collect urine from the kidney and extend downward to open into urinary bladder. The length of each ureter is 25-30 cm and the thickness is 3 mm.
- The urinary bladder is a thin walled sac that collects urine to a volume of 200-300 ml untill micturition occurs. It opens into urethra which has two sphincters, internal and external sphincters.

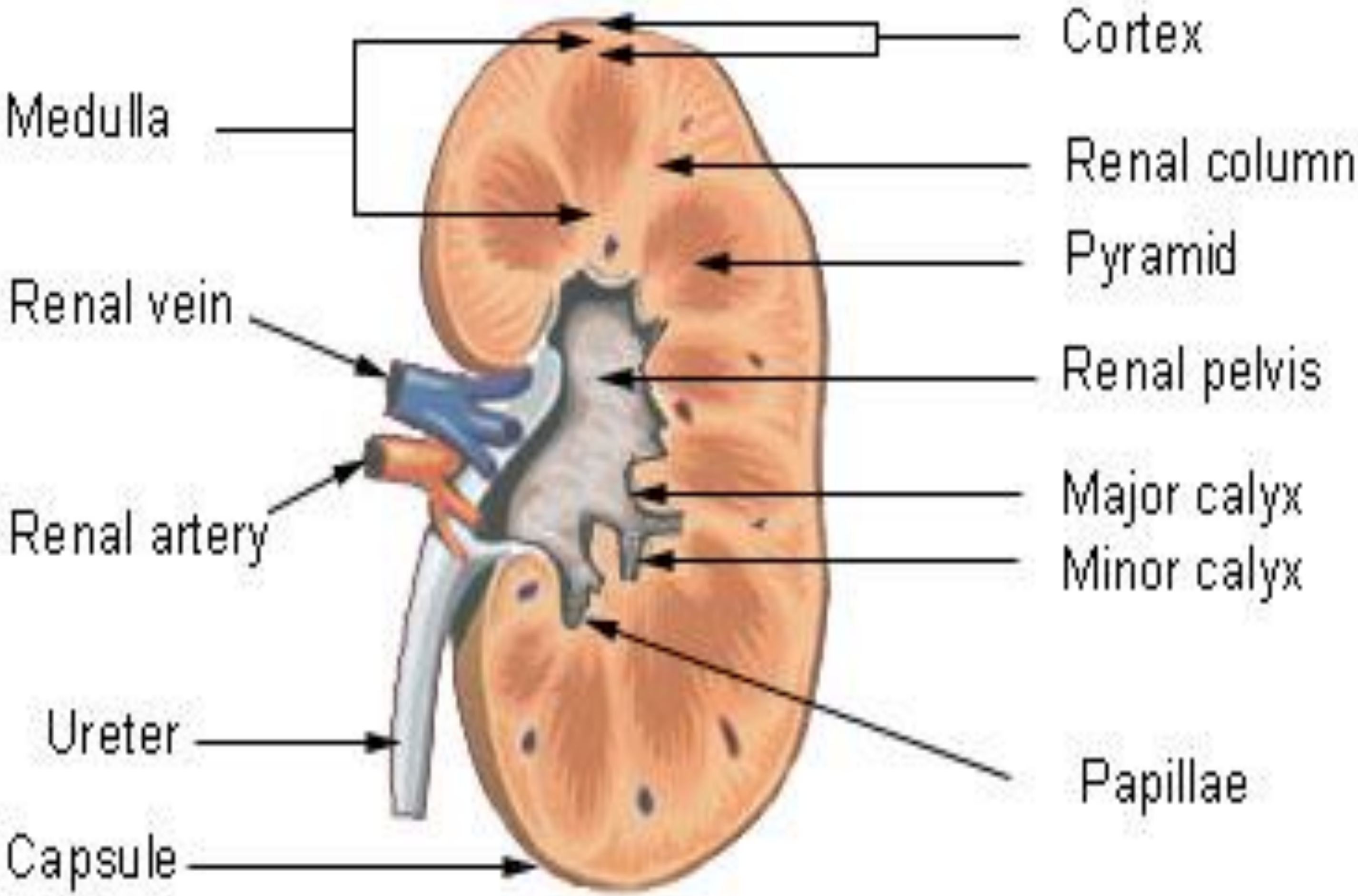
Renal Blood Supply

Renal artery coming from aorta - afferent arteriole - glomerular capillaries - efferent arteriole - peritubular capillary network - venules - renal vein - inferior vena cava.

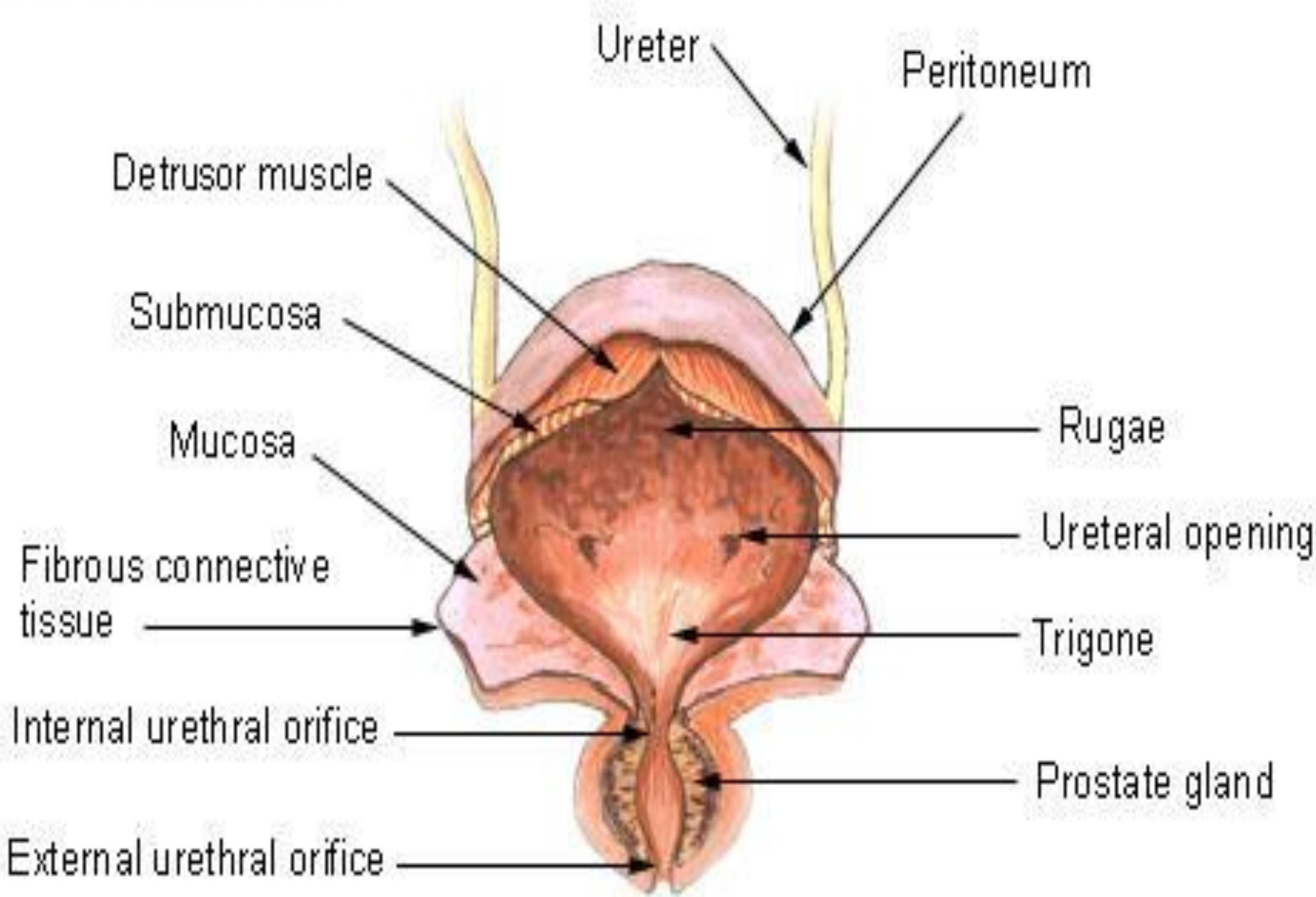
Components of the Urinary System



Frontal section through the Kidney



Urinary Bladder

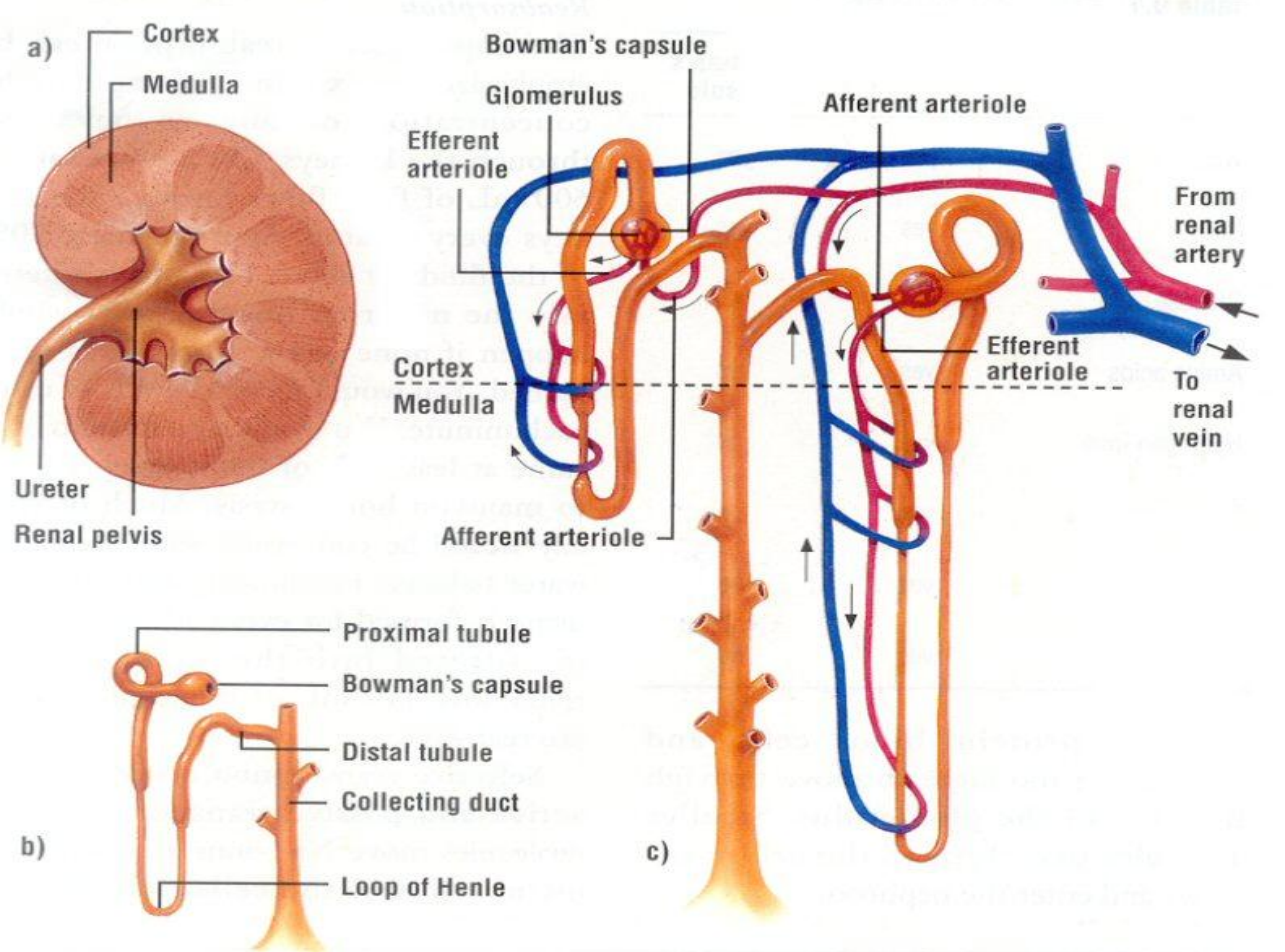


The nephron which is the functional and structural unit of kidney consists of:

- Malpighian (renal) corpuscle which is composed of glomerulus and Bowman’s capsule.

- Tubular part which is composed of proximal convoluted tubule, loop of Henle and distal convoluted tubule.

The nephrons open into collecting ducts which pour urine into pelvis of the kidney.



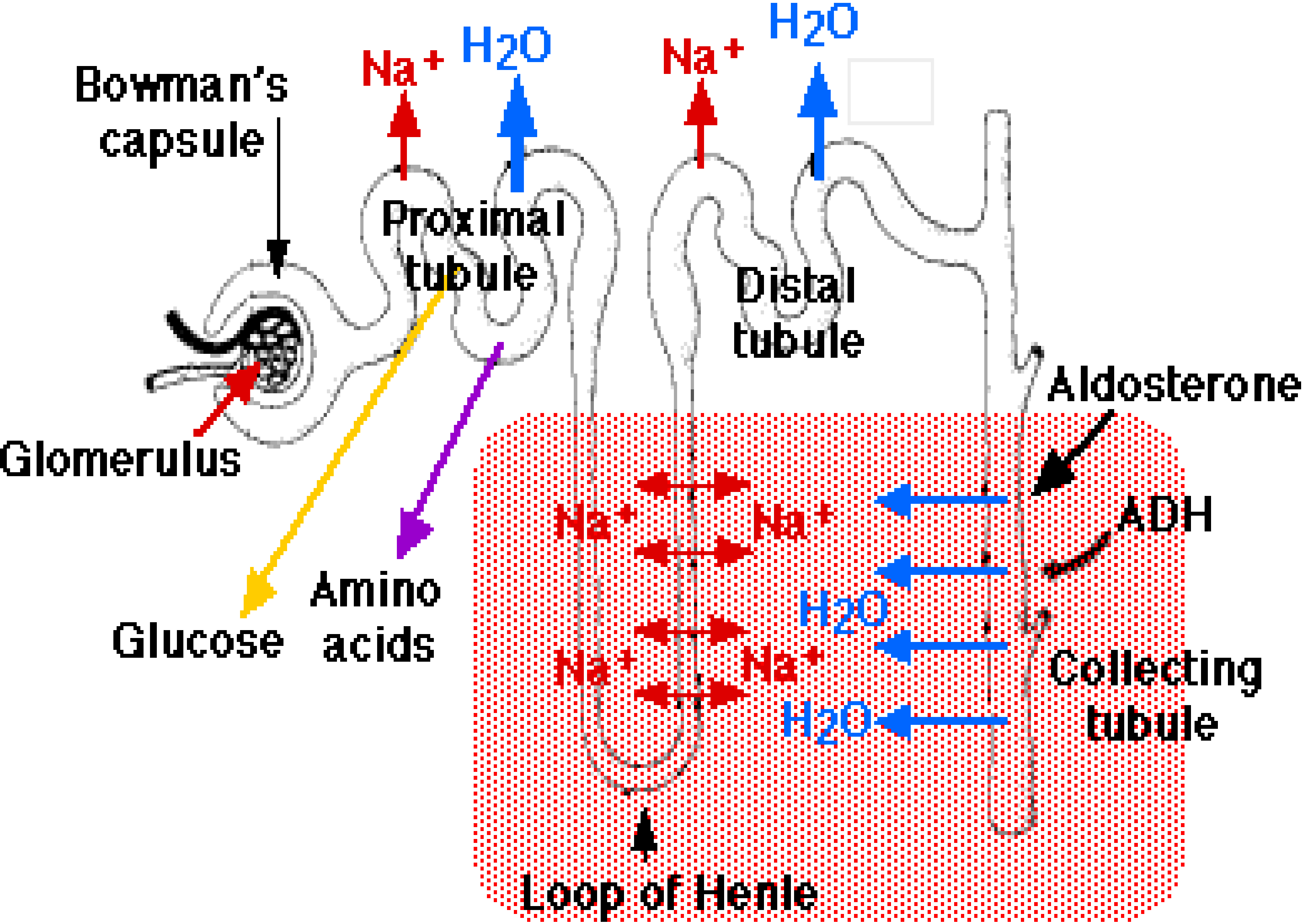
a)
Cortex
Medulla
Ureter
Renal pelvis
Bowman's capsule
Glomerulus
Efferent arteriole
Afferent arteriole
From renal artery
Efferent arteriole
To renal vein
Cortex
Medulla
Afferent arteriole
Proximal tubule
Bowman's capsule
Distal tubule
Collecting duct
b)
Loop of Henle
c)

Categories of Nephrons

1. Superficial cortical nephrons
• located within 1 mm of the capsular surface
• short-looped nephrons which makes a hairpin loop just above the junction between the outer and inner medulla

2. Midcortical nephrons
either short- or long- looped

3. Juxtamedullary nephrons
• located just above the junction between cortex and medulla
• long-looped nephrons which extends into the inner medulla


Bowman's capsule
Na+
H2O
Na+
H2O
Proximal tubule
Distal tubule
Glomerulus
Aldosterone
ADH
Na+
Na+
H2O
Na+
Na+
H2O
Glucose
Amino acids
Collecting tubule
Loop of Henle

Urine formation

Three processes take place in the nephron to form urine:

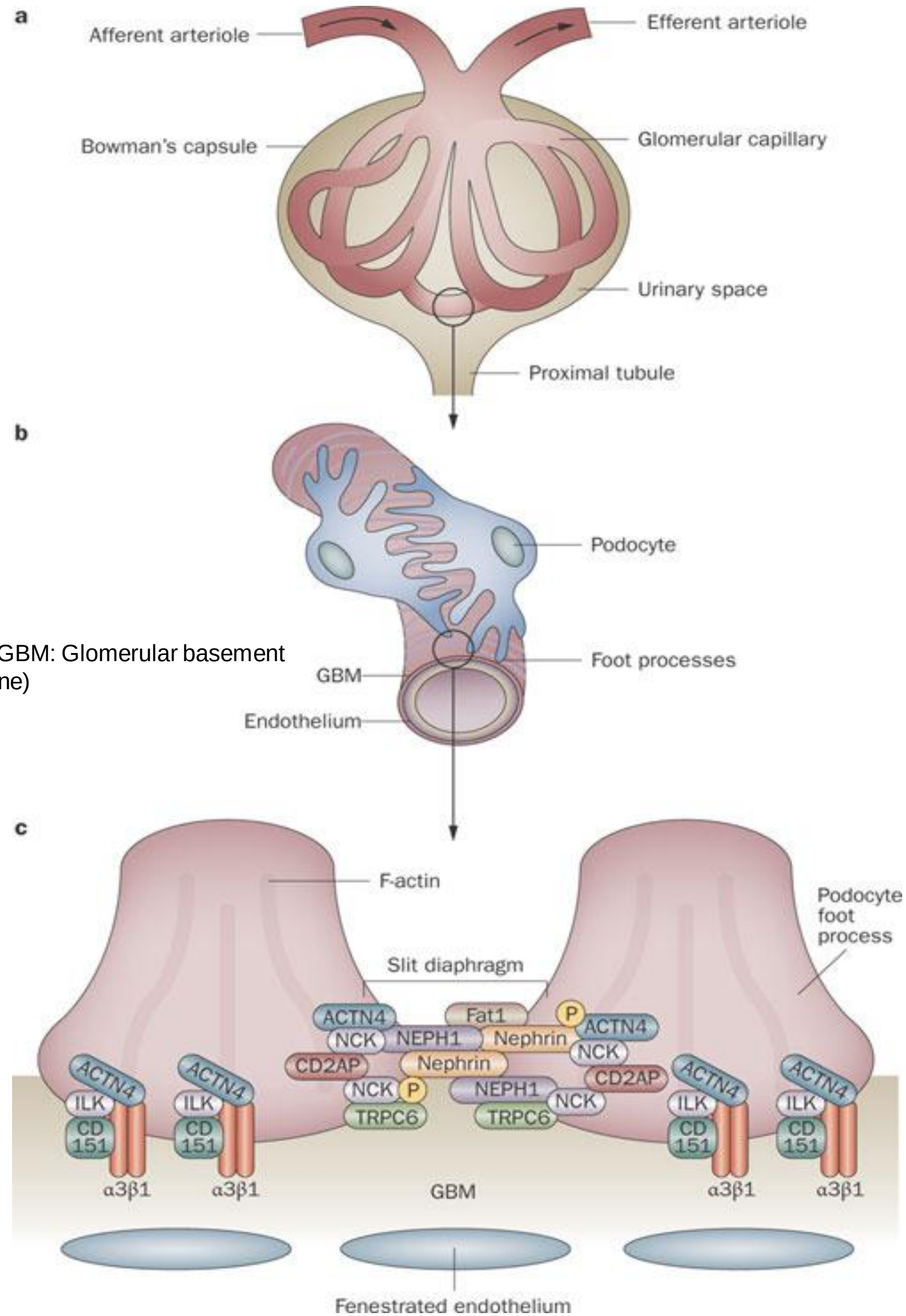
- Glomerular filtration
- Tubular reabsorption
- Tubular secretion

The Filtration Barrier

1. CAPILLARY ENDOTHELIUM
   - endothelial cells are perforated by numerous holes or fenestrae
2. BASEMENT MEMBRANE
   - gel-like acellular meshwork of glycoproteins and proteoglycans
   - effectively prevents filtration of proteins in part due to the strong negative charge of the proteoglycans
   - the primary restriction point for plasma proteins
3. EPITHELIAL CELL LAYER OF THE BOWMAN'S CAPSULE Consists of visceral layer (PODOCYTES) and parietal layer
   - epithelial cells (podocytes) posses numerous extensions called foot processes or pedicels
   - foot processes from adjacent podocytes interdigitate extensively with each other

Slit Pore:

- gaps between foot processes through which glomerular filtrate moves
- selectively permeable



(GBM: Glomerular basement membrane)

Filtration barrier

Glomerular filtration

Three pressures are found in the region of the glomerulus and Bowman's capsule

- capillary blood pressure = +70mm Hg (results from pumping of blood by the heart through the afferent arteriole which has a caliber wider than that of the efferent arteriole).
- capsular hydrostatic back pressure = -5 mm Hg
- colloidal osmotic blood pressure = -30 mm Hg (due to presence of colloidal proteins in the blood)

The net pressure = +70-5-30 = + 35 mm Hg, which is directed from glomerulus to Bowman's capsule. This pressure causes filtrations of most constituents of blood except erythrocytes, leucocytes, platelets, plasma proteins like albumin, globulin, fibrinogen and prothrombin.

Net filtration pressure = force favouring filtration – force opposing filtration

- Force favouring filtration: glomerular capillary pressure
- Forces opposing filtration: capsular hydrostatic pressure of capsular fluid and colloidal osmotic pressure of blood

Another reference indicates that (1)
- glomerular hydrostatic pressure= 60mmHg
- capsular hydrostatic pressure = 18 mmHg
- plasma colloidal osmotic pressure= 32mmHg

Net filtration pressure= 60-18-32= 10mmHg

(2) Net filtration pressure = 55-15-30= 10mmHg

Factors Which Determines Filterability

1**. SIZE** (molecular radius or molecular weight)

• between 7,000 and 70,000, filterability becomes progressively smaller as the molecule becomes larger

2. **ELECTRICAL CHARGE**

• negatively charged macromolecules are filtered to a lesser extent and positively charged macromolecules are filtered to a greater extent than neutral molecules

3. **PROTEIN BINDING**

• the protein-bound moiety does not filter across the membrane

• the unbound (free) solute is freely-filterable

DETERMINANTS OF GLOMERULAR FILTRATION RATE (GFR)

GFR = K_f x NFP (Net filtration pressure) - Normal GFR: 125 ml/ min. or 180 L/24 hours

1. Filtration Coefficient K_f

Normal kidney K_f = 12.5 ml/min/mmHg of filtration pressure

Increase K_f increase GFR

Decrease K_f decrease GFR

2. Glomerular Capillary Hydrostatic Pressure (P_{GC})

The primary means for physiological regulation of GFR:

• increased P_{GC} increase GFR

• decreased P_{GC} decrease GFR

3. Bowman's Capsule Hydrostatic Pressure (P_{BC})

increased P_{BC} ↓ GFR

decreased P_{BC} ↑ GFR

4. Glomerular Capillary Oncotic Pressure (Π_{GC})

↑ Π_{GC} ↓ GFR

Physiological control of glomerular filtration rate and renal blood flow

1.Autoregulation of GFR and RBF

intrinsic mechanism in the kidney that keeps the RBF and GFR relatively constant despite marked changes in arterial blood pressure

Mechanisms of Autoregulation

1. Myogenic mechanism
2. Tubuloglomerular feedback (TGF)

Myogenic Mechanism

based on contraction of vascular smooth muscle in response to increased stretch:

Tubuloglomerular Feedback (TGF)

↑ tubular flow leading to ↑ Na^+ and Cl^- concentration leading to ↑ production of a vasoconstrictor (Adenosine) that acts on the afferent arteriole leading to decrease RBF and ↓ GFR

Importance of autoregulation:

a. prevents major blood flow changes

b. prevents large changes in water and solute excretion

2. Sympathetic Nervous Control

A. DIRECT EFFECTS

1. Strong activation of the renal sympathetic nerves cause vasoconstriction of afferent and efferent arterioles ↓ RBF and ↓ GFR

2. Mild or moderate sympathetic stimulation has little influence on RBF and GFR:

B. INDIRECT EEFFECTS

Sympathetic nerves also stimulate renin secretion leading to ↑ Angiotensin II leading to renal arteriolar vasoconstriction

3.Hormonal and Autocoid Control of Renal Circulation

1. NOREPINEPHRINE and EPINEPHRINE
2. ENDOTHELIN
3. ENDOTHELIAL DERIVED RELAXING FACTOR (EDRF, Nitric Oxide)
4. PROSTAGLANDINS (PGE_2 , PGI_2)
5. ANTI-DIURETIC HORMONE (ADH, Vasopressin)
6. ADENOSINE
7. ATRIAL NATRIURETIC FACTOR (ANF)
8. ANGIOTENSIN II

RENAL TUBULE

A) PROXIMAL CONVOLUTED TUBULE

- cuboidal cells with brush borders (microvilli) in the luminal surface

B) LOOP OF HENLE

1. THICK DESCENDING LIMB

2. THIN DESCENDING LIMB

3. THIN ASCENDING LIMB

4. THICK ASCENDING LIMB

C) DISTAL CONVOLUTEDTUBULE

- last segment of the nephron proper

- pyramidal cells without brush borders

- opens into collecting duct in the medulla.

- the collecting ducts runs in cortex and medulla to open into calices

Tubular reabsorption

- In the proximal convoluted tubule, obligatory reabosrption occurs. 70-80% of water, minerals, glucose, amino acids, etc are reabsorbed under the rules of simple diffusion and osmosis.

In the ascending limb of loop of Henle, sodium is reabsorbed by active transport to the blood and to the fluid around loop of Henle. As a result, water is passively transported from filtrate in descending limb to the blood. There is a counter current system in loop of Henle.

- In the distal convoluted tubule, selective reabosrption occurs according to the need of the body.This is under the control of different hormones.

Reabsorption and secretion along different parts of the nephron

PROXIMAL TUBULE

Sodium Reabsorption

65% of filtered sodium is reabsorbed in the proximal tubule
accompanied by an anion

Water Reabsorption

65% of filtered water is reabsorbed in the proximal tubule

proximal tubule is highly permeable to water

Reabsorption of Glucose and Amino Acid

over 99% of filtered glucose and amino acids are normally reabsorbed by the proximal tubule coupled to reabsorption of Na^+ via the Na^+-solute symport mechanism

Reabsorption and Secretion of Urea

urea is the major end-product of protein metabolism

reabsorption of urea is completely dependent on water

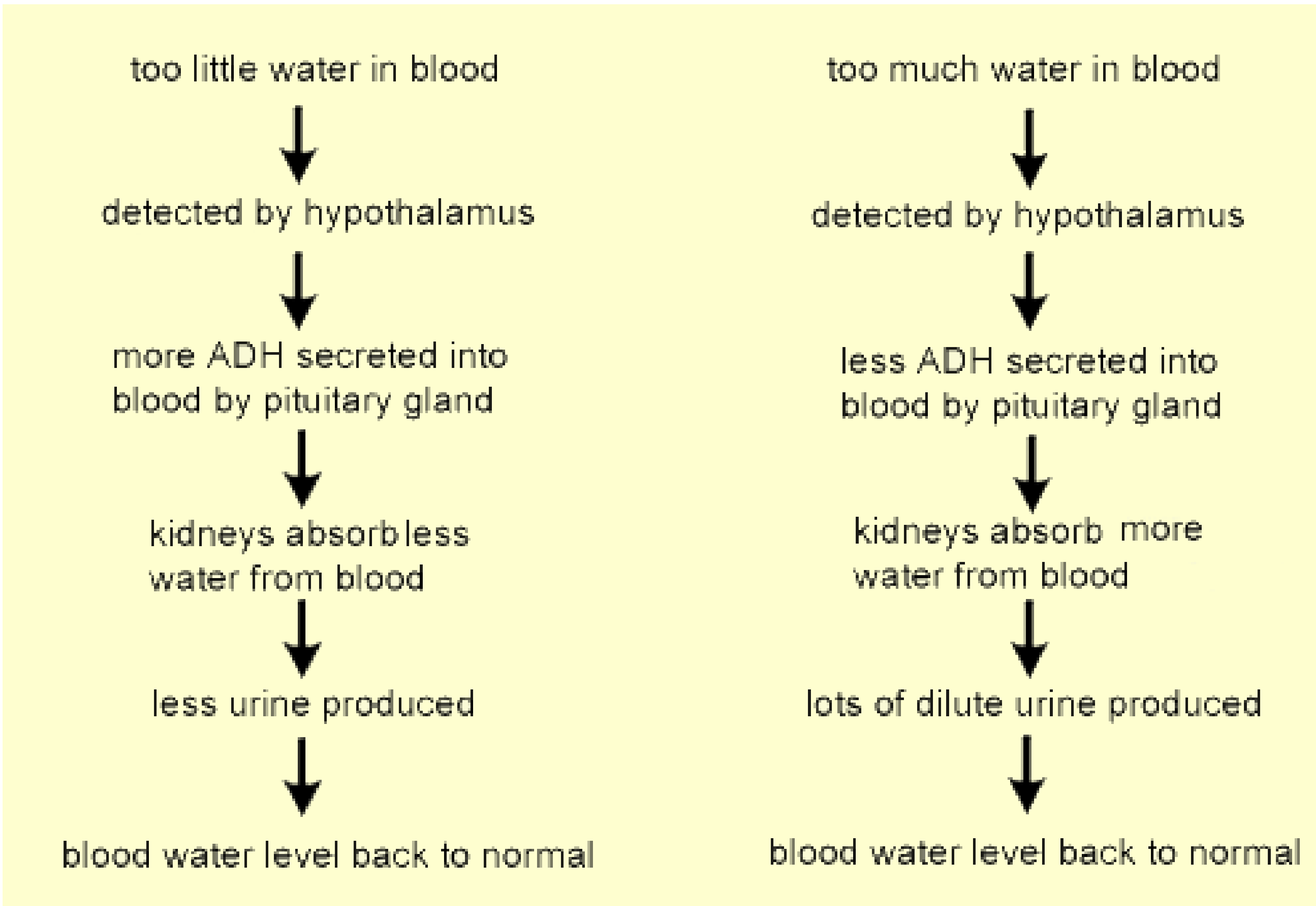
50% of filtered urea is reabsorbed by the proximal tubule

In distal convoluted tubules and collecting tubules

- Decrease of water in the blood (dehydration) leads to stimulation of osmoreceptors in the wall of blood vessels of hypothalamus which increases the synthesis and secretion of antidiuretic hormone (ADH) from the posterior lobe of pituitary gland. ADH, in turn, increases the reabsorption of water from distal convoluted tubule and collecting tubule to the blood (the urine will be concentrated).

- Increase of water in the blood (overhydration) leads to decrease in the secretion of antidiuretic hormone from the posterior lobe of pituitary gland. This, in turn, decreases the reabsorption of water from distal convoluted tubule and collecting tubule to the blood (the urine will be more diluted).

How does it work?



- Decrease of sodium in the blood stimulates renin in the juxtaglomerular apparatus stimulating the formation and secretion of angiotensin from cells of this apparatus. This latter hormone stimulates the secretion of aldosterone from adrenal cortex. Aldosterone activates the reabsorption of sodium from distal and collecting tubule to return its level to normal. This process is followed by increase in the reabsorption of water to blood. The reverse action occurs when sodium is increased in blood above normal level.

JUXTAGLOMERULAR APPARATUS

Components:

1- Macula Densa cells very short segment of the distal convoluted tubule that comes in contact with the vascular pole of the glomerulus

2. Granular cells (juxtaglomerular or JG cells)

    1. differentiated smooth muscle cells in the walls of the arterioles, particularly in the afferent arteriole
    2. granular appearance is due to secretory granules containing renin precursors

3. Extraglomerular mesangial cells (agranular cells)

Renin

It is proteolytic enzyme produced by the juxtaglomerular apparatus

It catalyzes the formation of angiotensin I from angiotensinogen.

Angiotensin Converting Enzyme (ACE)

- found mostly in endothelial surface of most blood vessels
- converts Angiotensin I to Angiotensin II

Functions of Angiotensin II:

1. increase arterial blood pressure

2. sodium retention

Tubular secretion

- H^+ is secreted to regulate the pH of the blood.
- K^+ is secreted into filtrate in exchange of Na^+.
- Some drugs are removed by secretion from blood into filtrate.

Urinary excretion rate= filtration rate – reabsorption rate + secretion rate

Glomerular filtration rate = K_f x net filtration pressure

The substances reabsorbed form the nephron tubules, are classified into two categories according to their ability to be reabsorbed:

- High threshold substances: The tubules have great ability to reabsorb them (glucose, amino acid, vitamins and mineral salts).
- Low threshold substances: The tubules have less ability to reabsorb them (uric acid, urea and creatinine).

RENAL INNERVATION

- kidneys has a rich supply of sympathetic neurons which are distributed to the afferent and efferent arterioles, juxtaglomerular apparatus and many portions of the tubule

- no significant parasympathetic innervation

FUNCTIONS OF THE KIDNEYS

1. Regulation of water and inorganic ion balance

2. Removal of metabolic waste products from blood and their excretion in urine

3. Removal of foreign chemicals from blood and their excretion in the urine

4. Gluconeogenesis

- **synthesis of glucose from proteins and other precursors**

5. Regulation of arterial pressure

- **kidneys play a dominant role in the long-term regulation of arterial pressure by excreting variable amounts of sodium and water**
- **contribute to short-term arterial pressure regulation by secreting vasoactive factors such as renin which causes the formation of angiotensin II**

6. Secretion of hormones (Renin, Erythropoietin, 1,25 Dihydroxy vitamin D3)

Micturition

http://msjensen.cehd.umn.edu/1135/Links/Animations/Flash/0041-swf_micturition_re.swf

Micturition (Urination)

The nerves supplying the bladder and urethra belong to the autonomic and somatic nervous system respectively. The mechanisms of urination are under the control of voluntary and reflex action. As the urinary bladder becomes full, the stimulation of mechanoreceptors (stretch receptors) in its wall triggers evacuation reflexes with a resulting of vesical contraction, the internal sphincter relaxation (autonomic reflexes) and evacuation. While urination is initiated by reflex action, it can be inhibited by external sphincter contraction (somatic reflexes) which prevents internal sphincter relaxation.

- Sensory signals from bladder stretch receptors are conducted to the sacral segment of the spinal cord through pelvic nerves (afferent fibres) and then reflexively back again to the bladder through the parasympatheic nerve fibres (efferent fibres) by way of these same nerves which leads to contraction of the bladder and opening of internal sphincter.

- Entry of urine to urethra will stimulate the stretch receptors present in the posterior urethra. The somatic afferent fibres (pudic) carry impulses from here. So the external sphincter relaxes and the urine gets voided from the body.

- In infants, the reflex is involuntary, but in children after two years and in adults, the process is controlled and the reflex can be inhibited by higher centers in the brain.

- Sympathetic supply to the urinary bladder comes from the lumbar segment