Human Renal Physiology

Objectives:

1. To understand the main functions of the kidneys .
2. To understand the functional renal anatomy
3. To understand the renal blood and plasma flow

Urinary system

Urinary system: Organ system that produces, stores, and carries urine.

Includes: two kidney, two ureters, the urinary bladder, two sphincter muscles, the urethra .

Humans produce about 1.5 liters of urine over 24 hours, although this amount may vary according to the circumstances :

- Increased fluid intake generally increases urine production.

- Increased perspiration and respiration may decrease the amount of fluid excreted through the kidneys .

- Some medications interfere directly or indirectly with urine production, such as diuretics

Role of Kidneys:

primarily regulation or homeostasis (rather than excretion)

1. **Regulation** of blood plasma and interstitial fluid composition (homeostasis), especially inorganic ions (e.g. Na^+, K^+, Cl^-, Ca^{2+}) and osmolality (osmotic activity of dissolved particles)

2. Regulation of body fluid volume -- fluid balance

3. Regulation of blood plasma and interstitial fluid pH

4. Excretion of (non-volatile) metabolic end products (e.g. urea, uric acid, creatinine, $NH4^+$) and "foreign" solutes (e.g. some drugs)

Note: The above are functions are vital; loss of renal function leads to debilitation beginning in about one day and terminating in death in one-two weeks (end stage renal/kidney failure/disease)

5. Endocrine organ, secreting:

a. renin, for regulation of Na^+, ECF (extracellular fluid) volume, vascular resistance

b. erythropoietin, for regulation of erythrocyte production

c. calcitriol, related to calcium regulation

6**. Metabolic functions:** e.g. peptide degradation, synthesis of NH_3 and H^+

Urine Formation Rate (V)

Normal	1 ml/min	1.5 L/day
Normal range	0.4-2 ml/min	0.5-3 L/day
Oliguria	< 0.4 ml/min	< 0.5 L/day
Anuria	< 0.04 ml/min	< 50 ml/day
Polyuria	> 2 ml/min	> 3 L/day

Kidney Functional Anatomy

1. Paired organs, located in the abdomen retroperitonealy just below the diaphragm

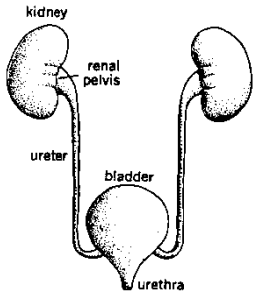
2. Size: 10 cm x 5 cm x 2.5 cm; weight about 150 gm each (300 gm total)

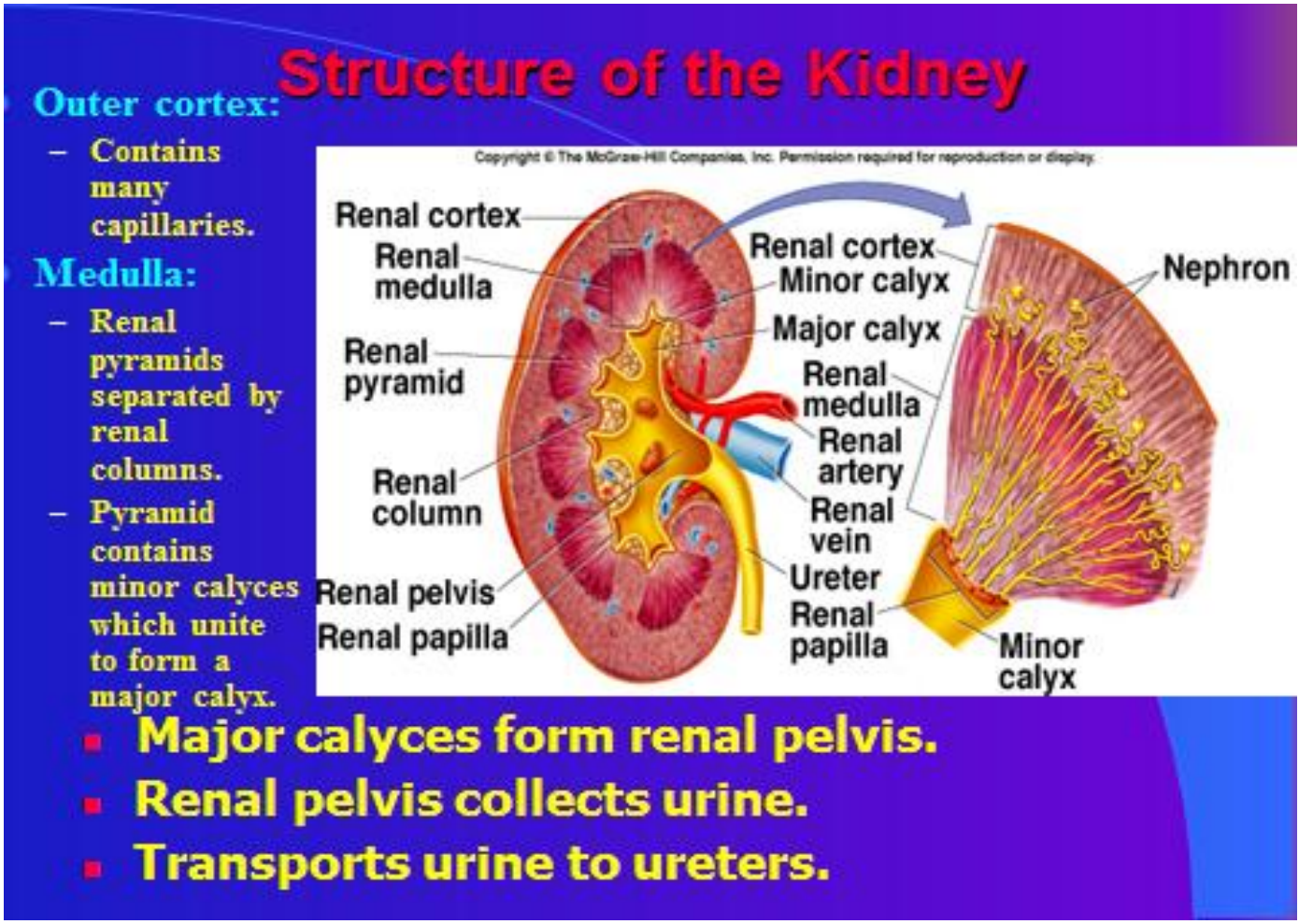
3. Supplied with blood by renal artery; after passing through the kidney, blood is returned to the heart by the renal vein

4. Forms urine, which is transported by the ureter to the bladder; excreted from the body at suitable intervals via the urethra (micturition reflex)

Note: the ureter, bladder, and urethra do not change the composition of urine; when urine leaves the kidney, its composition is fixed

5. Divided into cortex (outer) and medulla (inner) regions





Nephron Functional Anatomy

Functional unit: nephron (about one million per kidney); nephron divided into

a. glomerular region (renal corpuscle; about 0.2 mm diameter)

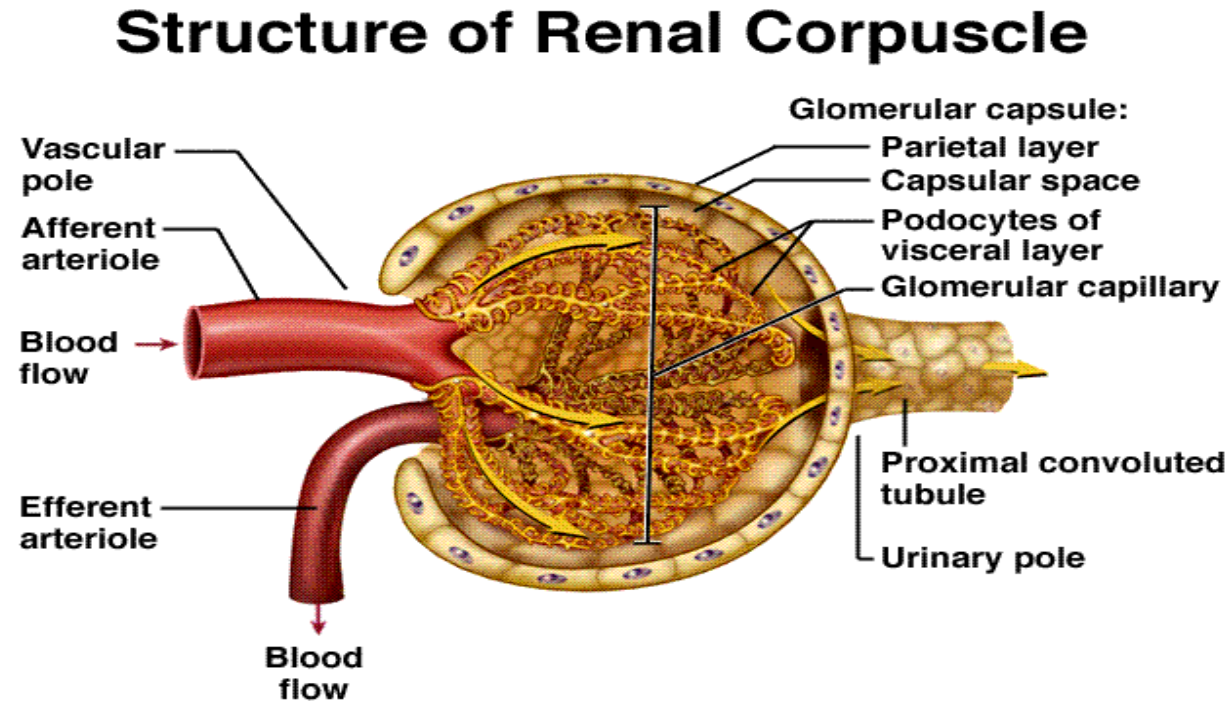
1) glomerulus (capillary tuft)
2) Bowman's capsule (blind end of the nephron)

(note: Bowman's capsule and the glomerulus together are named the Malpigian corpusle, but often refered to simply as the "glomerulus")

b. proximal convoluted and straight tubule (about 15 mm long, 0.05 mm diameter); sometimes divided into segments S1, S2, and S3

c. loop of Henle; dips deeply (juxtamedullary nephron) or slightly (cortical nephron) into the medulla; each has thick (12 mm long) and thin (2-15 mm long) segments

1) descending limb
2) hairpin turn
3) ascending limb (thin and thick segments)

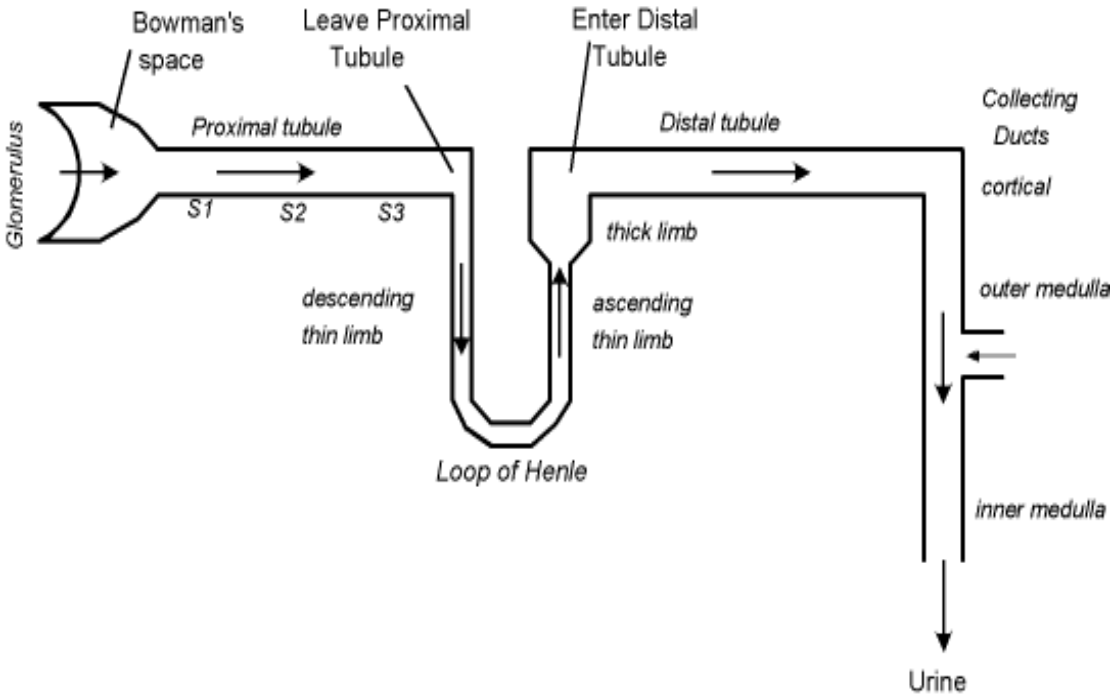


d. distal convoluted and straight tubule (5 mm long), divided into

1) early segment, functions as extension of Loop of Henle
2) later segment, functions as beginning of collecting tubule (connecting segment)

Note: the initial part of the distal tubule passes near the glomerulus of the nephron

e. collecting tubule/duct (20 mm long)



Types of nephrons:

Cortical and

Juxtamedullary (15% of nephrons) nephrons

are distinguished by the cortical location of their glomeruli and the depth to which their loops of Henle penetrate into the medulla; cortical nephrons are sometimes subdivided into superficial and midcortical.

Juxtaglomerular Apparatus

Region in each nephron where the Afferent arteriole comes in contact with the thick ascending limb LH(or distal tubules).

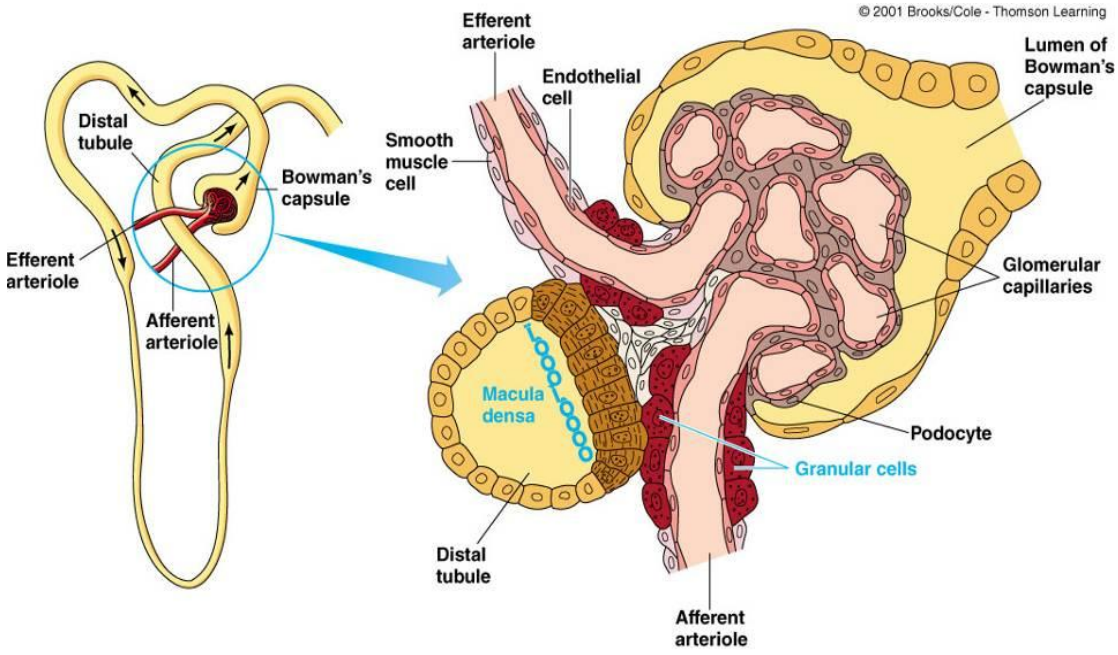
- Granular cells within Afferent arteriole secrete renin:

1. Converts angiotensinogen to angiotensin I.
2. Initiates the renin-angiotensin-aldosterone system.
3. Negative feedback.

- Macula densa: -
  Region where ascending limb is in contact with afferent arteriole.
  -Inhibits renin secretion when blood [Na^+] in blood increases.

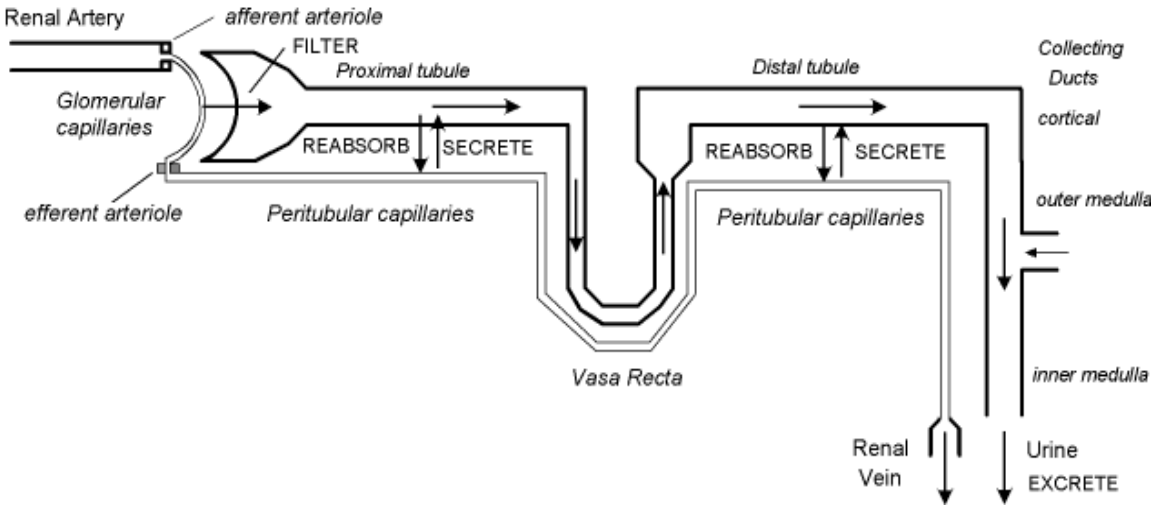
  Cells of macula densa are taller and have more prominent nuclei than surrounding cells.

  Sensitive to the concentration of sodium ions in the fluid.



Functional Anatomy of the Renal Microcirculation

Renal arteries ==> afferent arterioles ==> glomerular capillaries ==> efferent arterioles ==> proximal peritubular capillaries ==> vasa recta ==> distal peritubular capillaries ==> collecting duct capillaries and veins ==> renal venules



Renal Blood Flow (RBF) Value -- Rate and Distribution

1. **Normal (resting) blood flow**: 1.2 L/min (20-25% of cardiac output
Normal (resting) plasma flow: 650 ml/min *(measured by PAH clearance)*

Note: the high blood flow is required to furnish the kidney with sufficient plasma for filtration, reabsorption, etc.

2**. Range**: the highest renal blood flow occurs at rest; progressively increasing activity or stress progressively reduces renal blood flow; under extreme conditions (e.g. shock), renal blood flow can be reduced to almost zero

3. **Oxygen extraction (C_a - C_v):** low: 1-2 ml O_2/dl (10-20 O_2 ml / Liter blood)

Note 1: the major use of oxygen is to furnish energy for active transport, particularly Na^+ and co-transported substances

Blood flow in kidneys and other organs

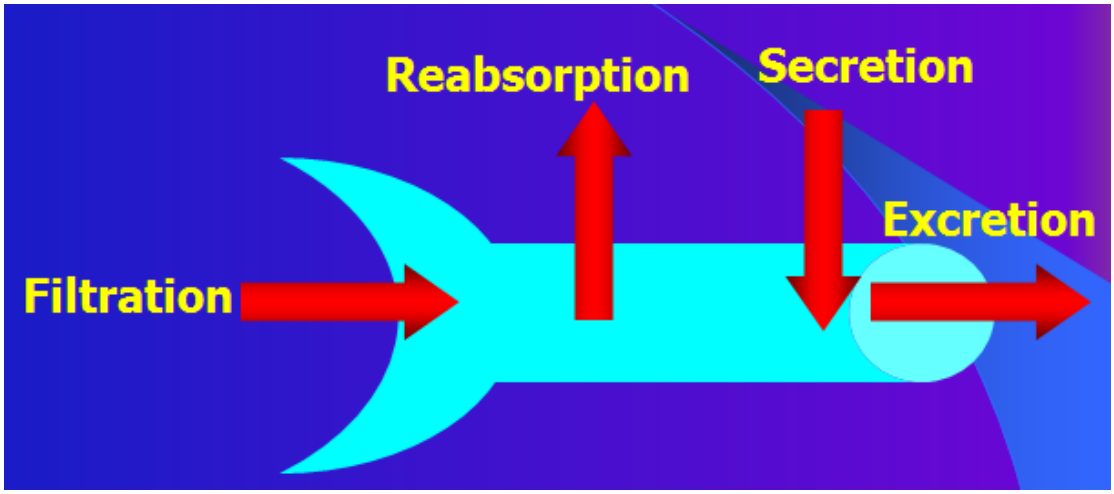
Organ	Approx. blood flow (mg/min/g of tissue)	A-V O_2 difference (ml/L)
Kidney	**4.00**	**12-15 (depends on reabsorption of Na^+)**
Heart	**0.80**	**96**
Brain	**0.50**	**48**
Skeletal muscle (rest)	**0.05**	**-**
Skeletal muscle (max. exercise)	**1.00**	**-**

Note 2: The low O2 a-v extraction indicates that resting renal blood flow is more than sufficient to satisfy the kidney's oxygen requirements and therefore RBF could be reduced without sacrificing renal function. However, excessive reduction in RBF can lead to permanent damage to the kidney.

4. **Distribution**: most flow is directed to renal cortex; medullary flow is much less

Functions of the Nephron: Four main processes

- **Filtration**
- **Reabsorption**
- **Secretion**
- **Excretion**



Filtration:

- First step in urine formation
- Bulk transport of fluid from blood to kidney tubule
  - » Isosmotic filtrate
  - » Blood cells and proteins don't filter
- Result of hydraulic pressure
- GFR = 180 L/day

Reabsorption:

Process of returning filtered material to bloodstream

- 99% of what is filtered
- May involve transport protein(s)
- Normally glucose is totally reabsorbed

Secretion:

- Material added to lumen of tubule from blood

- Active transport (usually) of toxins and foreign substances

» Saccharine

» Penicillin

Excretion:

Loss of fluid from body in form of urine

Amount of Solute =Amount + Amount - Amount Excreted
Filtered Secreted Reabsorbed