Renal system

Renal system includes:
1. A pair of kidneys.
2. Ureters.
3. Urinary bladder.
4. Urethra.

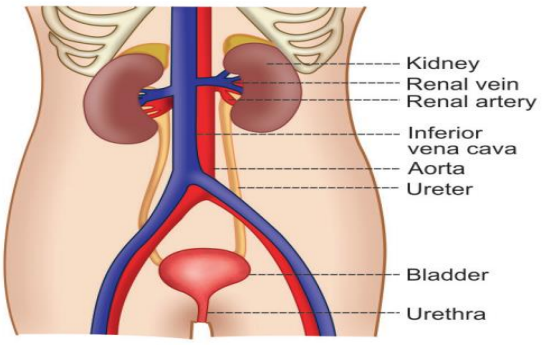

FIGURE 38.1: Urinary system

Kidneys produce the urine. Ureters transport the urine to urinary bladder. Urinary bladder stores urine until it is emptied. Urine is emptied from bladder through urethra (Fig. 38.1).

- **FUNCTIONS OF KIDNEY** Kidneys perform several functions besides formation of urine, excreting urine, kidneys play the principal role in homeostasis. Thus, the functions of kidneys are detailed below.

- **1. ROLE IN HOMEOSTASIS** The primary function of kidneys is homeostasis. During the formation of urine, kidneys regulate various activities in the body, which are concerned with homeostasis as detailed below.

I. Excretion of waste products which are formed during metabolic activities:
a. Urea: End product of amino acid metabolism.
b. Uric acid: End product of nucleic acid metabolism.
c. Creatinine: End product of metabolism in muscles.
d. Bilirubin: End product of hemoglobin degradation.
e. Products of metabolism of other substances.
f. Harmful foreign chemical substances: Toxins, drugs, heavy metals, etc.

II. Maintenance of Water Balance
Kidneys maintain the water balance in the body by conserving water when it is decreased and excreting water when it is excess in the body.

III. Maintenance of Electrolyte Balance
Especially sodium is in relation to water balance. Kidneys retain sodium if the osmolarity of body water decreases and eliminate sodium when osmolarity increases.

IV. Maintenance of Acid-base Balance

The pH of the blood and body fluids should be maintained within narrow range for healthy living. It is reached by the function of kidneys. Body is under constant danger to develop acidosis, because of production of lot of acids during metabolic activities. However, it is prevented by kidneys, lungs and blood buffers, which eliminate these acids. Among these organs, kidneys play major role in preventing acidosis.

- **2. HEMATOPOIETIC FUNCTION**

  Kidneys stimulate the production of erythrocytes by secreting erythropoietin(EPO). EPO is the important stimulating factor for erythropoiesis. Kidney also secretes another factor called **thrombopoietin**, which stimulates the production of thrombocytes (platelets).

- **3. ENDOCRINE FUNCTION**

  The hormones secreted by kidneys are:
  I. Erythropoietin.
  II. Thrombopoietin.
  III. Renin.
  IV. 1,25-dihydroxycholecalciferol (calcitriol).
  V. Prostaglandins.

- **4. REGULATION OF BLOOD PRESSURE**

  Kidneys play an important role in long-term regulation of arterial blood pressure by two ways by regulating ECF volume and through renin-angiotensin mechanism.

- **5. REGULATION OF BLOOD CALCIUM LEVEL**

  Kidneys play a role in the regulation of blood calcium level by activating 1,25-dihydroxycholecalciferol into vitamin D. Vitamin D is necessary for the absorption of calcium from intestine.

FUNCTIONAL ANATOMY OF KIDNEY

Kidney is a compound tubular gland covered by a connective tissue capsule. There is a depression on the medial border of kidney called hilum, through which renal artery, renal veins, nerves and ureter pass.

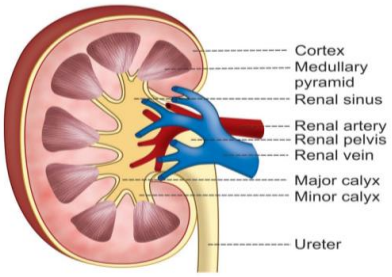

FIGURE 38.2: Longitudinal section of kidney

DIFFERENT LAYERS OF KIDNEY

The components of kidney are arranged in three layers (Fig. 38.2):
1. Outer cortex.
2. Inner medulla.
3. Renal sinus.

1. Outer Cortex

Cortex is dark and granular in appearance. It contains renal **corpuscles** and **convoluted tubules**. At intervals, cortical tissue penetrates medulla in the form of **columns**, which are called **renal columns**.

2. Inner Medulla

Medulla contains tubular and vascular structures arranged in parallel radial lines.
It is divided into 8 to 18 medullary or **Malpighian pyramids**.

3. Renal sinus

consists of the following structures:
i. Upper part of ureter called **renal pelvis.**
ii. Subdivisions of pelvis, **2 or 3 major calyces** and about **8 minor calyces**.
iii. Branches of nerves and arteries and tributaries of veins.
iv. Loose connective tissues and fat.

PARENCHYMA OF KIDNEY

Parenchyma of kidney is made up of tubular structures called uriniferous tubules. The uriniferous tubules are of **two types:**
1. Terminal or secretary tubules called nephrons, which are concerned with formation of urine.
2. Collecting ducts or tubules which are concerned with transport of urine from nephrons to pelvis of ureter. The collecting ducts unite to form ducts, which open into minor calyces through papilla.

Nephron

Nephron is the structural and functional unit of kidney. Each kidney consists of ***1 to 1.3 million of nephrons***. The number of *nephrons decreases in old age*. Each nephron is formed by two parts (Fig. 39.1):
1. A blind end called ***renal corpuscle or Malpighian corpuscle***.
2. A tubular portion called ***renal tubule.***

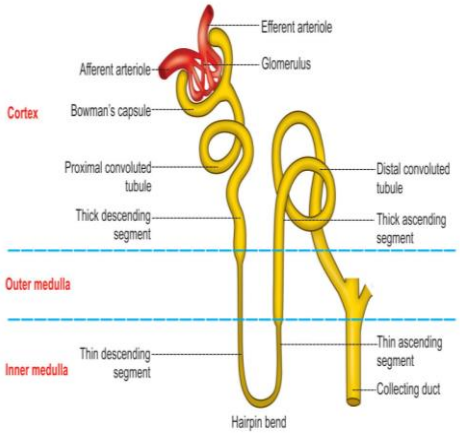

FIGURE 39.1: Structure of nephron

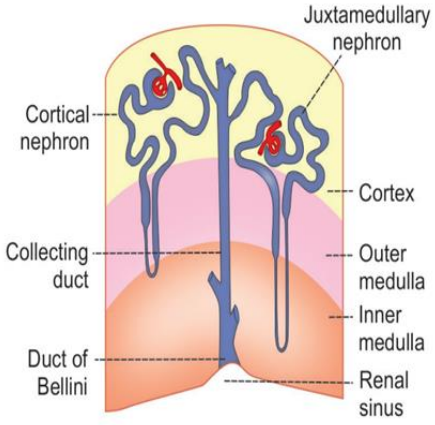

FIGURE 39.2: Types of nephron

RENAL CORPUSCLE

The renal corpuscle is also known as ***Malpighian corpuscle***. It is a spheroidal and slightly flattened structure with a diameter of *about 200 µ*. The function of the renal corpuscle is the filtration of blood which forms the first phase of urine formation.

SITUATION OF RENAL CORPUSCLE AND TYPES OF NEPHRON

Renal corpuscle is ***situated in the cortex*** of the kidney *either near the periphery* or *near the medulla.* Based on the situation of renal corpuscle, the nephrons are classified into two types:

1. Cortical nephrons or superficial nephrons.

2. Juxtamedullary nephrons.

1.Cortical Nephrons

Cortical nephrons are the nephrons, which have their corpuscles in the outer cortex of the kidney *near the periphery* (Fig. 39.2). In human kidneys ***85% nephrons are cortical nephrons.***

2. Juxtamedullary Nephrons

The nephrons which have their corpuscles *in the inner cortex near medulla*. The features of the two types of nephrons are given in Table 39.1.

TABLE 39.1: Features of two types of nephron

Features	Cortical nephron	Juxtamedullary nephrons
Situation of renal corpuscle	Outer cortex near the periphery	Inner cortex near medulla
Loop of Henle	Short	Long
	Hairpin bend penetrates only up to outer zone of medulla	Hairpin bend penetrates up to the tip of papilla
Blood supply to tubule	Peritubular capillaries	Vasa recta
Function	Formation of urine	Mainly the concentration of urine and formation of urine

STRUCTURE OF RENAL CORPUSCLE

The renal corpuscle is formed by two portions:

1. Glomerulus.
2. Bowman's capsule.

Glomerulus: is a *tuft of capillaries enclosed by Bowman's capsule*. These capillaries are predisposed between afferent arteriole efferent arteriole. Thus, the vascular system in the glomerulus is purely arterial (Fig. 39.3). The glomerular capillaries arise from the afferent arteriole. After entering the Bowman's capsule, the afferent arteriole divides into many small capillaries. These small capillaries are arranged in irregular loops and form anastomosis. All the smaller capillaries finally reunite to form the efferent arteriole which leaves the Bowman's capsule. ***The diameter of the efferent arteriole is less than that of afferent arteriole***. This difference in diameter has functional significance. The *capillaries are made up of single layer of endothelial cells* which are *attached to a basement membrane*. The *endothelium has many pores called fenestra or filtration pores*. The *diameter of each pore is* ***0.1 µ.*** The *presence of the fenestra is evidence of the filtration function of the glomerulus.*

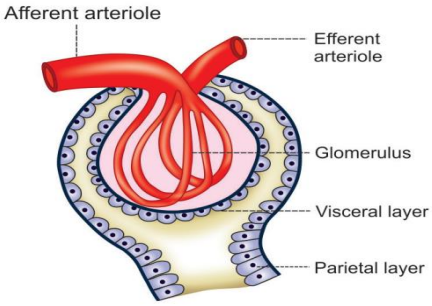

FIGURE 39.3: Renal corpuscle

Bowman's Capsule

Bowman's capsule encloses the glomerulus. The structure of Bowman's capsule is similar to a funnel with filter paper. *Its diameter is 200 µ*. It is **formed by two layers:** 1. The inner visceral layer. 2. The outer parietal layer. **Visceral layer** covers the glomerular capillaries. It is continued as the parietal layer at the visceral pole. The parietal layer is continued with the wall of the tubular portion of nephron. The cleft-like space between the visceral and parietal layers is continued as the lumen of the tubular portion.

Both the layers of Bowman's capsule are composed of a *single layer of flattened epithelial cells resting on a basement membrane.* The basement membrane of the visceral layer fuses with the basement membrane of glomerular capillaries on which the capillary endothelial cells are arranged. Each cell is connected with the basement membrane by *cytoplasmic extensions of epithelial cells called* ***pedicles*** *or feet.* These pedicles are arranged in an interdigitating manner *leaving small cleft-like spaces* in between. The *cleft-like space is called* ***slit pore***. The epithelial cells with pedicles are *called* ***podocytes*** (Fig. 39.4).

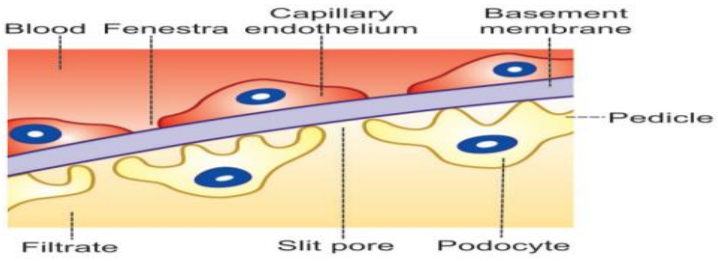

FIGURE 39.4: Filtering membrane in renal corpuscle. It is formed by capillary endothelium on one side (red) and visceral layer of Bowman's capsule (yellow) on the other side.

TUBULAR PORTION OF NEPHRON

The tubular portion of nephron is the continuation of Bowman's capsule. It is made up of three parts:
1. The proximal convoluted tubule.
2. Loop of Henle.
3. The distal convoluted tubule.

PROXIMAL CONVOLUTED TUBULE

It is the coiled portion *arising from Bowman's capsule*. It is *situated in the cortex*. It is *continued as* ***descending limb of loop of Henle***. *Length of proximal convoluted tubule* ***is 14 mm*** *and the diameter* ***is 55 µ***. *Proximal convoluted tubule is formed by single layer of* ***cuboidal epithelial cells***. The *special feature of these cells is the presence of hair-like projections directed towards the lumen of the tubule*. Because of the presence of these projections, the *epithelial cells are called brush-bordered cells*.

LOOP OF HENLE

Loop of Henle consists of:
i. Descending limb.
ii. Hairpin bend.
iii. Ascending limb.

Descending Limb

Descending limb of loop of Henle *is made up of* ***thick descending*** *segment* ***and thin descending segment.*** The thick descending segment is the direct continuation of the proximal convoluted tubule. *It descends down into medulla*. *It has a length of 6 mm and a diameter of 55 µ. The thick descending segment of Henle's loop is continued as thin descending segment* (Fig. 39.5).

Hairpin Bend

The *thin descending segment is continued as hairpin bend of the loop*. *The hairpin bend is continued as the ascending segment of loop of Henle.*

Ascending Limb
Ascending limb of Henle's loop **has two parts**, *thin ascending segment* and *thick ascending segment.* Thin ascending segment is the continuation of hairpin bend. The thin ascending segment is continued as thick ascending segment. *It is about 9 mm long with a diameter of 30 µ.* Thick ascending segment ascends to the cortex and continues as distal convoluted tubule. The total length of thin descending segment, hairpin bend and thin ascending segment of Henle's loop 10 to 15 mm and the diameter is 15 µ.
The length and the extent of the loop of Henle vary in different nephrons:
1.In ***cortical nephrons, it is short*** and ***the hairpin bend penetrates only up to outer medulla.*** 2. In ***juxtamedullary nephrons, this is long*** and ***the hairpin bend extends deep into the inner medulla.*** In some nephrons it even runs up to the papilla.

Functional Histology Thick descending segment is formed by brush-bordered cuboidal epithelial cells. Thin descending segment, hairpin bend and thin ascending segment are lined by flattened epithelial cells without brush border. Thick ascending segment is lined by cuboidal epithelial cells without brush border. The terminal portion of thick ascending segment which runs between the afferent and efferent arterioles of the same nephrons forms the macula densa. Macula densa is the part of juxtaglomerular apparatus.

DISTAL CONVOLUTED TUBULE
It is the continuation of thick ascending segment and occupies the cortex of kidney. It is continued as collecting duct. The length of the distal convoluted tubule is 14.5 to 15 mm. It has a diameter of 22 to 50 µ.
Functional Histology
Distal convoluted tubule is *lined by single layer of cuboidal epithelial cells without brush border.* The epithelial cells in distal convoluted tubule are *called intercalated cells (I cells)*.

COLLECTING DUCT
The distal convoluted tubule continues as the initial or arched collecting duct, which is in cortex. The lower part of the collecting duct lies in medulla. 7 to 10 initial collecting ducts unite to form the straight collecting duct, which passes through medulla. The length of the collecting duct is 20 to 22 mm. The diameter of collecting duct varies between 40 and 200 µ.

Functional Histology
The collecting duct is formed by cuboidal or columnar epithelial cells. The epithelial cells of collecting duct are of two types:
1. The principal or P cells. 2. Intercalated or I cells

Passage of Urine.
At the inner zone of medulla, the straight collecting ducts from each medullary pyramid unite to form ***papillary ducts*** or *ducts of Bellini*, which open into the ***papilla***. Papilla collects the urine from each medullary pyramid and drains into ***a minor calyx***. Three or four minor calyces unite to form one ***major calyx***.

Each kidney has got about ***8 minor calyces*** and ***2 to 3 major calyces***. The major calyces open into the pelvis of the ureter. The pelvis is the expanded portion of ureter present in the renal sinus. Through ureter, urine enters the urinary bladder

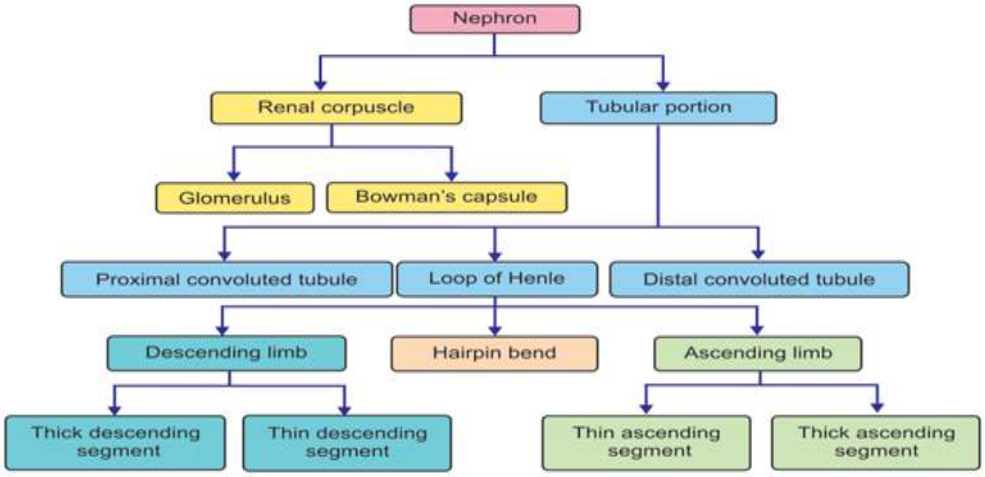

FIGURE 39.5: Parts of nephron

Juxtaglomerular Apparatus

Juxtaglomerular apparatus is a specialized organ situated near the glomerulus of each nephron (juxta = near).

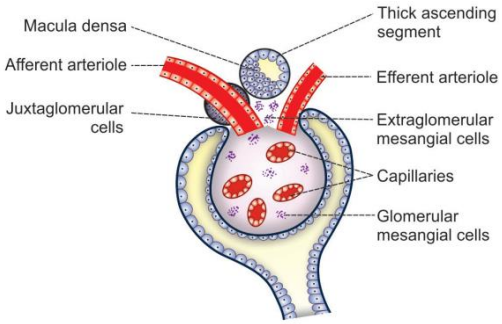

FIGURE 40.1: Juxtaglomerular apparatus

STRUCTURE

The juxtaglomerular apparatus is formed by three different structures (Fig. 40.1):

1. Macula densa. 2. Extraglomerular mesangial cells. 3. Juxtaglomerular cells.

1. MACULA DENSA

Macula densa is the ***terminal portion of thick ascending segment that runs in between afferent and efferent arterioles of the same nephron***. Actually, it is very close to afferent arteriole. In this part of thick ascending segment, the *cuboidal epithelial cells are tightly packed.* Macula densa plays an important role in tubuloglomerular feedback mechanism. It also secretes thromboxane A2.

2. EXTRAGLOMERULAR MESANGIAL CELLS

These cells are situated in the triangular region bound by afferent arteriole, efferent arteriole and macula densa. These cells are also called ***agranular cells***, ***lacis cells***. *mesangial cells secrete* ***prostaglandin*** *and* ***cytokines***.

Glomerular Mesangial Cells

Glomerular mesangial cells or *intraglomerular mesangial cells are situated in between the glomerular capillaries and form a cellular network which supports the capillary loops.* These cells are contractile in nature and play an important role in regulating the glomerular filtration. The *glomerular mesangial cells are also* ***phagocytic*** *and secrete matrix of glomerular interstitium*, prostaglandins and cytokines.

3. JUXTAGLOMERULAR CELLS

Juxtaglomerular cells are ***situated in the wall of afferent arteriole just before it enters the Bowman's capsule.*** This part of the afferent arteriole is *thickened like a cuff and it is called polar cushion* or polkissen.
Juxtaglomerular cells which are the *specialized type of smooth muscle cells derived from the tunica media and tunica adventitia of wall of the afferent arteriole*. Because of the presence of secretary granules in their cytoplasm, the juxtaglomerular cells are also called granular cells.

FUNCTIONS OF JUXTAGLOMERULAR APPARATUS

The primary function of juxtaglomerular apparatus is the secretion of hormonal substances. It also regulates the glomerular blood flow and glomerular filtration rate.

SECRETION OF RENIN

The juxtaglomerular cells secrete **renin**. Renin is a peptide with 340 amino acids. Along with angiotensins, renin forms the renin-angiotensin system which is a hormone system that plays an important role in the maintenance of blood pressure.

Stimulants for Renin Secretion

Secretion of renin is stimulated by four factors:
1. Fall in arterial blood pressure.
2. Reduction in the ECF volume.
3. Increased sympathetic activity.
4. Decreased load of sodium and chloride in macula densa.

Renin-angiotensin System When renin is released into the blood; it acts on a specific plasma protein called angiotensinogen or renin substrate. It is the α2 globulin. By the activity of renin, the angiotensinogen is converted into a *decapeptide (10)* called **angiotensin I**. Angiotensin I is converted into **angiotensin II** which is an *octapeptide(8)* by the activity of **angiotensin converting enzyme (ACE)** *secreted from lungs.*

Most of the conversion of angiotensin I into angiotensin II takes place in lungs. Angiotensin II has a short half-life of about 1 to 2 minutes. Then it is rapidly degraded into a heptapeptide(7) called angiotensin III by angiotensinases which are present in RBCs and vascular beds in many tissues. **Angiotensin III** is converted into **angiotensin IV** *which is a hexapeptide(6)* (Fig. 40.2).

Actions of Angiotensins

Angiotensin I It is physiologically i*nactive* and serves only as the precursor of angiotensin II.

Angiotensin II Angiotensin II is the *most active form*. Its actions are given below: **1. On blood vessels:**

i. Angiotensin II *increases arterial blood pressure by **directly acting on the blood** vessels and **causing vasoconstriction**.*

ii. It *increases blood pressure indirectly* also by increasing the release of *noradrenaline from postganglionic sympathetic fibers*. Noradrenaline is a general vasoconstrictor.

2. On adrenal cortex:

*It stimulates zona glomerulosa of **adrenal cortex** to secrete **aldosterone***. Aldosterone acts on renal tubules and increases retention of sodium which is also responsible for elevation of blood pressure.

3. On kidney:

i. Angiotensin II *regulates glomerular filtration rate by **two ways***:

a. It constricts the efferent arteriole which causes decrease in filtration after an initial increase.

b. It contracts the glomerular mesangial cells leading to decrease in surface area of glomerular capillaries and filtration

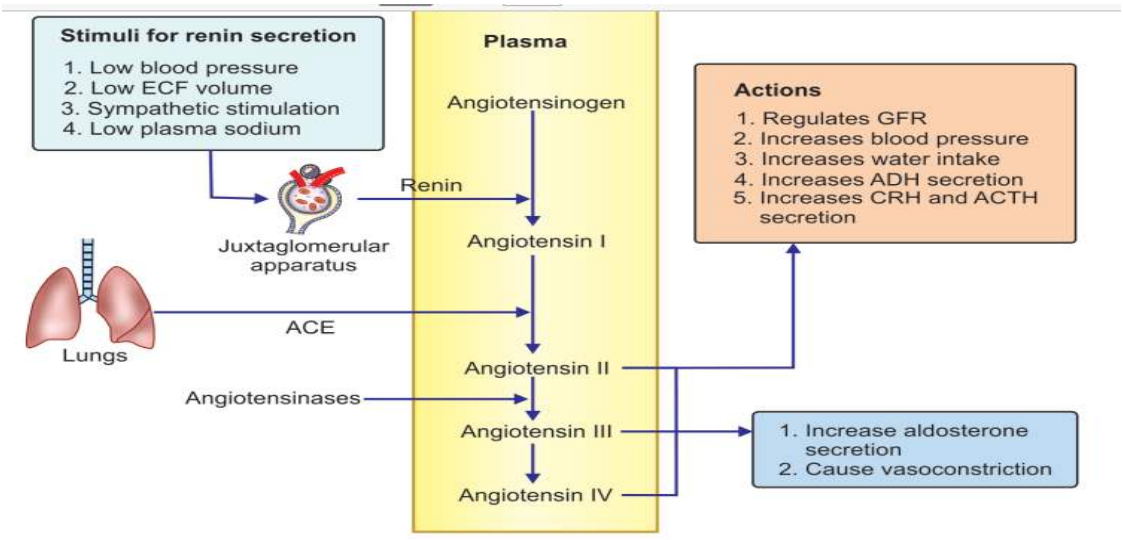

FIGURE 40.2: Renin-angiotensin system

ii It increases sodium reabsorption from renal tubules. This action is more predominant on proximal tubules.

4. On brain:

i. Angiotensin II inhibits the baroreceptor reflex and thereby indirectly increases the blood pressure. Baroreceptor reflex is responsible for decreasing the blood pressure.

ii. It increases water intake by stimulating the thirst center.

iii. It increases the secretion of corticotropin-releasing hormone (CRH) from hypothalamus. CRH in turn increases secretion of adrenocorticotropic hormone (ACTH) from pituitary.

iv. It increases secretion of antidiuretic hormone (ADH) from hypothalamus.

5. **Other actions:** Angiotensin II acts as a growth factor in heart and it is thought to cause muscular hypertrophy and cardiac enlargement. **Angiotensin III** increases the blood pressure and stimulates aldosterone secretion from adrenal cortex. It has 100% adrenal cortical stimulating activity and ***40% vasopressor activity of angiotensin II***. **Angiotensin IV** It also has adrenal cortical stimulating and vasopressor activities.

6. **SECRETION OF OTHER SUBSTANCES**

The extraglomerular mesangial cells of juxtaglomerular apparatus secrete prostaglandin. In vitro secretion of cytokines like IL-2 and TNF by the mesangial cells is observed recently. Macula densa secretes thromboxane A2.

REGULATION OF GLOMERULAR BLOOD FLOW AND GLOMERULAR FILTRATION RATE

Macula densa of juxtaglomerular apparatus plays an important role in the feedback mechanism called tubuloglomerular feedback mechanism, which regulates the renal blood flow and glomerular filtration rate.

RENAL BLOOD VESSELS

Renal artery arises directly from ***abdominal aorta*** and enters the kidney through the ***hilus***. While passing through renal sinus, *the renal artery divides into many segmental arteries,* which *subdivide into interlobar arteries* (Fig. 41.1). Each *interlobar artery passes in between the medullary pyramids*. At the base of the pyramid, *it turns and runs parallel to the base of pyramid* ***forming arcuate artery***. *Each arcuate artery gives rise to* ***interlobular arteries***. The *interlobular arteries run through the renal cortex perpendicular to arcuate artery. From each interlobular artery,* ***numerous afferent arterioles*** *arise*. The *afferent arteriole enters the Bowman's capsule and forms glomerular capillary tuft*. *The afferent arteriole divides into 4 or 5 large capillaries*.

Each large capillary divides into small capillaries, which form the loops. And, the capillary loops unite to form the efferent arteriole, which leaves the Bowman's capsule. The ***efferent arterioles*** *form a second capillary network called peritubular capillaries which surround the tubular portions of the nephrons*. Thus, the renal circulation forms a portal system by the presence of *two sets of capillaries – glomerular capillaries and peritubular capillaries*.

The ***peritubular capillaries*** are found around the tubular portion of cortical nephrons only. *The tubular portion of juxtamedullary nephrons are supplied by some* ***specialized capillaries called vasa recta***.

Vasa recta ***arise directly from the efferent arteriole*** **of the juxtamedullary nephrons** and run parallel to the renal tubule into the medulla and ascend up towards the cortex (Fig. 41.2).

The ***peritubular capillaries*** *and* ***vasa recta*** *drain* into the venous system. Venous system starts with peritubular venules and continues as interlobular veins, arcuate veins, interlobar veins, segmental veins and finally the renal vein (Fig. 41.3)

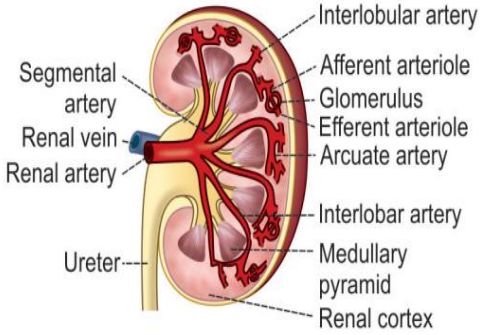

FIGURE 41.1: Renal blood vessels

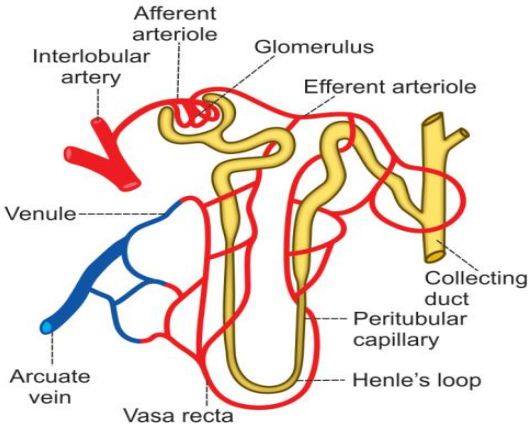

FIGURE 41.2: Renal capillaries

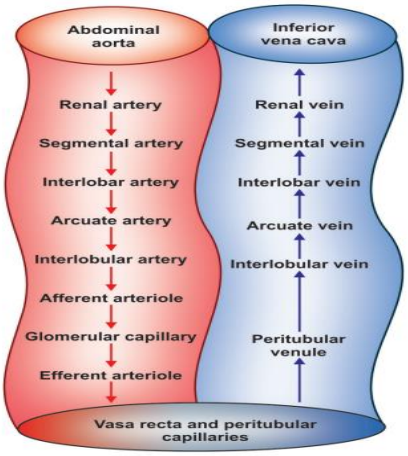

FIGURE 41.3: Schematic diagram showing renal blood flow

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