Lecture # 38

Functional organization of the kidney and renal blood flow

Objectives:

1. Describe the different types of the nephron.
2. Describe the functions of juxtaglomerular apparatus and its physiological significance.
3. Know the blood and nerve supply to the kidneys.
4. Know the different functions of the kidneys.

Reference book: Kaplan USMLE step 1Lecture note 2021 (pages # 189-203)

The kidneys are primarily responsible for the maintenance of the internal environment of the human body. The kidney composed of cortex and medulla.

Table 38. 1: Difference between cortex and medulla.

Item	Cortex	Medulla
Blood supply	Rich in blood supply 95-98%	Poor in blood supply 2-5%
Contents	Glomeruli Proximal convoluted tubules (PCT) & distal convoluted tubules (DCT). Cortical collecting tubules (CCT). Peritubular capillaries	Loop of Henle (LOH). Distal convoluted tubules (DCT). Medullary collecting tubules (MCT). Vasa recta

TYPES OF NEPHRONS: There are 2 types

1. Cortical nephrons. **2. Juxtamedullary nephrons**.

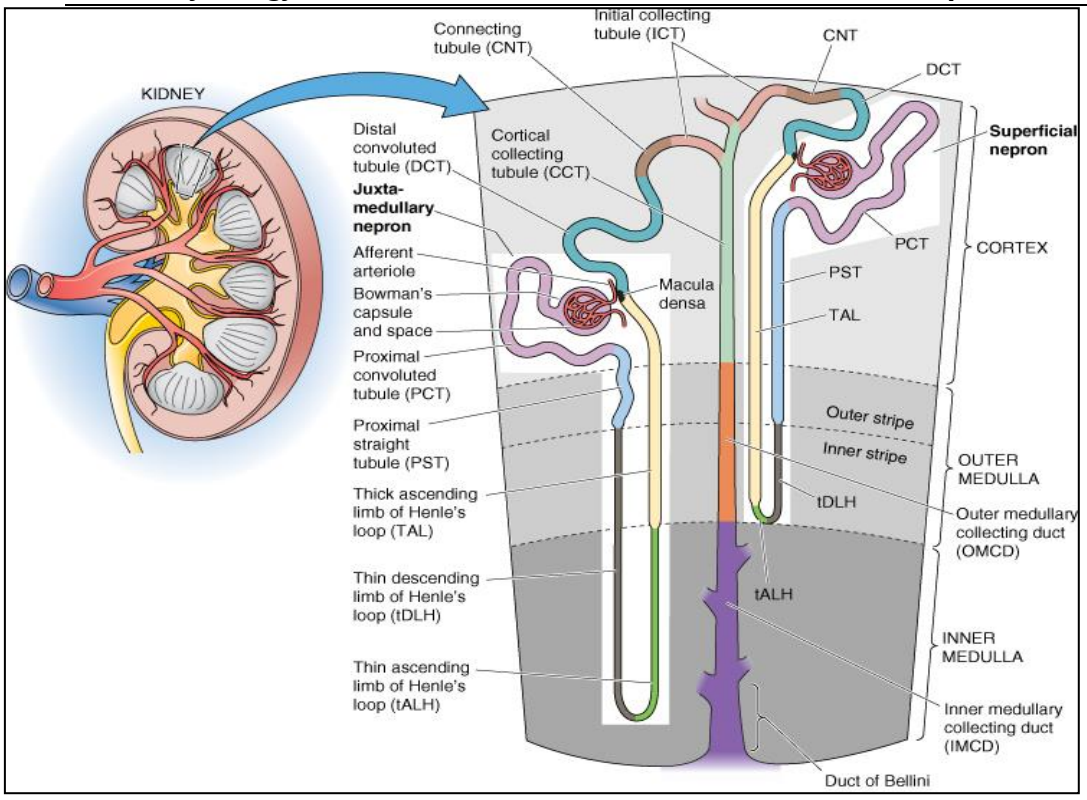


Figure 38. 1: Cortical and juxtamedullary nephron.

Table 38. 2**:** Difference between cortical and juxta-medullary nephrons.

Item	**Cortical nephrons**	**Juxta-medullary nephrons**
Number	About 85%	About 15%
Site of glomeruli	Outer cortex	Inner cortex
Loop of Henle	Short reaches inner strip of outer medulla	Long reaches renal papilla
Capillaries	Peritubular capillaries	Peritubular capillaries and Vasa recta
Juxta glomerular apparatus	Present	Not present
Autoregulation	Present	Not present
Afferent arterioles	Thick wall rich in sympathetic nervous system fibers.	Thin wall poor in sympathetic nervous system fibers.
Efferent arterioles	Thin wall, little muscles in its wall.	Thick muscle wall Sensitive to sympathetic nervous system, and vasopressin → vasoconstriction. Sensitive to prostaglandin → vasodilatation.
Functions	Formation of urine mainly Na^+ reabsorption.	Concentration of urine (H_2O reabsorption) or dilution of urine (H_2O secretion).

JUXTAGLOMERULAR APPERATUS (JGA):

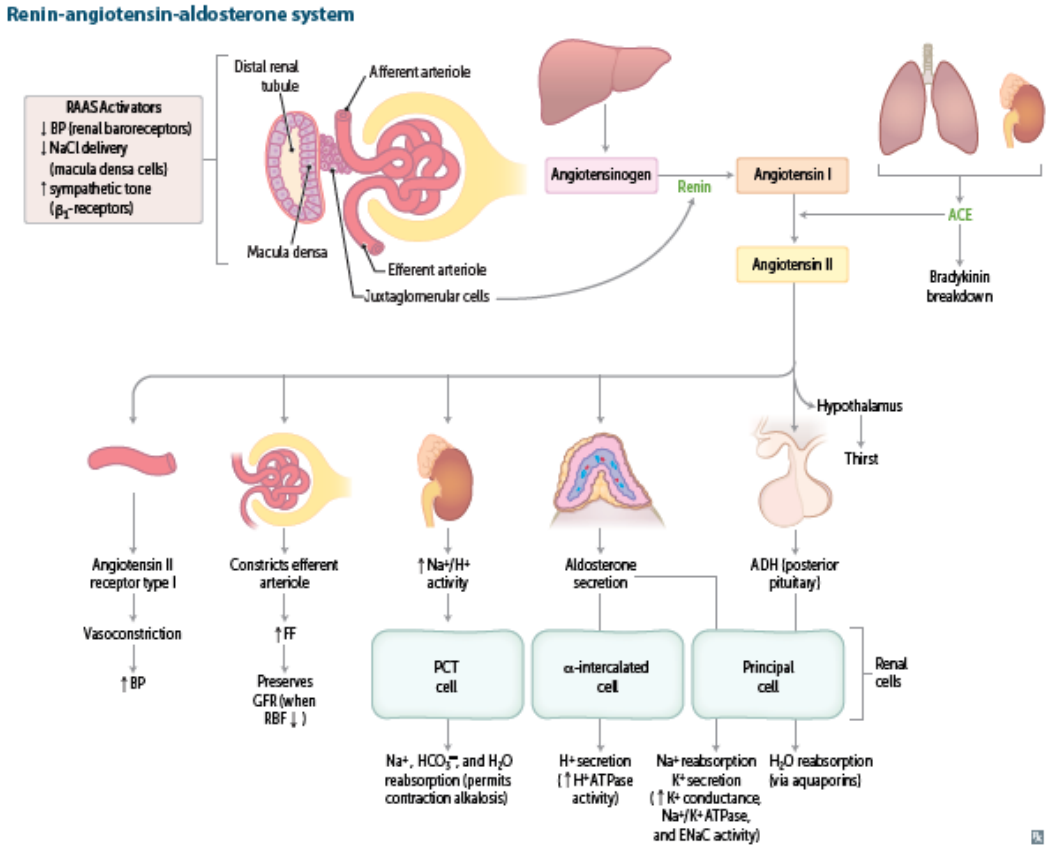
JGA are specialized tubular & vascular cells at area of contact between DCT and afferent and efferent arterioles at vascular pole, where they enter & leave the glomerulus.

Functions of different components of JGA:

1. ***Juxtaglomerular cells,*** these cells can **form & release renin**. They act as *baroreceptors* stimulated by *decreased* renal perfusion or by hypovolemia.
2. ***Macula densa,*** they monitor composition of tubular fluid i.e. function as *chemoreceptor* that are stimulated by *decrease* of *NaCL load in DCT*.
3. ***Lacis cells***, these exhibit *phagocytic activity*.

FUNCTIONS OF JGA:

It acts as *autoregulation* of renal blood flow and glomerular filtration during decrease in arterial blood pressure by secreting renin.



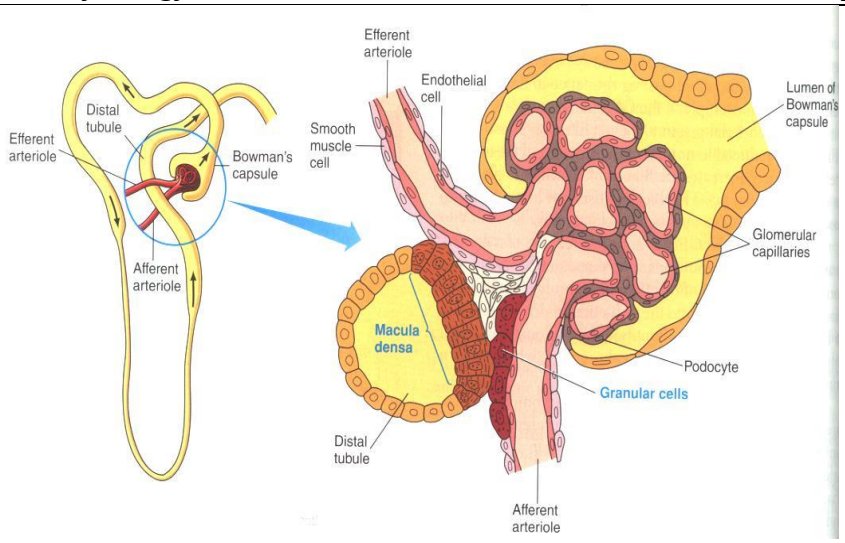


Figure 38. 2: Juxtaglomerular apparatus.

RENAL VASCULATURE:

ARTERIAL SUPPLY:

- The kidneys receive *20%–25% of cardiac output*, which corresponds to 1000–1200 ml/minute, but only account for about *10% of oxygen* consumption of body. **About 90%** of **renal blood** supply goes to **cortex and about 5-10%** goes to **medulla**.
- The renal arteries arise from abdominal aorta. Each *renal artery* divides into five ***segmental arteries*** which branches within renal sinus into ***interlobar* arteries**. At medulla-cortex junction, interlobar arteries branch into ***arcuate arteries*** that arch over bases of medullary pyramids. Small *cortical radiate arteries* radiate outward from arcuate arteries to supply cortical tissue. Then they give rise to ***interlobular*** *arteries*, which penetrate cortex perpendicularly toward surface and then give rise to ***afferent arterioles***. The latter divided to form ***glomerular capillary tuft*** which join at their outflow ends to form ***efferent arteriole***. This vessel divides at its outflow to form ***peritubular capillaries***. The efferent arterioles also give rise to ***vasa recta*** that accompanied loop of Henle in *juxtamedullary nephrons only.*

Table 38. 3**:** Capillary bed related to each nephron.

Item	**Glomerular capillary bed**	**Peritubular capillary bed**
Blood supply	Received blood from afferent arterioles.	Received blood from efferent arterioles
Pressure	High pressure bed 60 mmHg	Low pressure bed 13 mmHg
Representation	Arterial end of capillaries.	Venous end of capillaries
Function	Allow fluid filtration	Allow fluid reabsorption.

VENOUS DRAINGE:

Veins pretty much trace pathway of arterial supply in reverse. The renal veins issue from the kidneys and empty into the *inferior vena cava*.

The pressure in the glomerular capillary bed is high due to:

a. Renal artery is a direct branch of the abdominal aorta.

b. Afferent arteriole is a short straight branch of the interlobular arteries.

c. Efferent arteriole has higher resistance than the afferent arteriole.

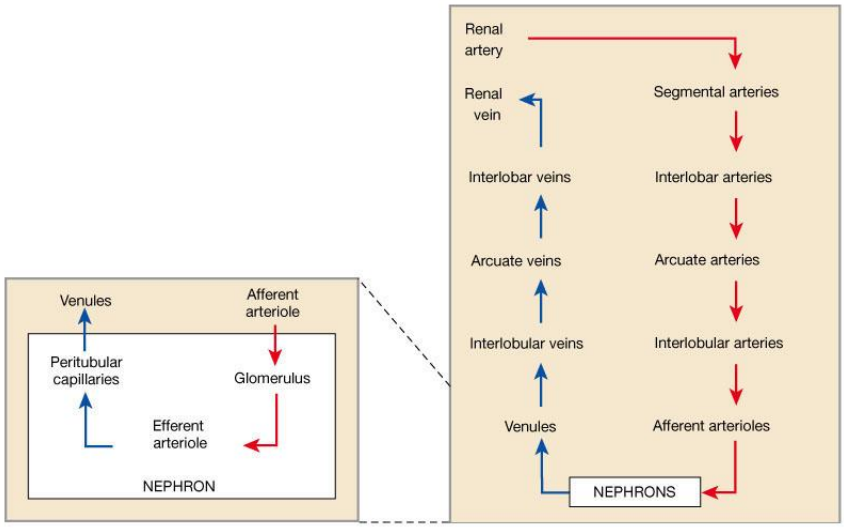


Figure 38. 3: Blood supply of the kidney.

LYMPHATICS:

Lymphatic are very *rich in cortex* and *poor in medulla*.

RENAL INNERVATION:

Afferent nerves: These accompany the sympathetic efferent nerves and they *mediate pain and reno-renal reflexes*.

Efferent sympathetic nerves: kidney received mostly *sympathetic* efferent nerves from greater splanchnic nerves (T6-T12). It is distributed

to supply glomerular arterioles, PCT & DCT, juxtaglomerular cells & thick ascending limb of LOH.

Stimulation of the renal sympathetic nerves leads to:

a. Vasoconstriction of the glomerular arterioles via alpha adrenergic receptors.

b. Increased renin secretion via beta-1 adrenergic receptors.

c. Increased Na^+ reabsorption by renal tubules via alpha or beta adrenergic receptors or both.

FUNCTIONS OF THE KIDNEY

The following are specific functions performed by the kidneys, most of which are directed toward preserving constancy of internal fluid environment (homeostasis):

1) REGULATORY FUNCTIONS:

a. Regulation of electrolyte balance: kidneys regulate quantity and concentration of most extracellular fluid electrolytes (e.g. sodium, chloride, potassium, calcium, etc…) by excreting them in amounts adequate to maintain their normal concentrations in extracellular fluid (ECF).

b. Regulation of water balance: kidneys maintain water balance in the body, which is important in maintaining proper ECF osmolality (concentration of solutes) and stability of cell volume by preventing cells from swelling or shrinking as a result of water osmotically moving in or out of cells, respectively.

c. Regulation of arterial blood pressure: ***short term regulation*** by renin angiotensin system. ***Long term regulation*** via excretion of variable amounts of sodium and water to keep plasma volume constant.

d. Regulation of acid-base balance: kidneys contribute to maintenance of proper pH of the blood, along with lungs and body fluid buffers, by

eliminating excess H^+ (acid) or HCO_3^- (base) in urine, regulation of buffer stores, formation of ammonia.

2) EXCRETORY FUNCTIONS:

a. Excretion of metabolic waste products: These include urea (from protein), uric acid (from nucleic acids), creatinine (from muscle creatine), and the end products of hemoglobin breakdown, which gives urine its yellow color.

b. Excretion of many foreign chemicals such as drugs, food additives, pesticides, and other exogenous non-nutritive materials.

3) ENDOCRINE FUNCTIONS:

a. Erythropoietin: It is a glycoprotein hormone that is **secreted by endothelial cells of peritubular capillaries** in renal cortex in response to hypoxia. ***Erythropoietin*** exerts its action through ***Erythropoietin* receptors** on the surface of **proerythroblasts** in the bone marrow. This accelerates the **maturation of proerythroblasts** (to their erythroblastic stage). In the absence of ***Erythropoietin***, few red blood cells (RBCs) are formed by the bone marrow. About **90%** of erythropoietin is **secreted by kidney and 10% by liver cells**.

b. Renin: it is **secreted by juxtaglomerular cells**. It is **glycoprotein** enzymatic hormone, that is synthesized from preprorenin (inactive form), which is converted to prorenin (inactive form) then to active renin. Renin **initiates renin-angiotensin-aldosterone** pathway for controlling renal tubular Na^+ reabsorption.

c. 1,25 dihydroxy vitamin D_3: **Vitamin D** and parathyroid hormone (PTH) are critical for regulating calcium and phosphate metabolism. Vitamin D is a fat-soluble vitamin that is mainly produced in the skin by ultraviolent (UV)-B light conversion of 7-dehydrocholesterol or ingested in the diet or dietary supplements. Vitamin D is stored in the liver in its inactive form, 25-OH-cholecalciferol; its activation depends on the plasma Ca^{2+} concentration. Decreased plasma Ca^{2+} levels stimulate PTH

secretion, which activates ***1α-hydroxylase enzyme*** secreted by PCT in the kidneys. This in turn enables the hydroxylation of 25-OH-cholecalciferol into 1,25-(OH)2-cholecalciferol (physiologically active form of vitamin D3), which increases intestinal absorption of Ca^{2+} and decreases renal Ca^{2+} excretion.

d. Prostaglandins (PG):

1. PGE_2: this is predominantly secreted by **type-1 medullary interstitial cells** and by **cells of collecting ducts.**

2. PGI_2 (prostacyclin) and other PGs: They are **secreted** by the **glomerular arterioles** and **certain glomerular cells**.

Renal PGs act locally in kidney and concerned mainly with autoregulation of glomerular filtration rate (GFR) and renal blood flow (RBF). Prostaglandins **PGE_2** and **PGI_2, <u>dilate</u>** the afferent arterioles to increase RBF and GFR.

e. **Dopamine:** Secreted by PCT cells, promotes natriuresis (increase sodium excretion in urine). **At low doses**; **dilates** interlobular arteries, afferent arterioles, efferent arterioles leads to increase renal blood flow (RBF), little or no change in glomerular filtration rate (GFR). **At higher doses**; acts as **vasoconstrictor**.

f. **Catabolism of polypeptide hormones** as parathyroid hormone and insulin.

4) <u>METABOLIC FUNCTIONS:</u> Gluconeogenesis: during **prolonged fasting**, the kidneys **synthesize glucose** from amino acids and other precursors and release it into the blood.