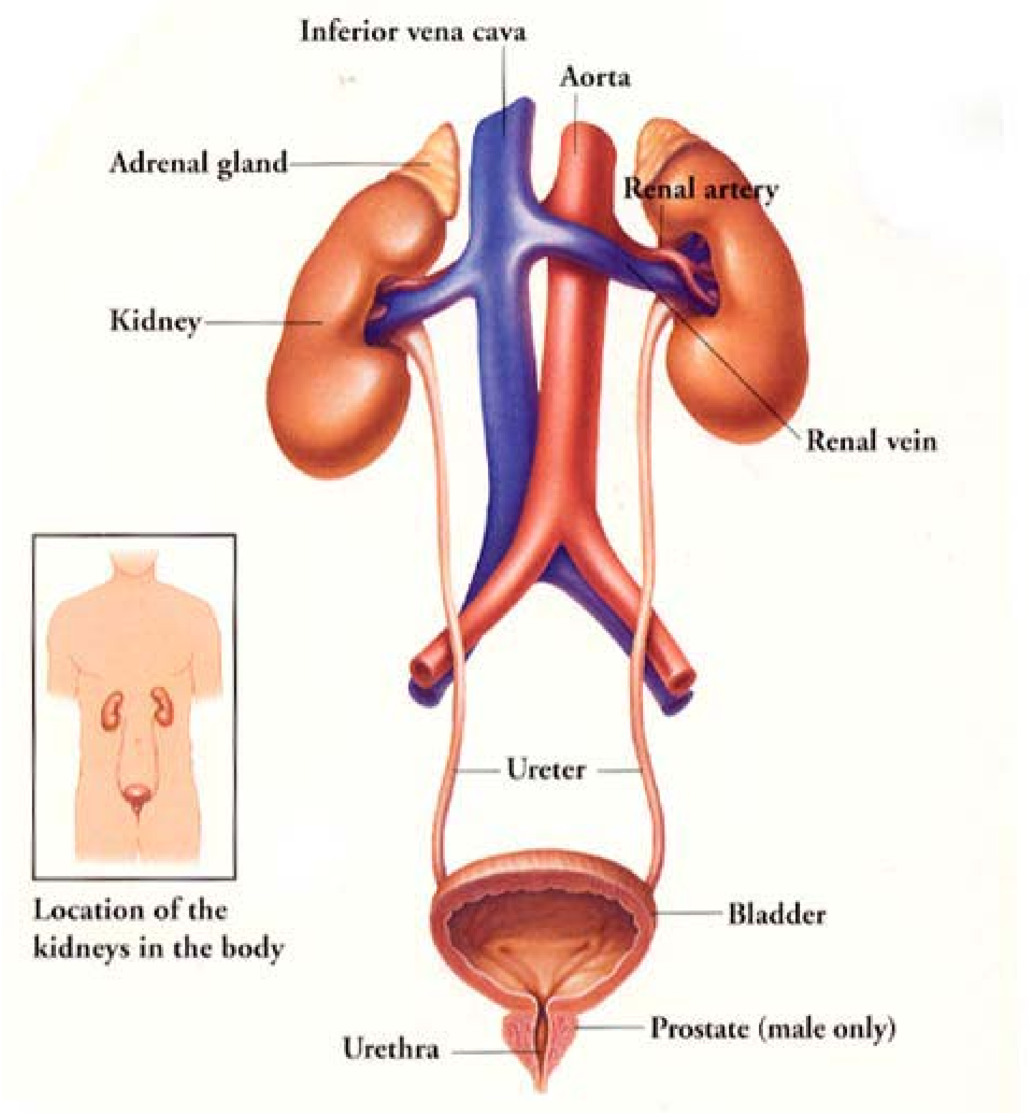
Urinary System

Gross Anatomy

Consist of six organs

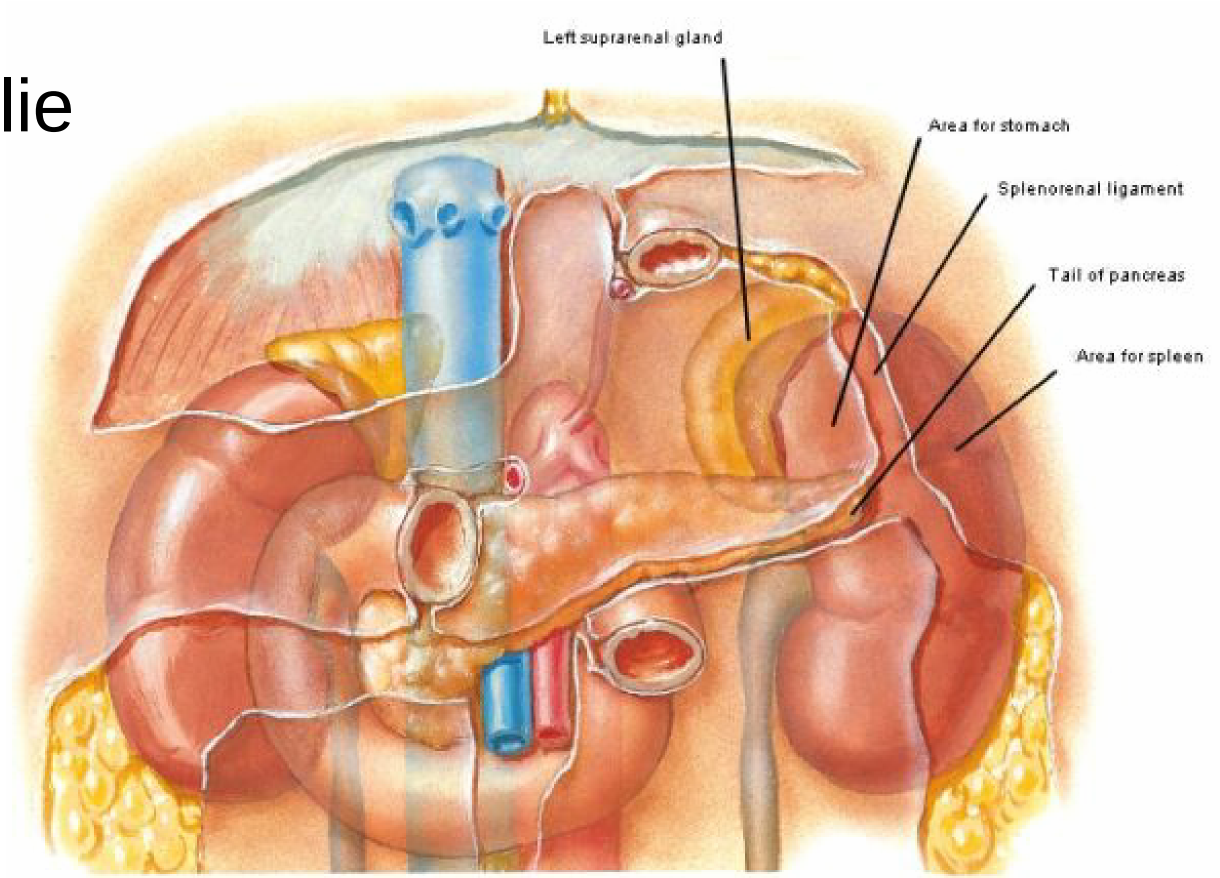
- Kidneys (2)
- Ureters (2)
- Urinary bladder
- Urethra

- Right slightly lower than left due to space occupied by liver



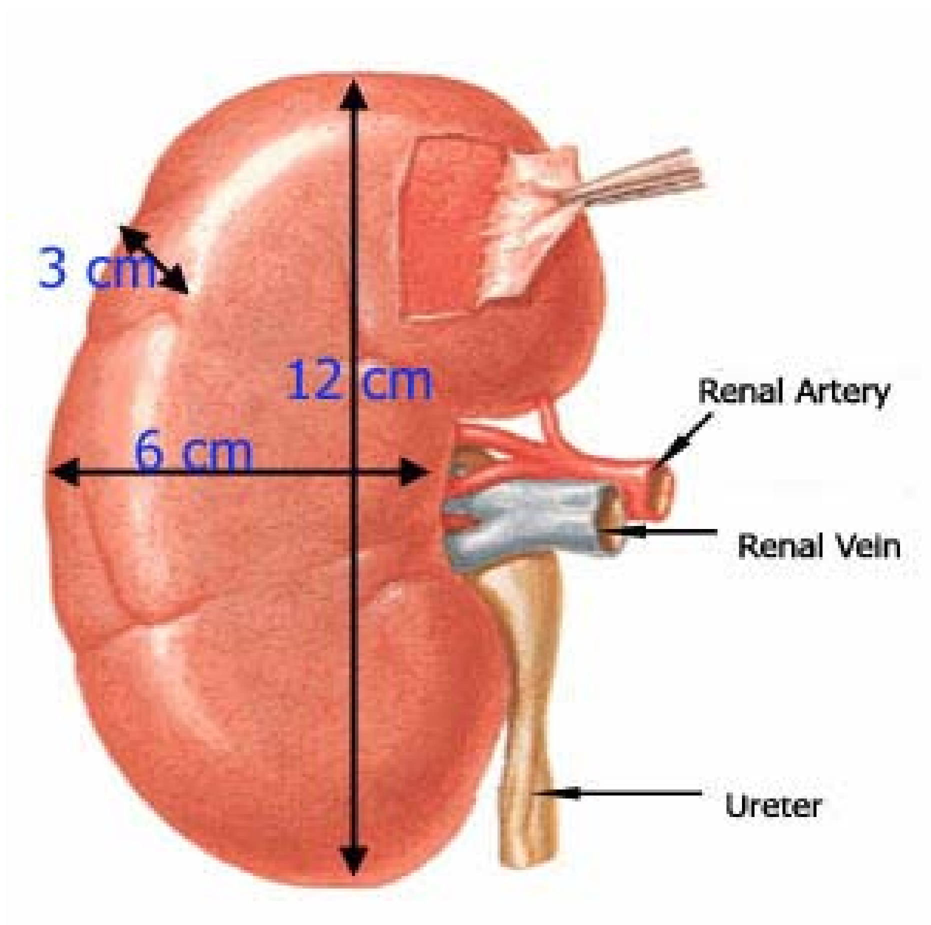
Gross Anatomy

- Retorperitoneal (lie between the peritoneum and body wall) at the level of T12-L3



Gross Anatomy

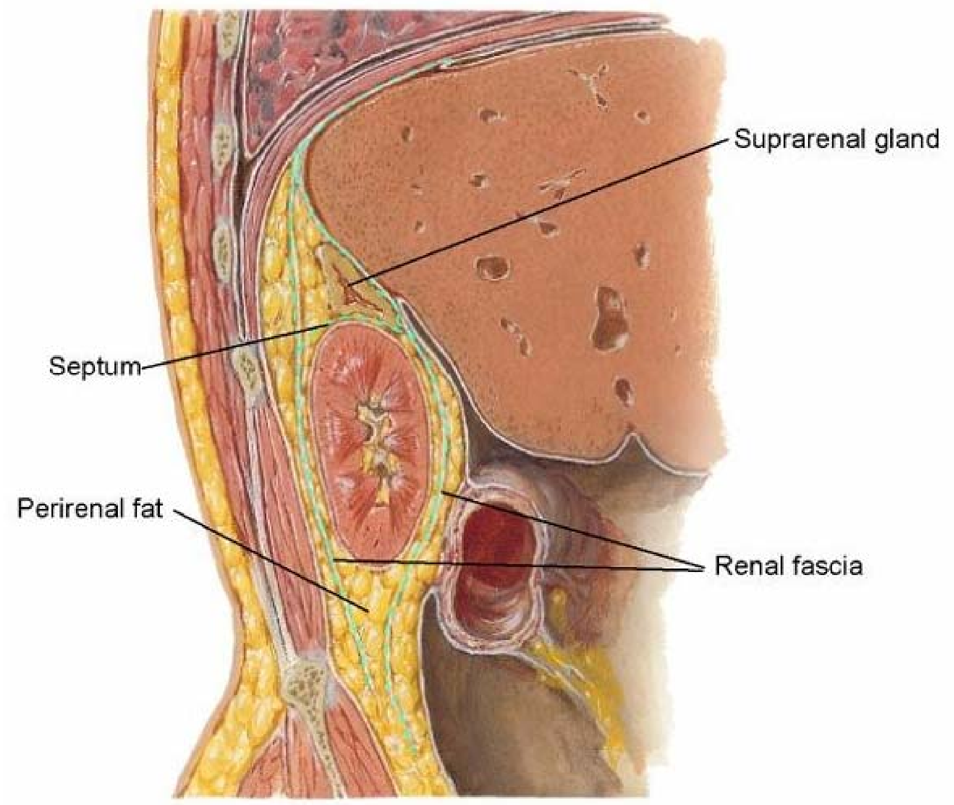
- Each weight about 160g and measures 12cm long by 5-6cm wide and 2.5-3cm thick
- Lateral surface convex, medial surface concave and has a slit called the **hilum** where it receives the renal artery, vein, ureter and lymphatic vessels



Gross Anatomy

Protected by three layer of c.t.

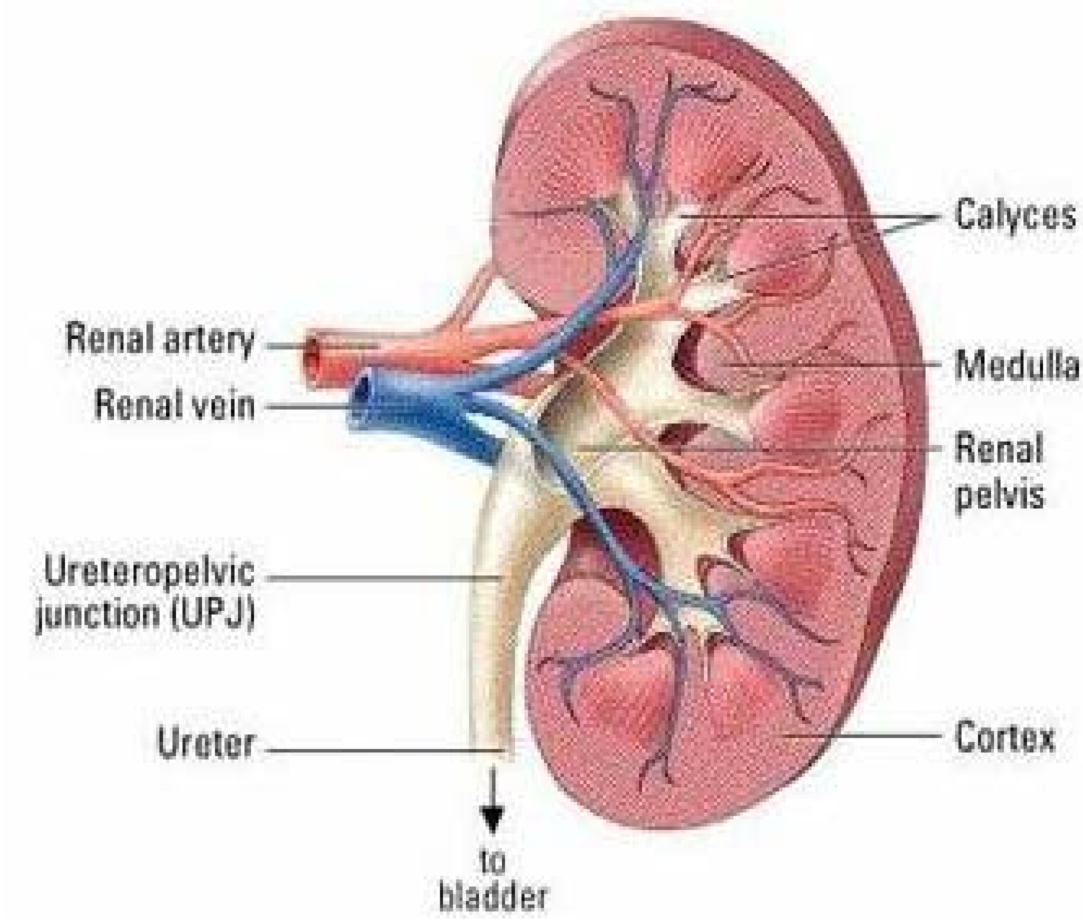
- **Renal fascia-** binds the kidney and associated organs to the abd. Wall
- **Adipose tissue-** a layer of fat that cushions the kidney and holds it in place
- **Renal capsule-** a fibrous sac that is anchored at the hilum and encloses the rest of the kidney like a cellophane wrapper, and protects it from trauma and infection




http://www.gen.umn.edu/courses/1135/lab/

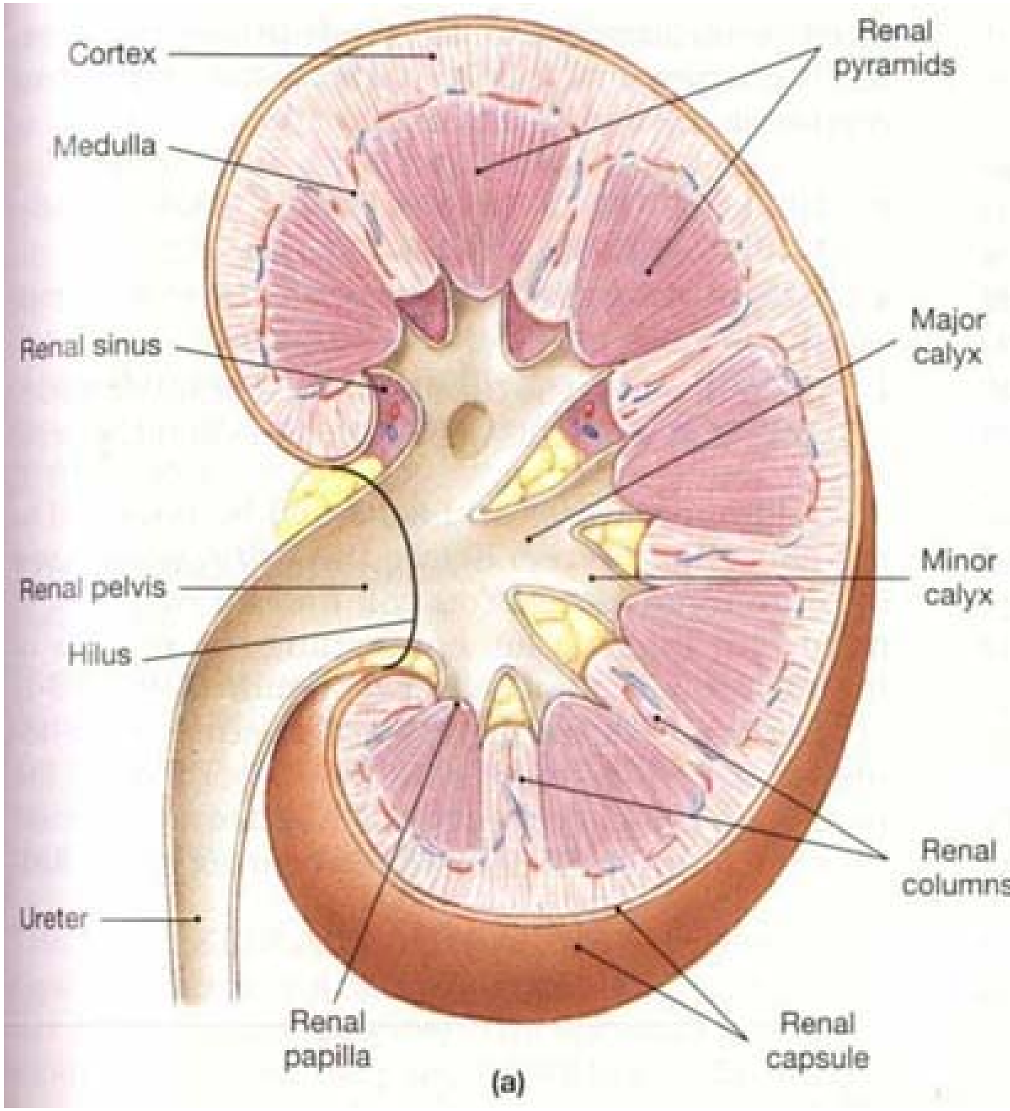
Gross Anatomy

- **Renal parenchyma** (glandular tissue that forms the urine) appears C-shaped in frontal section and encircles a medial space called the **renal sinus** (containing blood vessels, nerves, and urine collecting structures)
- Parenchyma is divided into two zones
  - **Renal cortex-** about 1cm thick
  - **Inner medulla**



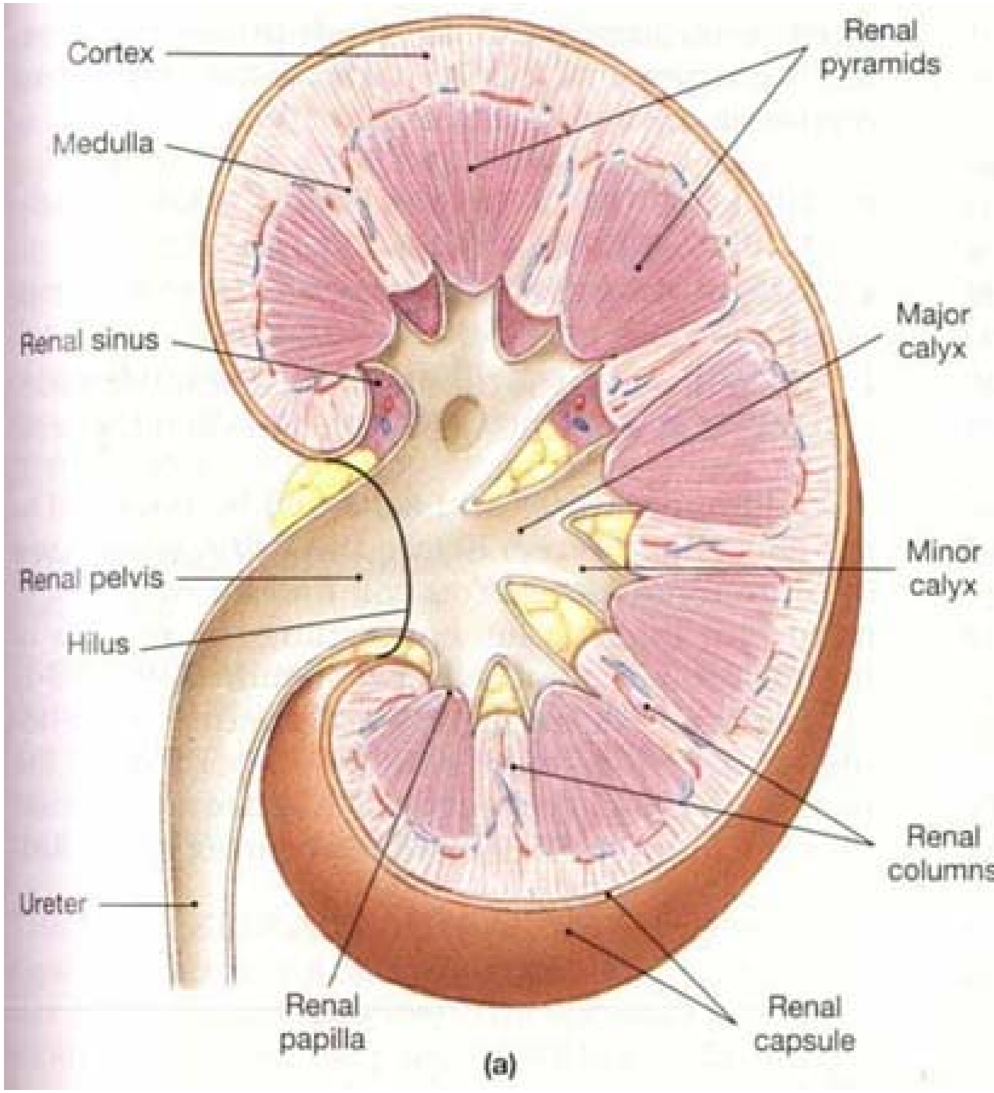
Gross Anatomy

- **Renal columns** (extensions of the cortex) project toward the sinus and divided the medulla into 6-10 **renal pyramids**
- Each pyramid is conical, with a broad base facing the cortex and a blunt point called the **renal papilla** facing the sinus
- One pyramid and the over laying cortex constitute one lobe of the kidney

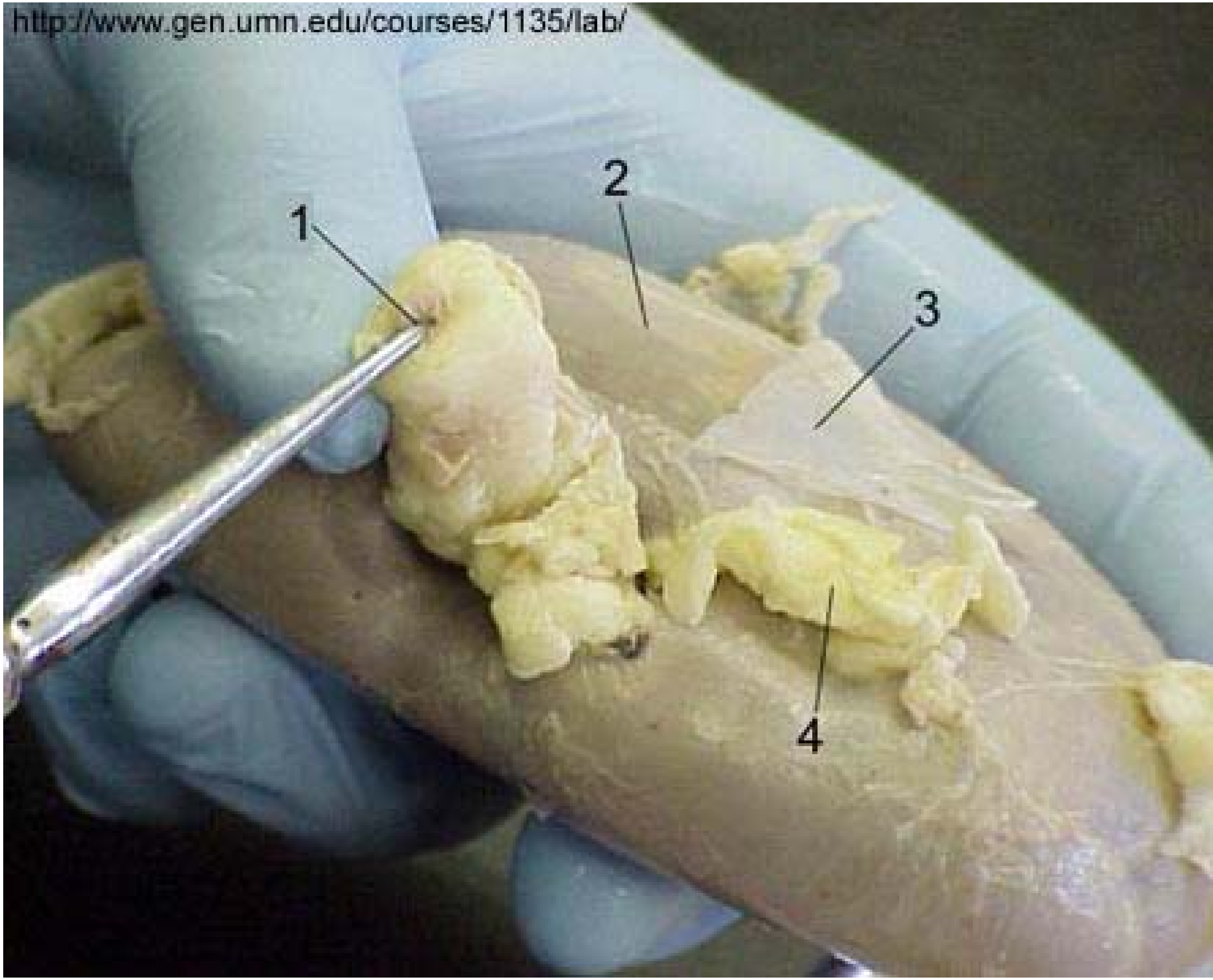


Gross Anatomy

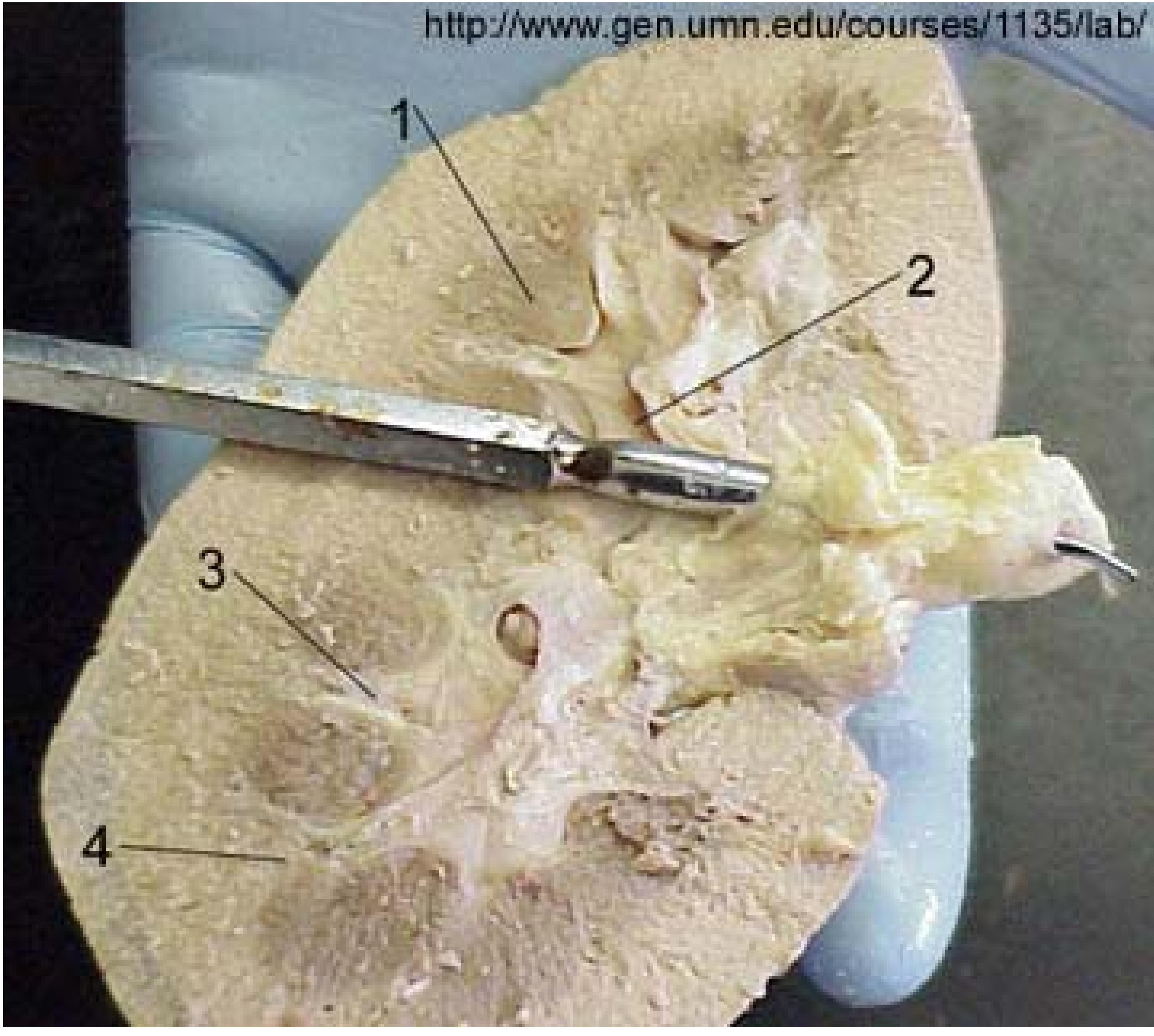
- The papilla and each renal pyramid is nestled in a cup called a **minor calyx** which collects urine.
- Two or three minor calices converge to form a **major calyx**, and two or three major calices converge in the sinus to form the funnel-like **renal pelvis**
- The **ureter** is a tubular continuation of the renal pelvis that drains urine down to the urinary bladder.



1. URETER
2. CORTEX
3. CAPSULE
4. ADIPOSE

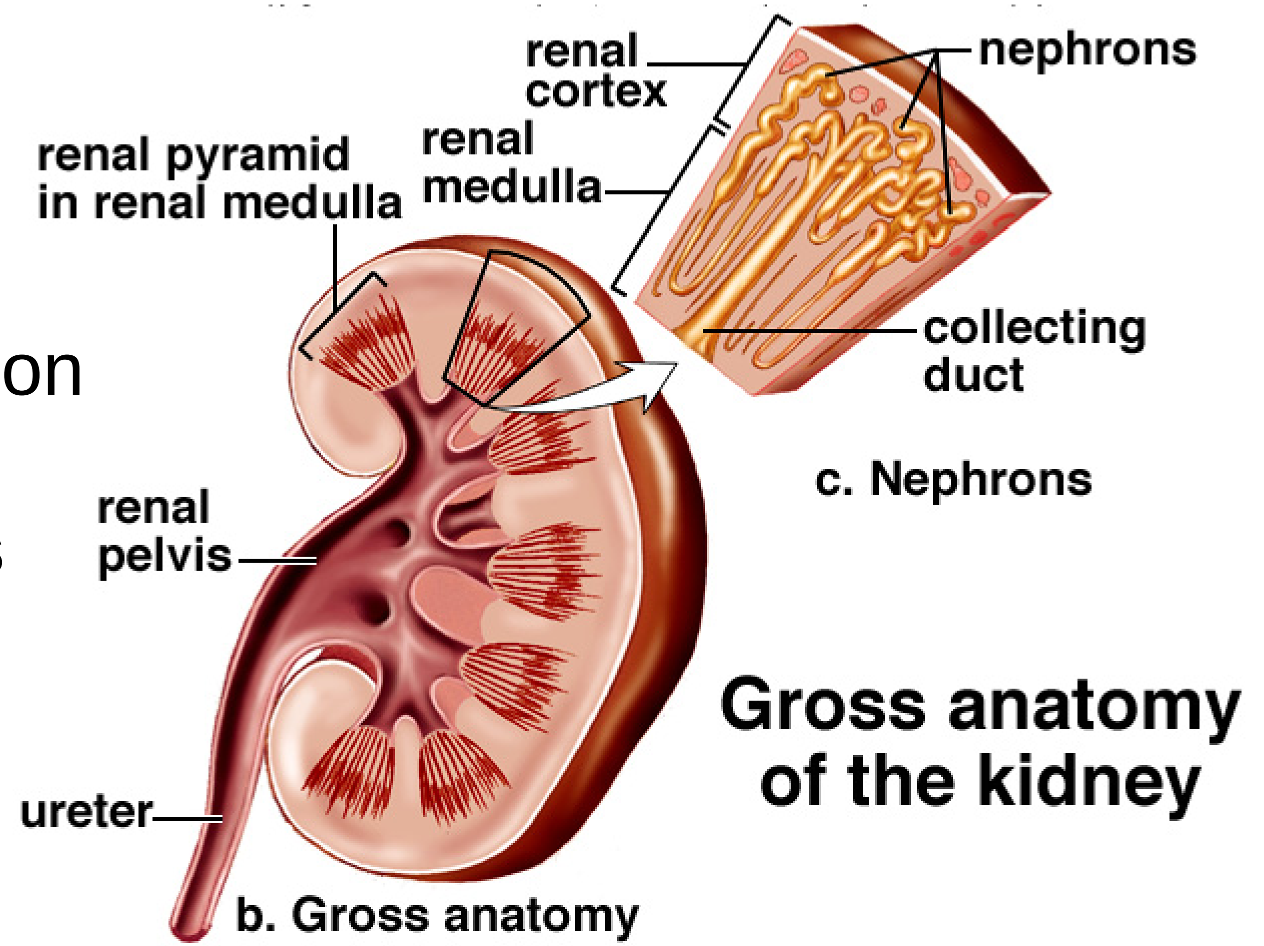


1. PYRAMID
2. PELVIS
3. CALYX
4. COLUMN



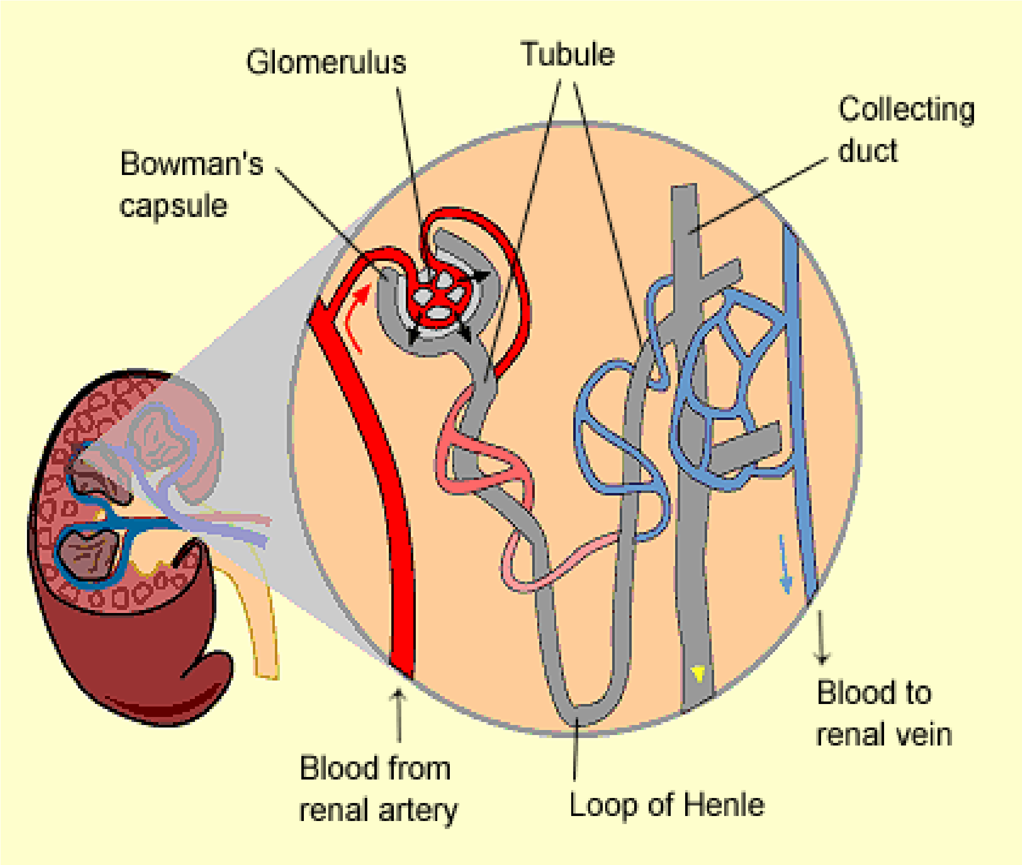
Micro Anatomy

- Each kidney contains 1.2 million functional units called **nephrons**



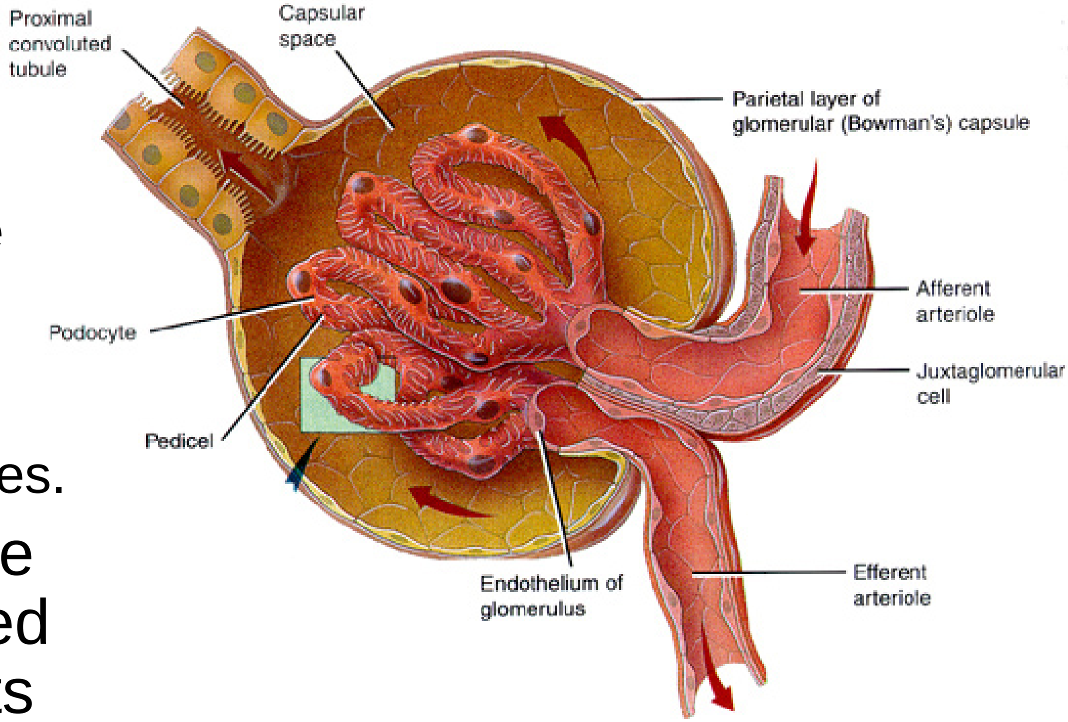
Micro Anatomy

- A nephron consist of two principal parts
  - **Renal corpuscle-** (glomerulus) where the blood plasma is filtered
  - **Renal tubule-** processes the filtrate into urine



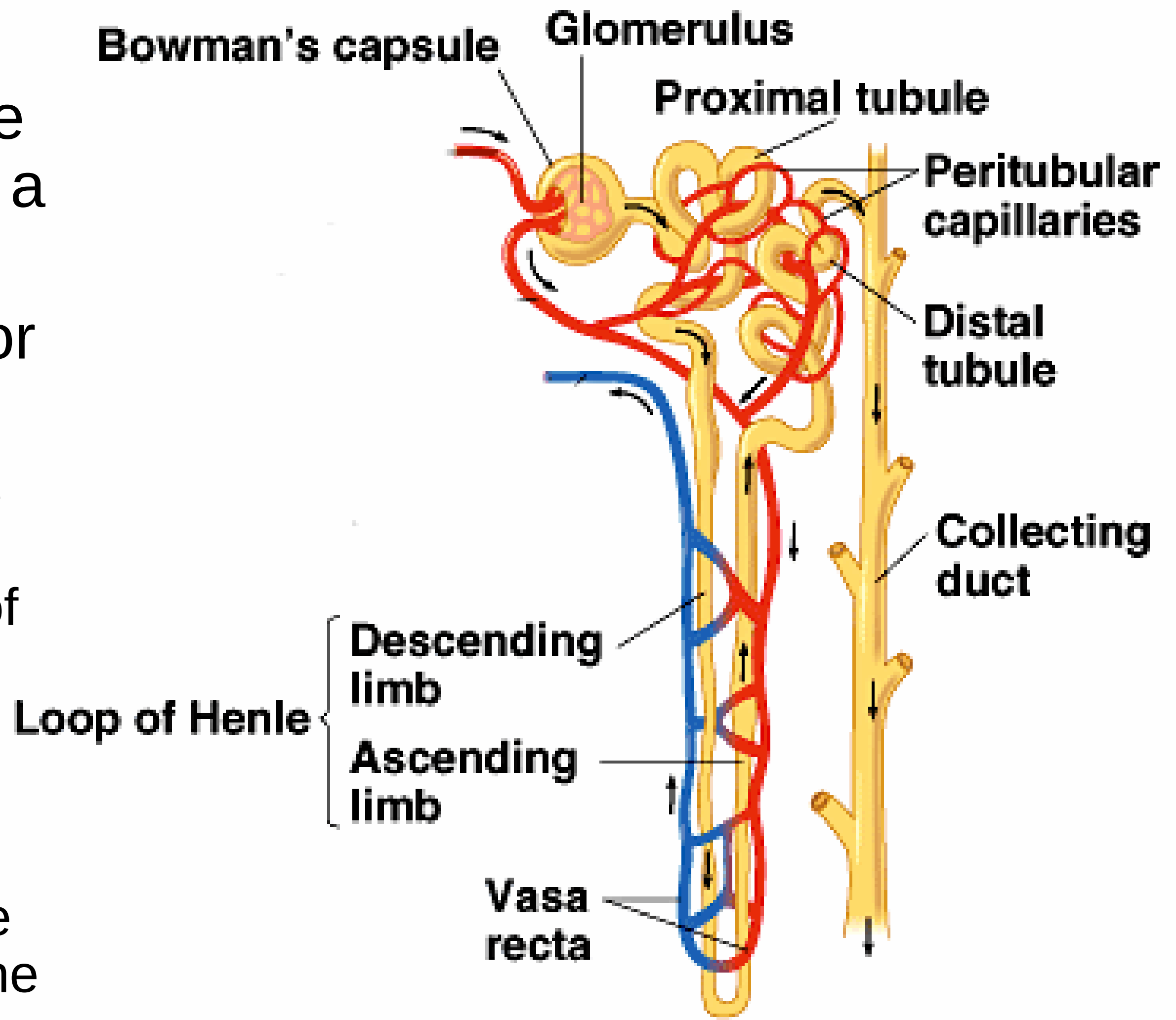
Micro Anatomy

- Consist of a ball of capillaries called a **glomerulus** enclosed in a two-layered **glomerular (Bowman's) capsule**
  - The parietal layer is a simple squamous epithelium.
  - The visceral layer consist of cells called **podocytes** wrapped around the capillaries.
- The fluid that filters from the glomerular capillaries, called **glomerular filtrate**, collects in the **capsular space** between the parietal and visceral layer and then flows into the renal tubule.

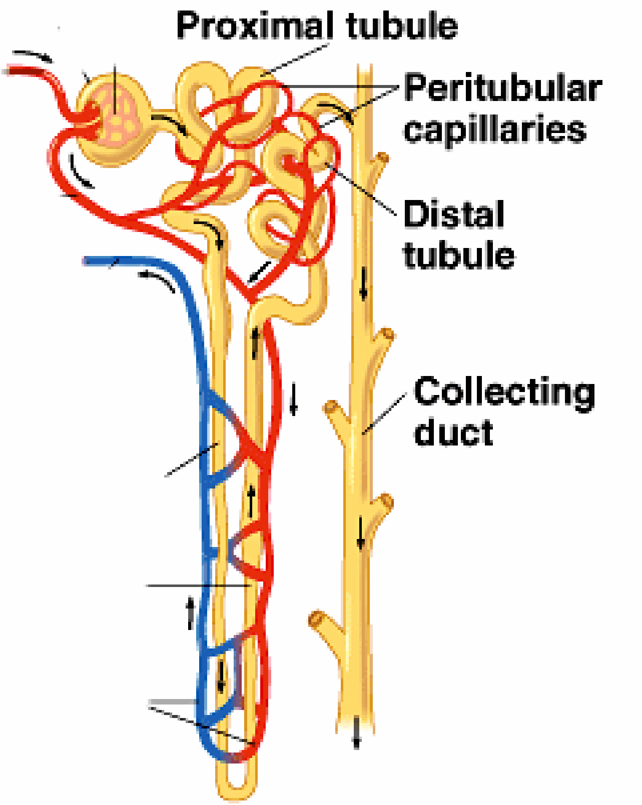


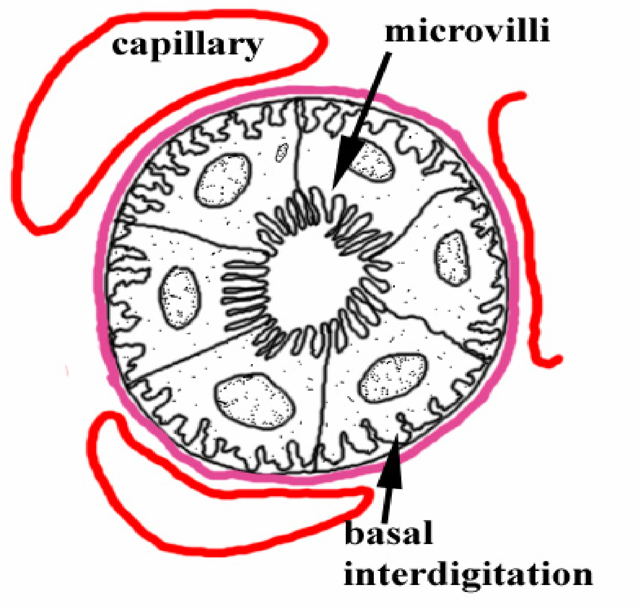
Renal (Uriniferous) Tubule

- Is a duct that leads away form the glomerular capsule and ends at the tip of a medullary pyramid
- Divided into four major regions
  - **Proximal convoluted tubule**
  - **Nephron loop** (loop of Henle)
  - **Distal convoluted tubule**
  - **Collecting duct** (not really a part of the nephron- receives urine from many nephrons



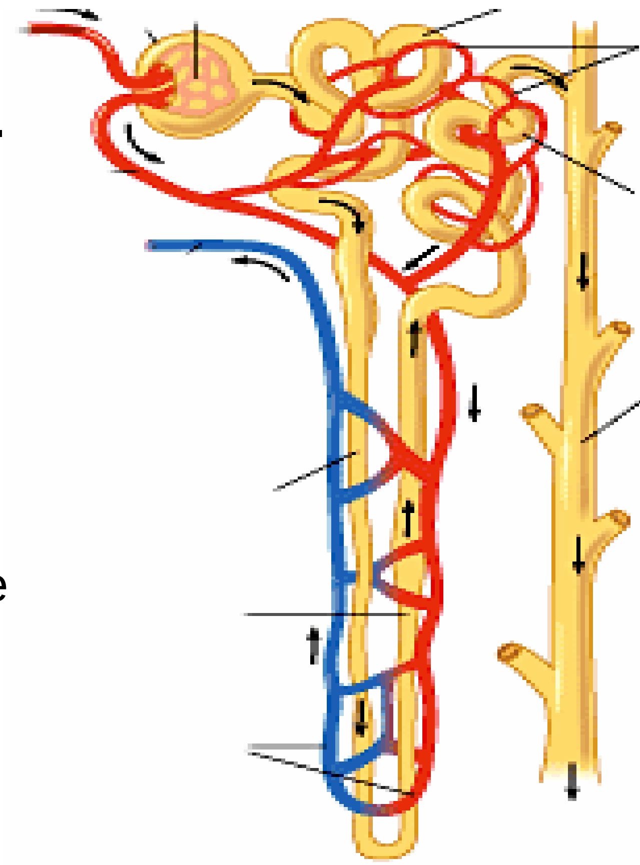
- Proximal Convoluted Tubule
  - Longest and most coiled
  - Simple cuboidal epithelium with microvilli (brush border for absorption capacity)





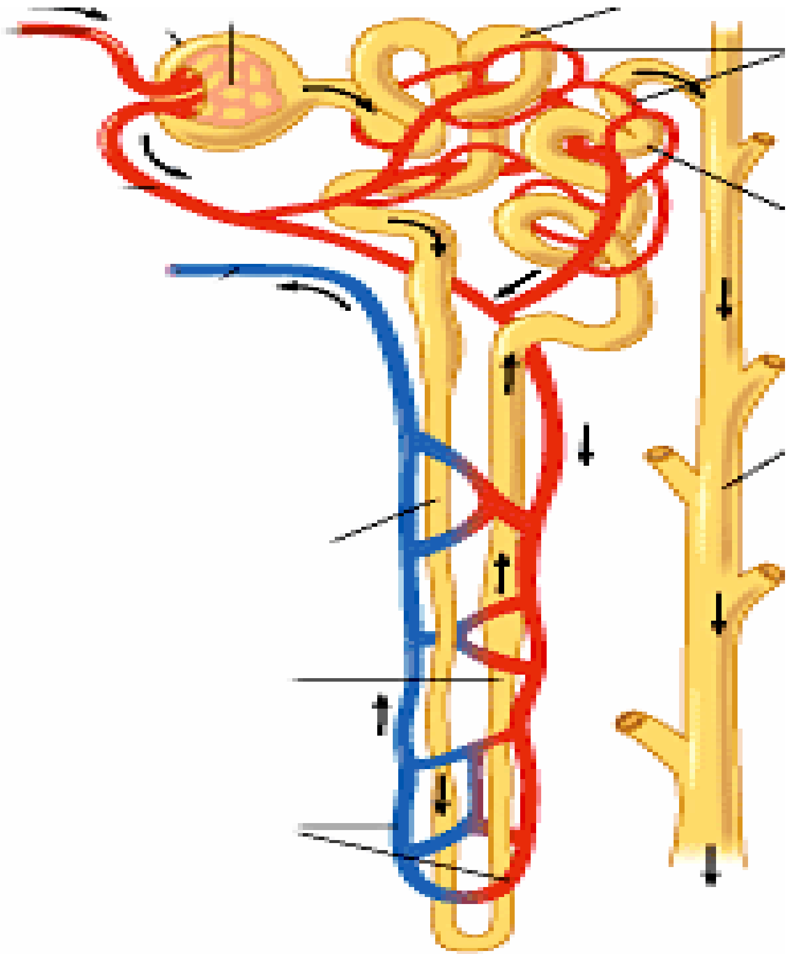
Nephron Loop

- **Descending limb-** first portion of the loop, passes from the cortex into the medulla
- At its deep end it turns 180º and forms an **ascending limb** that returns to the cortex.
- The nephron loop is divided into thick and thin segments
  - **Thin segments**- has a simple squamous epithelium
    - Cells have low metabolic rate but are very permeable to water
    - Forms the lower part of the descending limb, the bend, and partway up the ascending limb
  - **Thick segments**- have a simple cuboidal epithelium with lots of mitochondria in the cells due to the high metabolic activity of active transport.
    - Form initial parts of the descending limb and part or all of the ascending limb



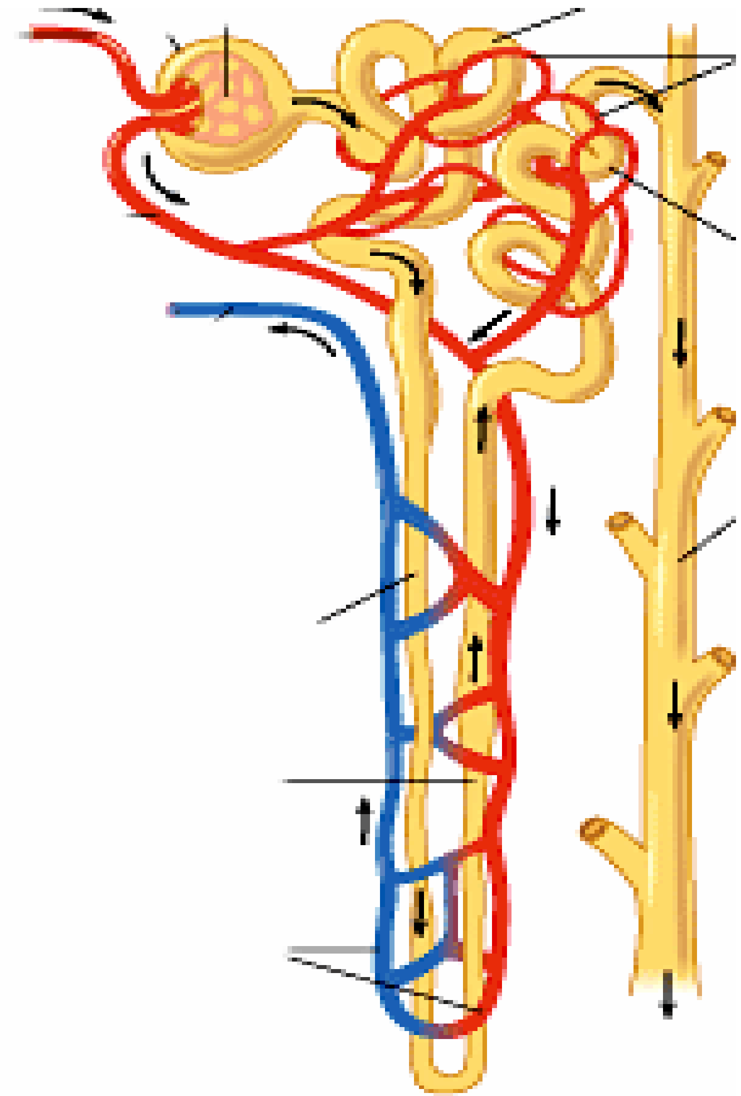
Distal Convoluted Tuble

- Shorter and less coiled than the PCT, so fewer sections are seen in histological sections
- Has a cuboidal epithelium with smooth-surface cells nearly devoid of microvilli



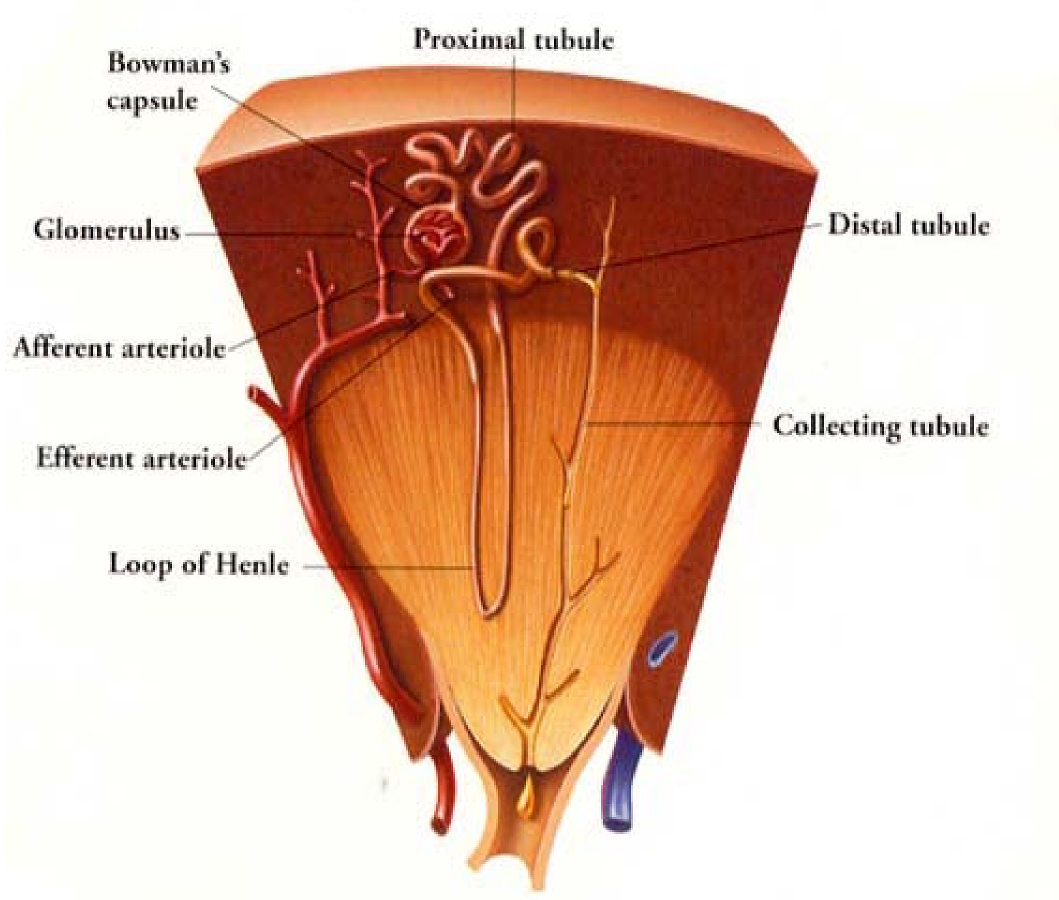
Collecting Duct

- The DCTs of several nephrons drain into a this straight tube, which passes into the medulla
- Are both lined with simple cuboidal epithelium



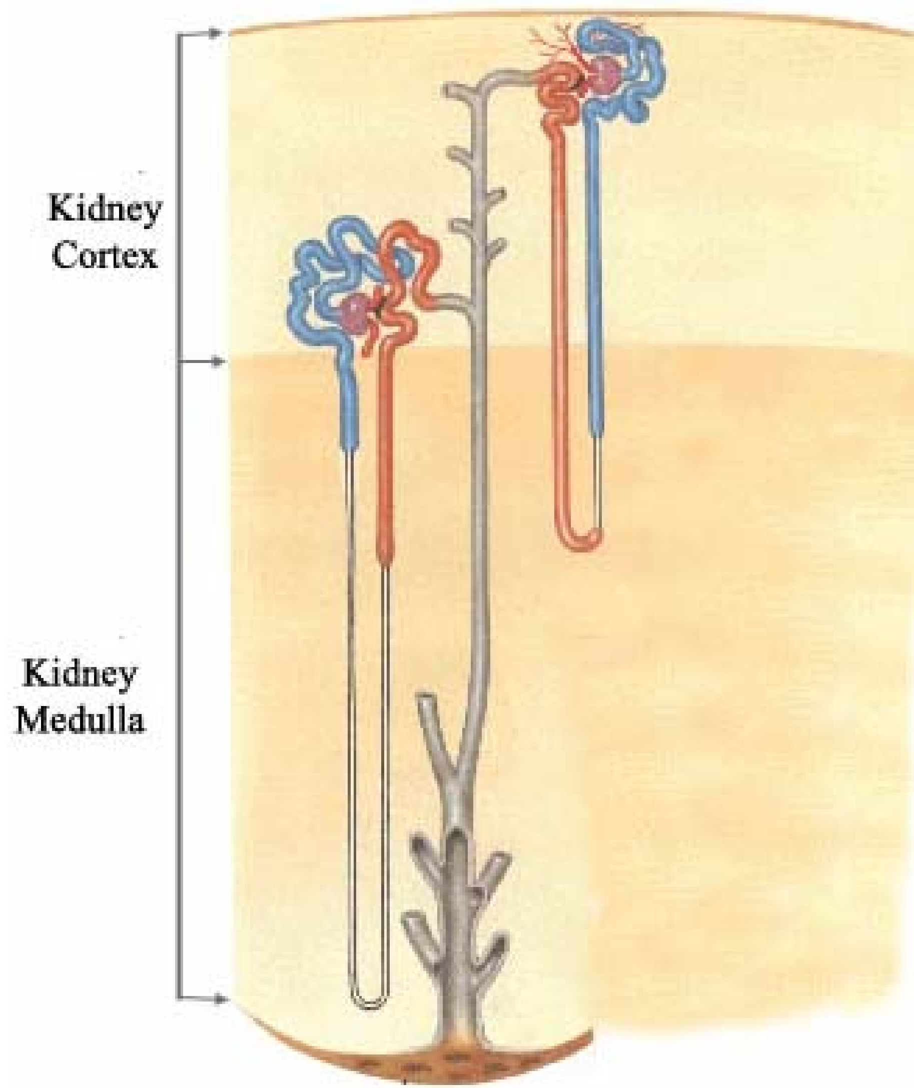
Collecting Duct

- Near the papilla, several collecting ducts merge to form a larger **papillary duct**
- About 30 of these from each papilla into its minor calyx



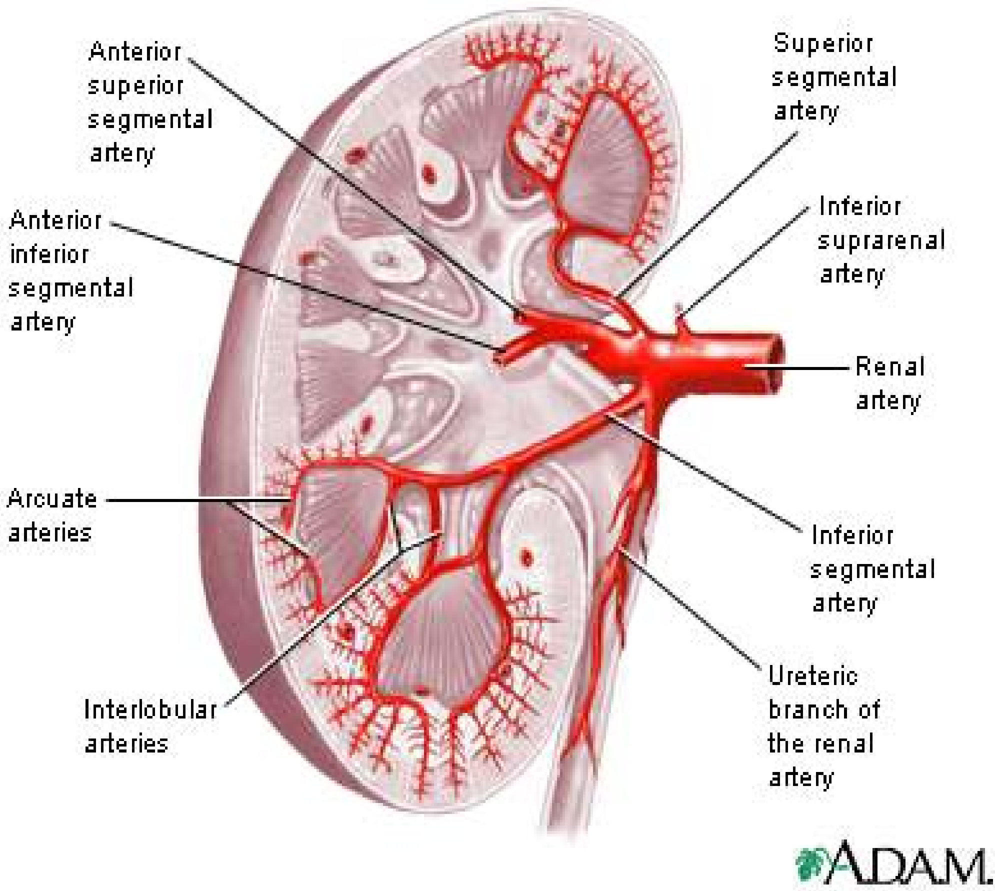
Cortical and Juxtamedullary Nephrons

- **Cortical Nephrons-** nephrons close to the kidney surface
  - Have shorter nephron loops that dip only slightly into the outer medulla before turning back
- **Juxtamedullary nephron-** nephrons close to the medulla
  - Have very long loops that extend to the apex of the renal pyramid
  - Responsible for maintaining the salinity gradient



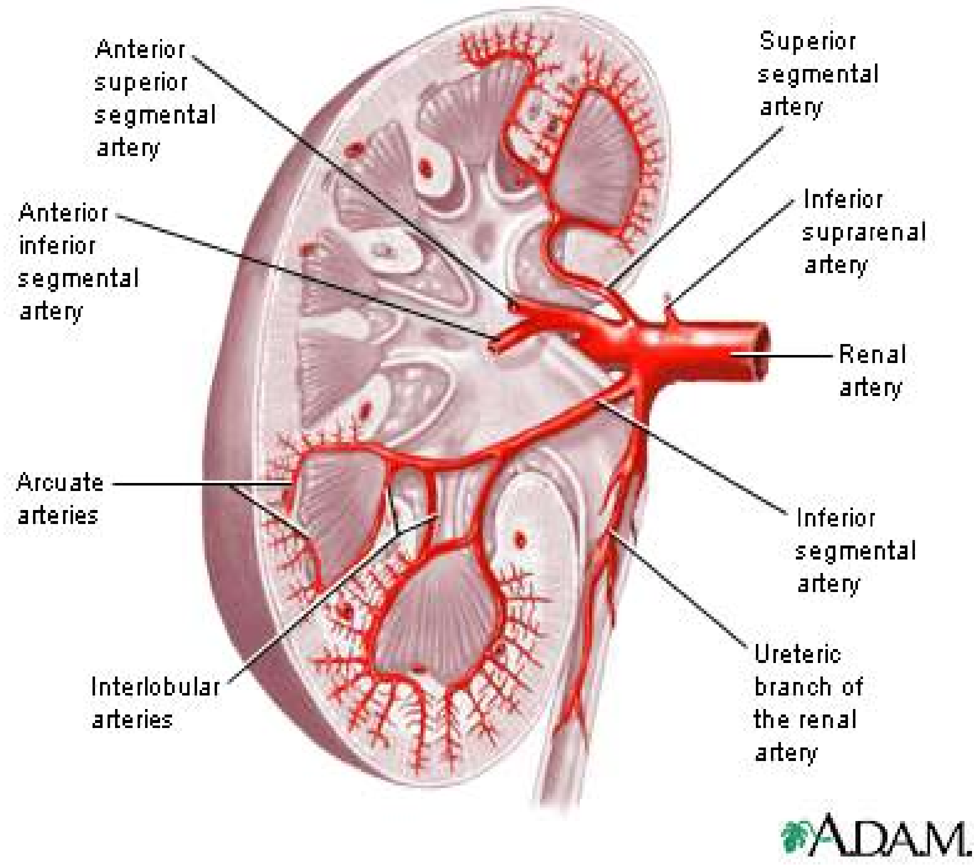
Blood Supply

- Receives 21% of the cardiac output
- •attests to their importance in controlling blood volume and composition
- •Each kidney is supplied by a **renal artery** (sometimes 2 or more)



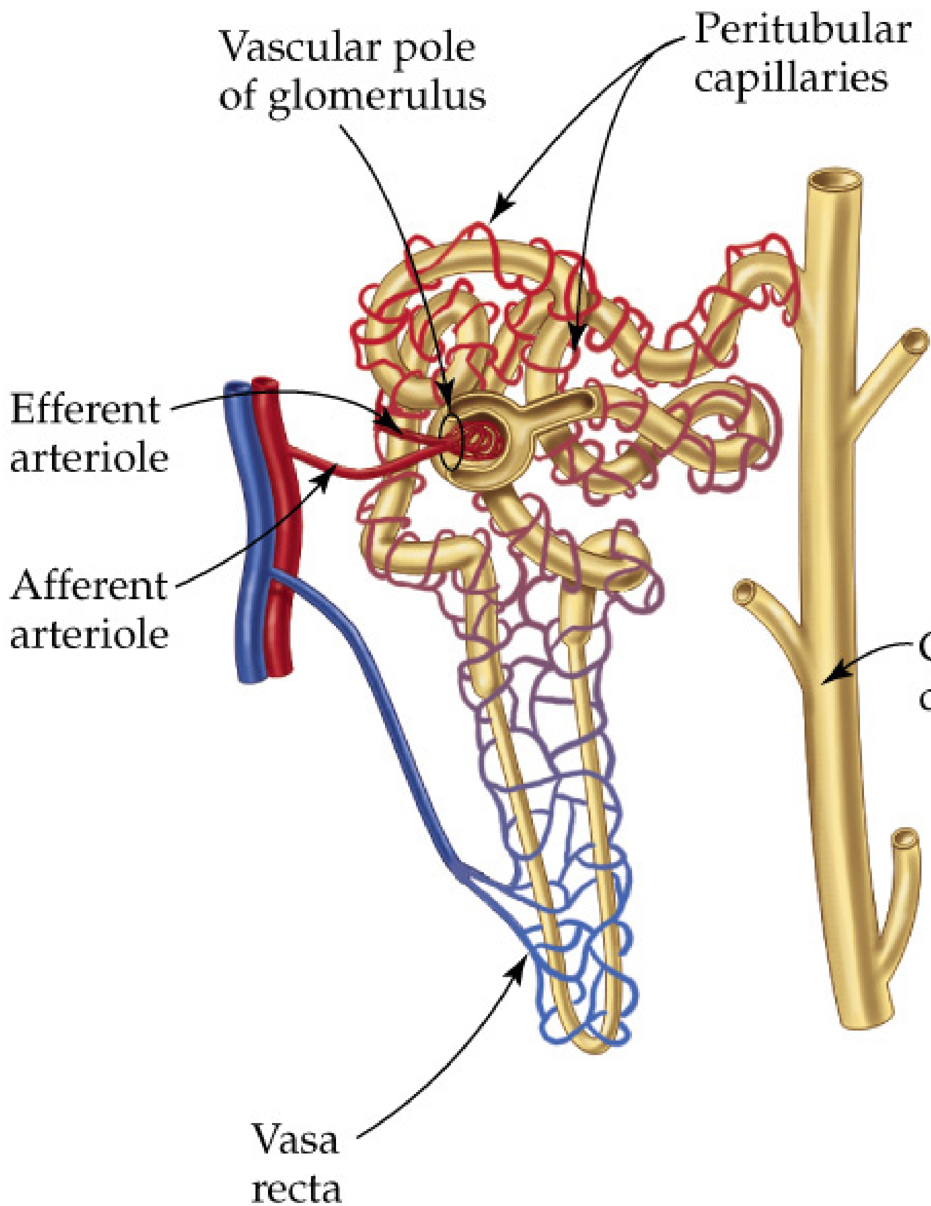
Blood Supply

- Renal aretery enters hilum and divides to **segmental arteries**
- Segmental arteries divide into **interlobular arteries** which penetrate each renal column and travels between the pyramids to the **cortico-medullary junction** where it branches to form the arcuate ateries
- **Arcuate arteries** run parallel along the base of the pyramid and branches to give rise to several **interlobular arteries**, which pass upward into the cortex to form the **afferent arterioles**



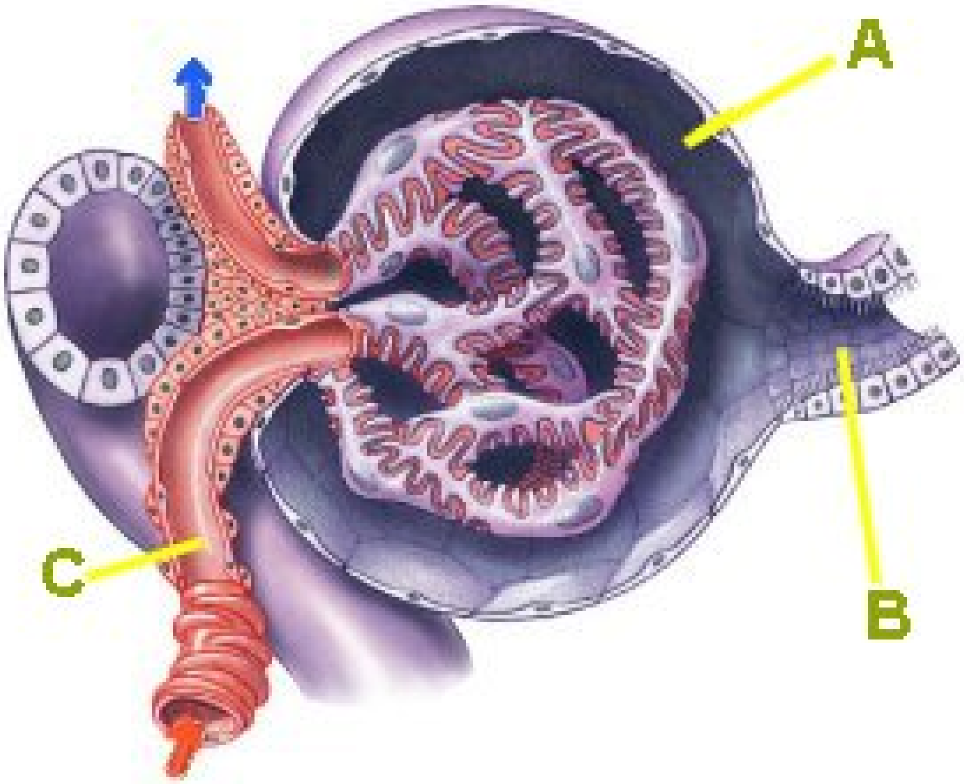
Blood Supply

- The interlobular artery gives of **afferent arterioles** to the glomerulus of each nephron
- The glomerulus is drained by an **efferent arteriole**
- The efferent arterioles leads next to a plexus of **peritublar capillaries** to drain into the interlobular, **arcuate, interlobar, and renal veins.**



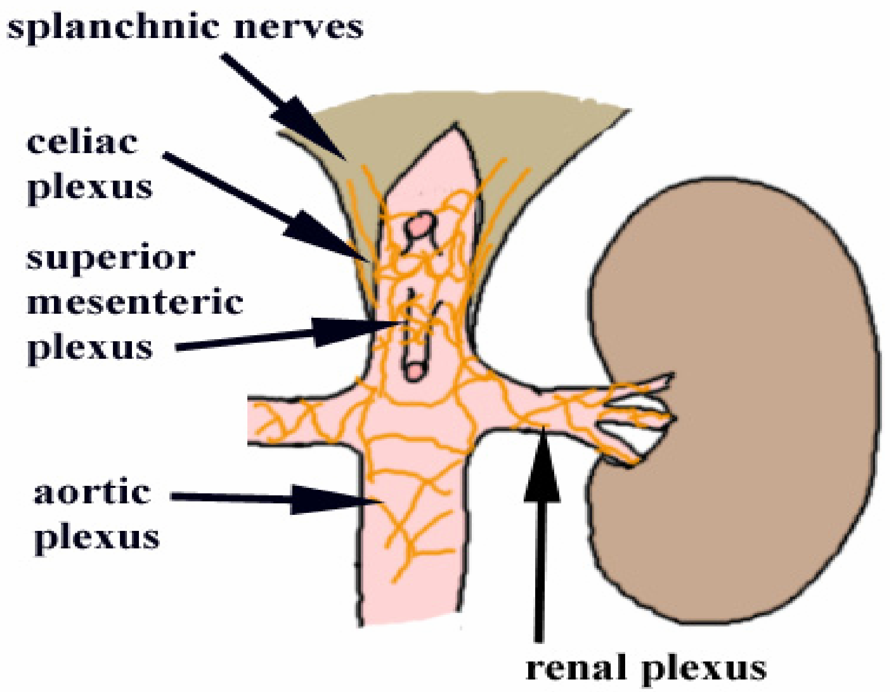
Juxtaglomerular Apparatus

- Area just outside the capsule where the afferent and efferent arterioles contacts the first part of the DCT
- Enables the nephron to monitor and stabilize its own performance and compensate for fluctuations in blood pressure.



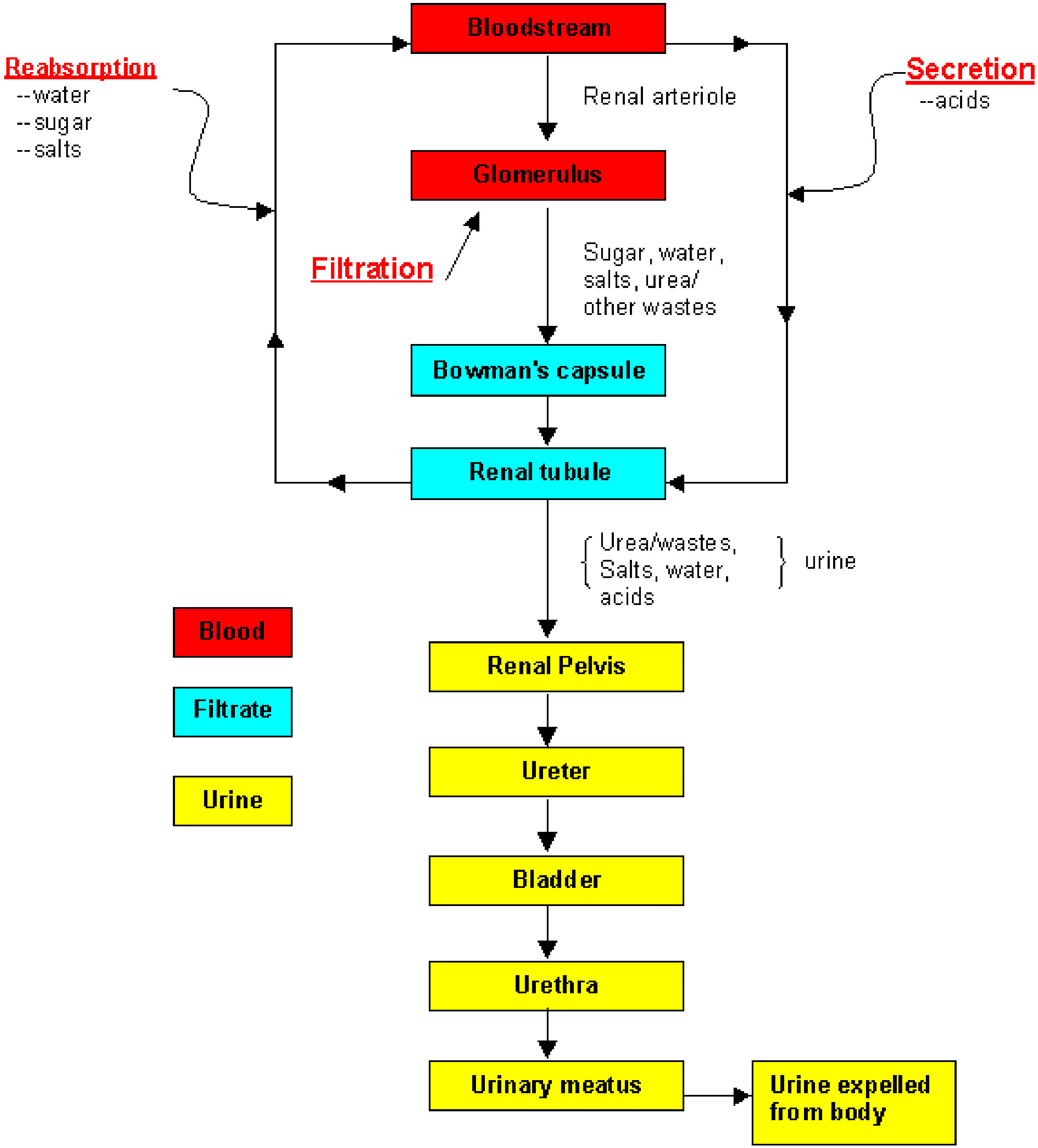
Nerve Supply

- **Renal nerves** arise from the superior mesenteric ganglion and enter the kidney at the hilium.
- They follow the branches of the renal artery to innervate each nephron
- Consist mostly of **sympathetic fibers** that **regulate blood flow into and out of each nephron** thus controlling the filtration rate and urine formation



Innervation of the Kidney

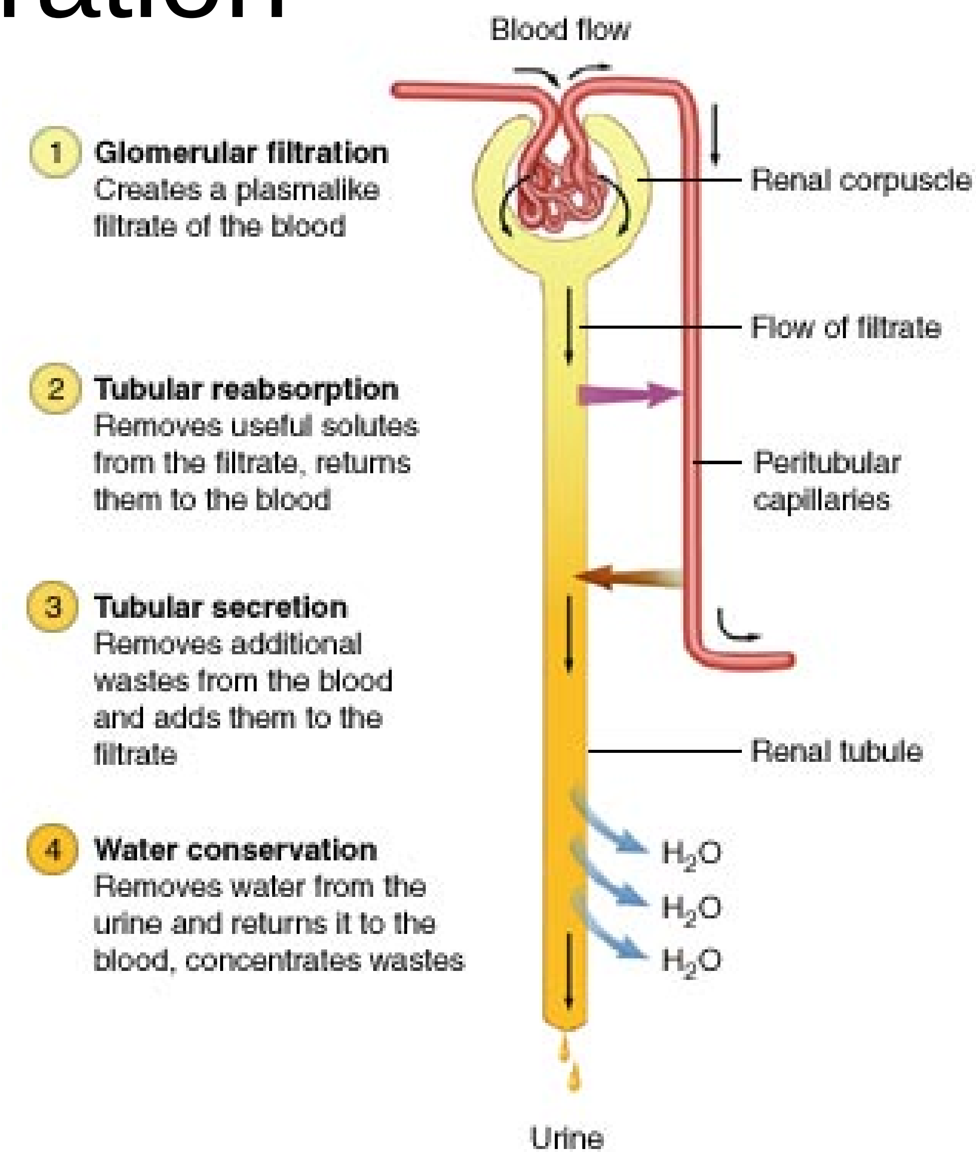
Urine Formation



Urine Formation I: Glomerular Filtration

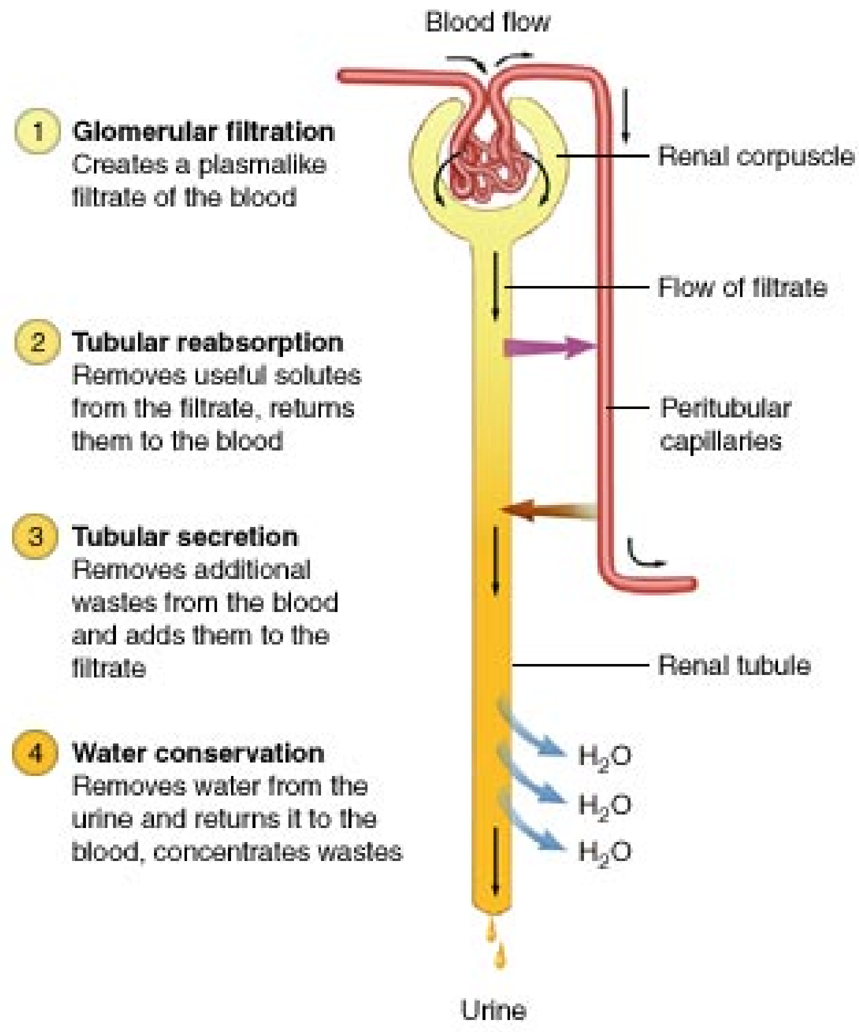
The kidney converts blood plasma to urine in three stages

- **Glomerular filtration**
- **Tubular reabsorption and secretion**
- **Water conservation**



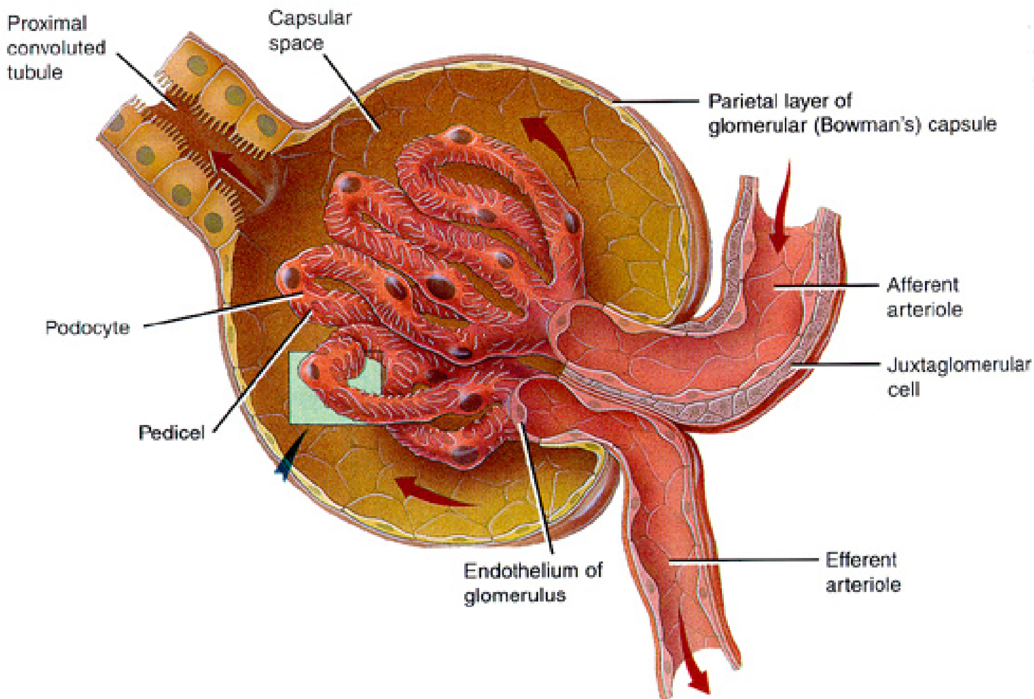
Urine Formation I: Glomerular Filtration

- As fluid travels through the nephron, its composition changes, thus its name
  - **Glomerular filtrate-** fluid in the capsular space that is similar to blood plasma except that it has almost no protein
  - **Tubular fluid-** fluid from the PCT through the DCT
- Differs from the glomerular filtrate in that substances are removed and added by the tubule cells
  - **Urine**- fluid that enters the collecting ducts

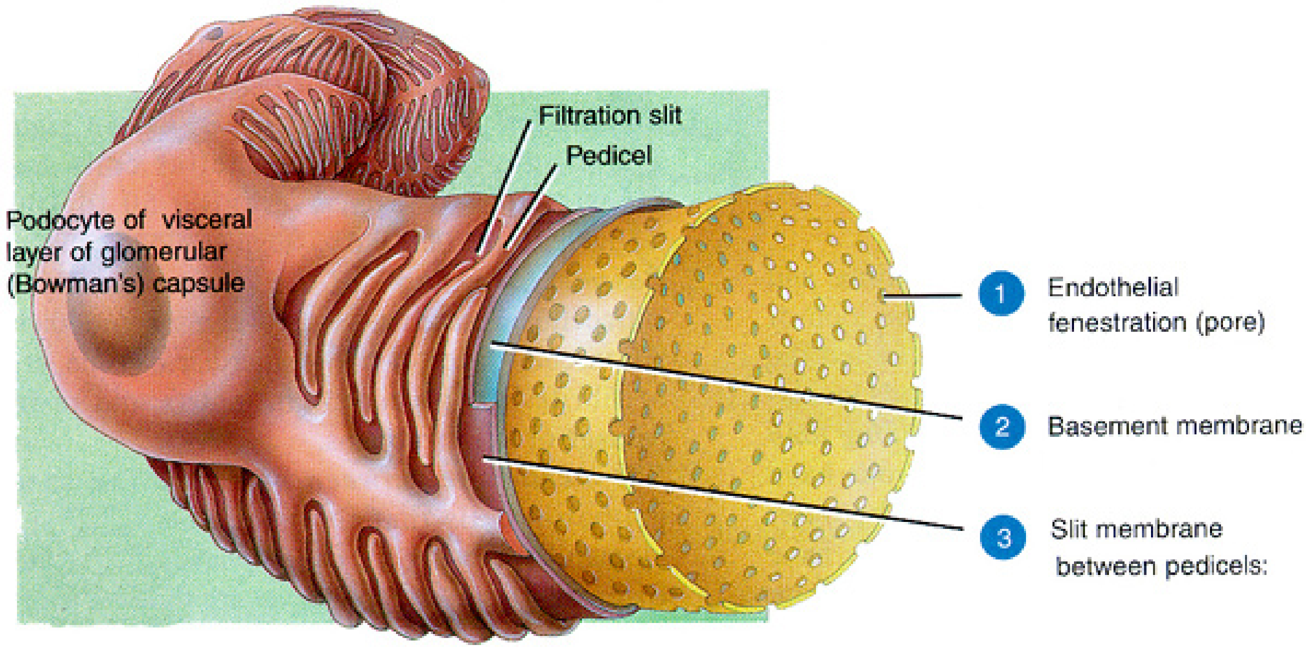


Components of Filtration

- Filtration membrane- the barrier through which the fluid must pass to enter the capsular space. Consist of:
  - The **fenestrated endothelium** of the capillary
  - **The basement membrane**
  - **Filtration slits**

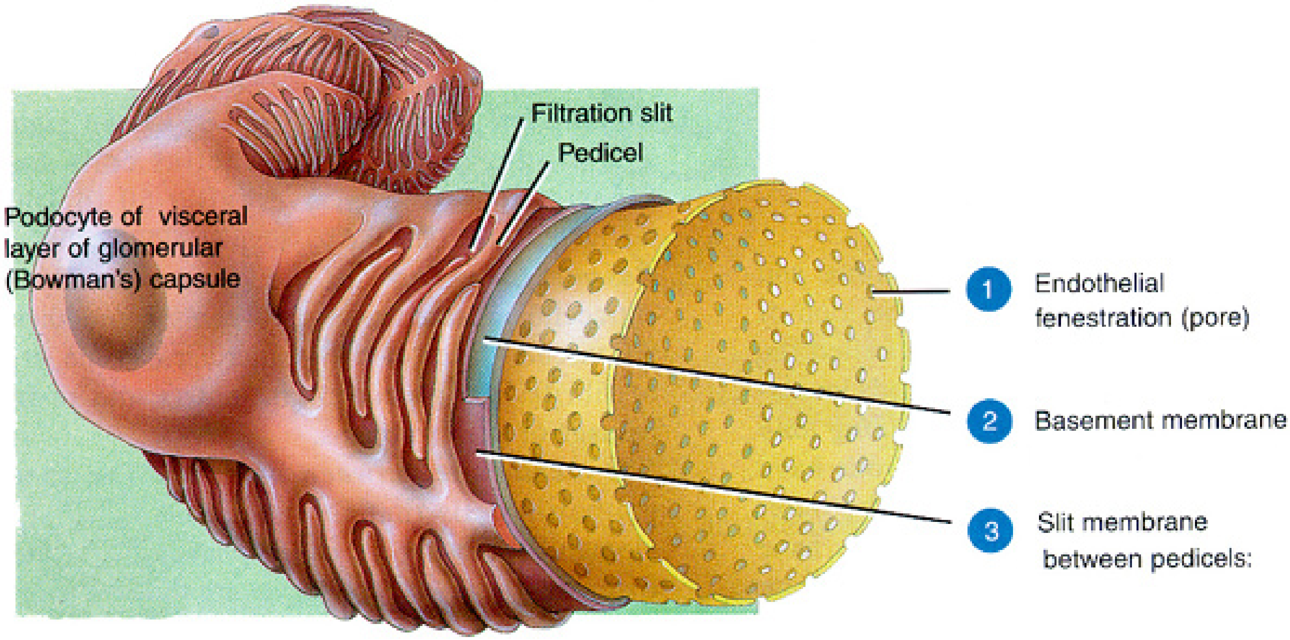


The Filtration Membrane



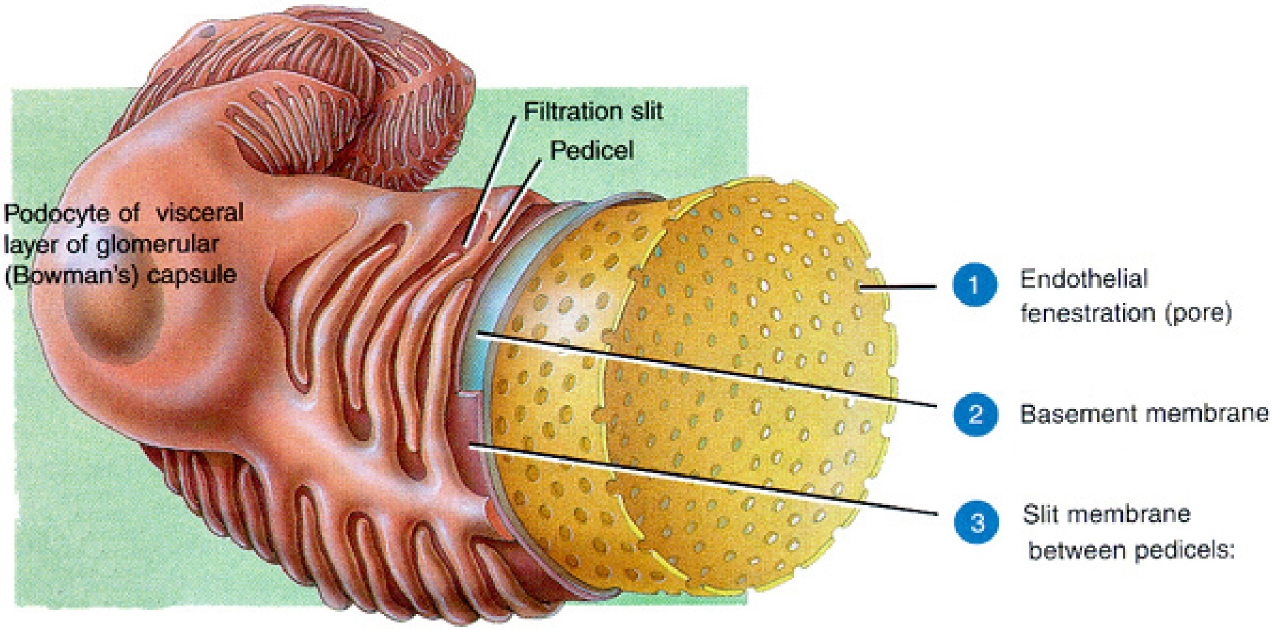
- **The fenestrated endothelium of the capillary**- the honeycombed structure of the capillary endothelium, containing large pores that allow various substances to pass through (not blood cells or large proteins)

The Filtration Membrane



- **The basement membrane-** Its structure is like a kitchen sponge. Most particles larger than 8nm are held back and those with negative charge due to the repelling force created by the negative proteoglycan gel of the membrane.
  - While blood plasma is 7% protein, the glomerular filtrate is only 0.03% protein.
  - It has traces of albumin and smaller polypeptides, including some hormones.

The Filtration Membrane



Filtration slits- octopi like structure of the podcytes

- Each arm has numerous little extensions called pedicles (foot processes) that wrap around the capillaries and interdigitate with each other
- Pedicles have a negatively charged filtration slits

The Filtration Membrane

- Almost any molecule smaller than 3nm can pass through the filtration membrane into the capsular space
  - Water, electrolytes, glucose, fatty acids, amino acids, nitrogenous wastes, and vitamins
  - Some substances that are of low molecular weight are retained in the blood plasma because they are bound to plasma proteins
    - Calcium, iron, thyroid hormome
    - The small fraction of the above that are unbound will pass through

Filtration

- About 20% of the plasma that passes through the kidney gets filtered into the nephron
- Filtration is takes place in the glomerulus
- Driven by the hydrostatic pressure of the blood (osmosis opposes filtration, but the hydrostatic pressure is larger)
- Water and small molecules are filtered; blood cells and large molecules (most proteins) do not pass through the filter

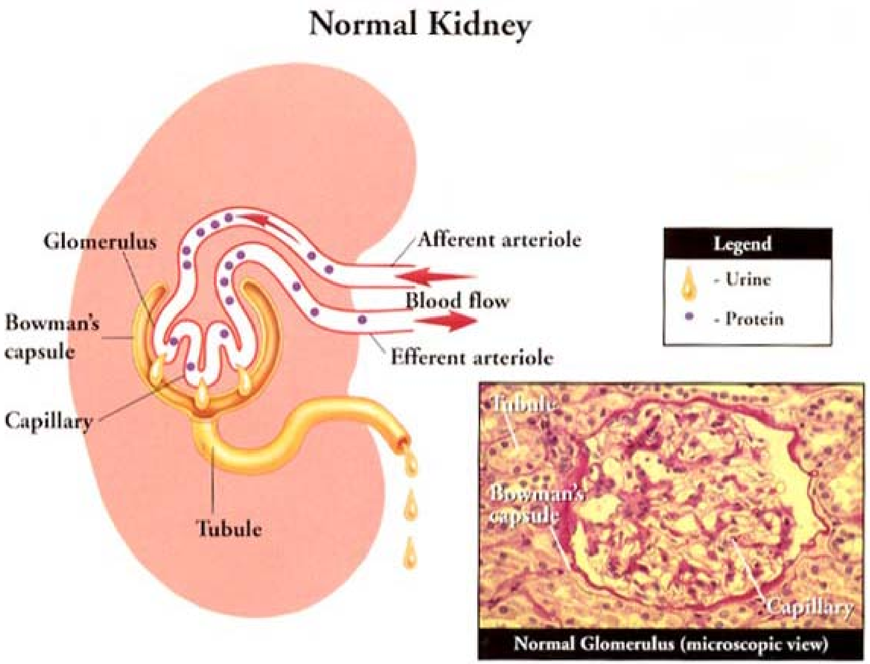
Filtration Membrane

- Kidney trauma and infections can damage the filtration membrane and allow albumin or blood cells to filter through
  - **Proteinuria** (albuminuria)- the presence of protein in the urine
  - **Hematuria**- the presence of blood in the urine
- Strenuous exercise can temporarily cause proteinuria or hematuria
  - Strenuous exercise greatly reduces perfusion of the kidney causing glomerular deterioration due to prolonged hypoxia.

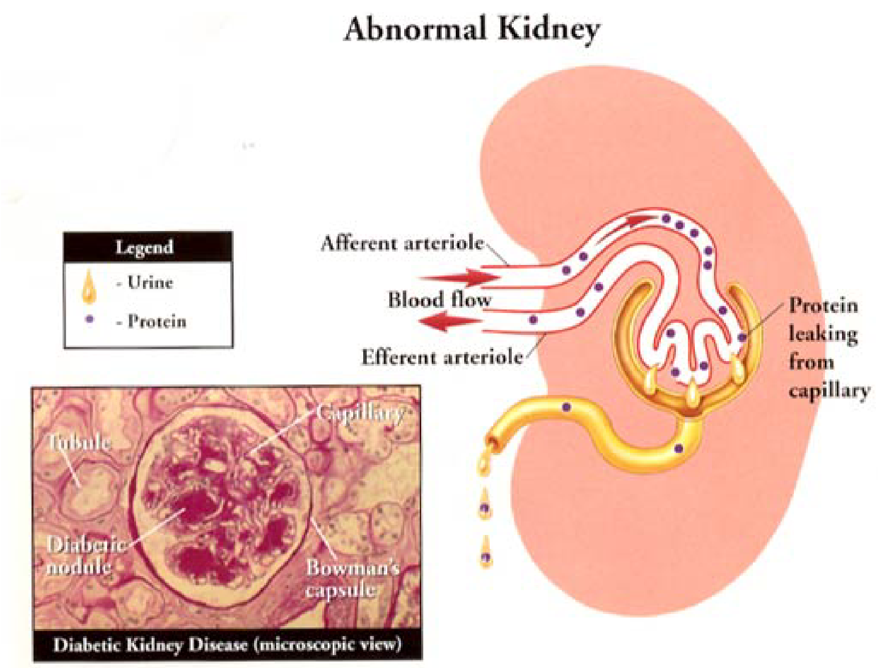
Albuminuria

- More than the normal amount of albumin in the urine. Albumin is the predominant protein in human blood and it is the key to the regulation of the osmotic pressure of blood.
- It is normal to have some albumin in urine. But too much albumin indicates that protein is leaking through the kidney.
- Albuminuria can mean many things. For example, albuminuria may be a sign of significant kidney disease or it may simply be a sequel of vigorous exercise. Albuminuria is a form of proteinuria.

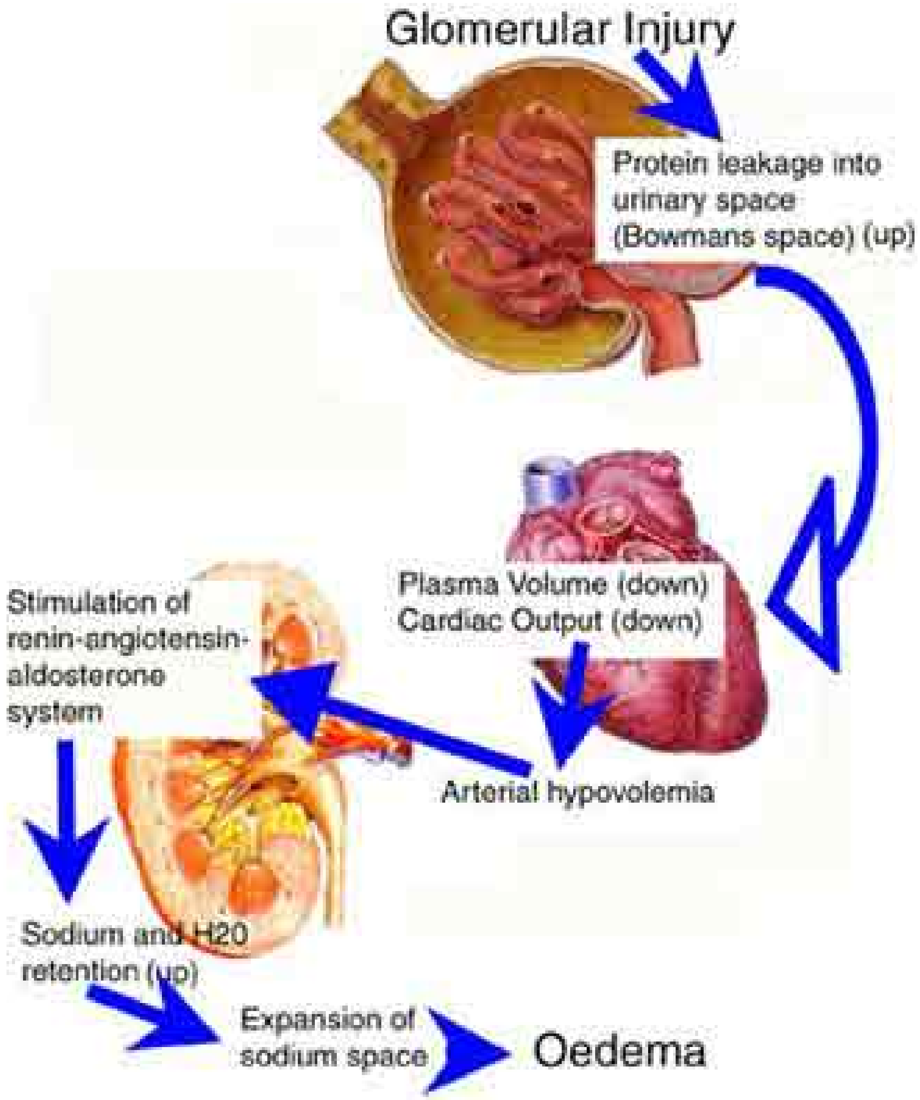
Nephrotic Syndrome



- A group of symptoms caused by excessive loss of protein in the urine
  - Hypoalbuminemia
  - hypercholesterolemia
  - edema



Nephrotic Syndrome

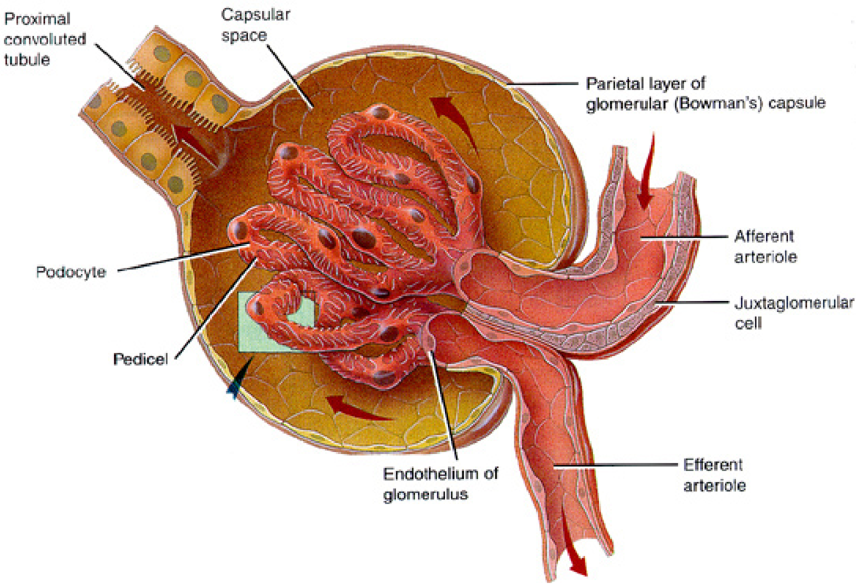


Hematuria

- is a sign that something is causing bleeding in the genitourinary tract
- There are two types of hematuria,
  - **Microscopic**- the amount of blood in the urine is so small that it can be seen only under a microscope.
  - **gross (or macroscopic)-** the urine is pink, red, or dark brown and may contain small blood clots.
  - **Joggers hematuria"** results from repeated jarring of the bladder during jogging or long-distance running.
- Reddish urine that is not caused by blood in the urine is called **pseudohematuria**.
  - Excessive consumption of beets, berries, or rhubarb; food coloring; and certain laxatives and pain medications can produce pink or reddish urine.
- Hematuria occurs in up to 10% of the general population.

Filtration Pressure

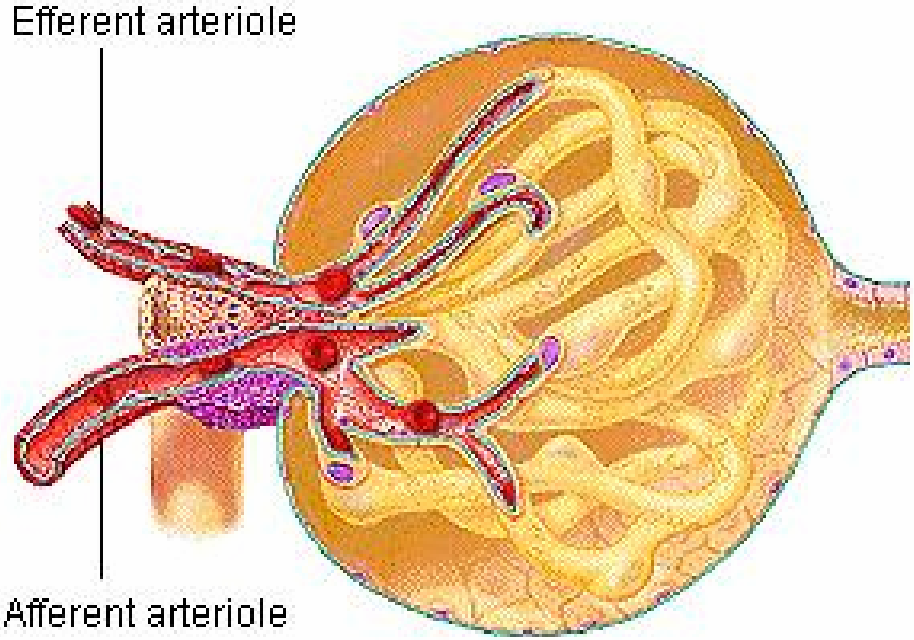
- Glomerular filtration follows the same principles that govern filtration in other blood capillaries but with some significant differences in the magnitude of forces invloved
  - The **blood hydrostatic pressure is much higher**, about 60mm Hg compared with 10-15 mm Hg in most other capillaries
  - Results from the fact that the afferent arteriole is substantially larger than the efferent arteriole, giving the glomerulus **a large inlet and small outlet.**

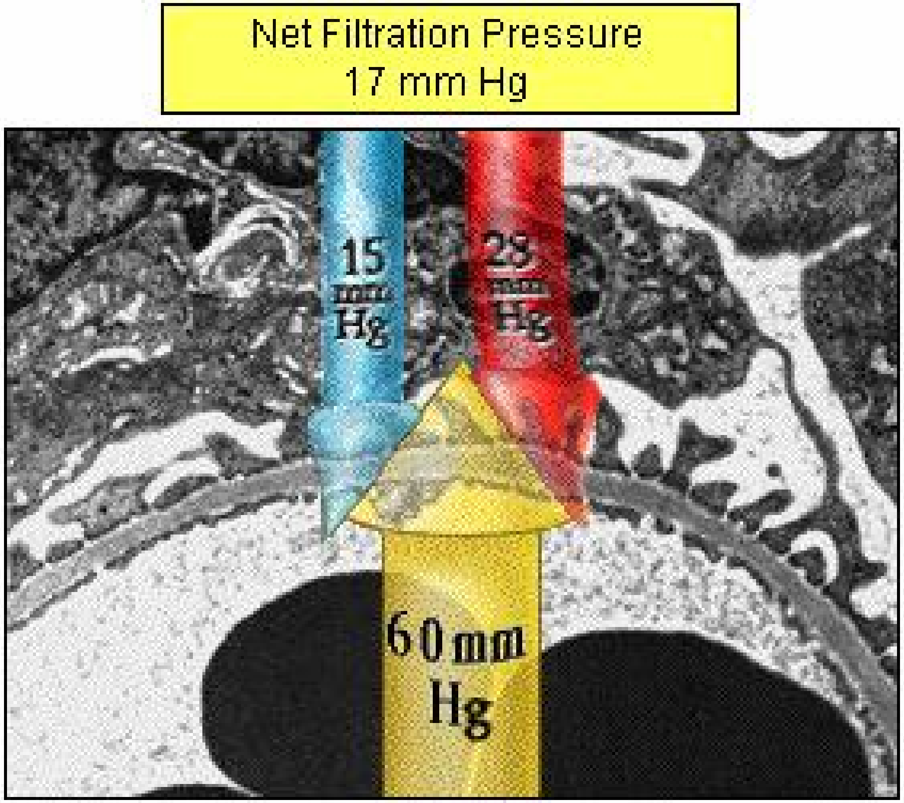


Glomerular and Capsular Pressures

- The hydrostatic pressure in the capsular space is about 18mm Hg compared with the slightly negative interstitial pressure elsewhere
  - Resulting from the high rate of filtration occurring here and the continual accumulation of fluid in the capsule
- The **colloid osmotic** pressure (COP) of the blood is about the **same here as anywhere else** (32mm Hg)
- The **glomerular filtrate** is almost **protein-free and has no significant COP**
  - This can change markedly in kidney diseases that allow protein to filter into the capsular space
- Result, high outward pressure of 60mm Hg, opposed by inward pressures of 18 and 32mm Hg giving a net filtration pressure (NFP) of 10mm Hg

Forces Affecting Filtration





- Glomerular **hydrostatic pressure** (blood pressure) promotes filtration = 60 mm Hg
- Capsular hydrostatic pressure opposes filtration = 15 mm Hg
- Glomerular **osmotic pressure** opposes filtration = 28 mm Hg
- **Net filtration pressure**: 60 mm Hg - (15 mm Hg + 28 mm Hg) = 17 mm Hg

Nephrosclerosis

- High blood pressure in the glomeruli makes the kidneys especially vulnerable to hypertension, which can rupture glomerular capillaries and lead to scarring of the kidney (nephrosclerosis) and atherosclerosis of renal blood vessels, leading to renal failure

Glomerular Filtration Rate

- Is the amount of filtrate formed per minute by the two kidneys combined.
- **Filtration coefficient** (Kf)- for every 1mm Hg of net filtration pressure, the kidney produce about 12.5 mL of filtrate per minute
- Filtration coefficient depends upon
  - **Permeability** of the filtration barrier
  - **Surface area** of the filtration barrier
- GFR = NFP X Kf = 10 X 12.5 = 125mL/min
  - Females have a 10% lower Kf, therefore they calculate at 105mL/min
- The approx. filtrate produced is a rate of 180 L/day in males and 150 L/min in females.
  - 99% of the filtrate is reabsorbed and approx. 1-2 L of urine are excreted per day

Glomerular Filtration is Easy to Measure From Inulin or Creatinine Clearance

- **Renal Clearance-** the volume of blood plasma from which a particular waste is completely removed in 1 minute.
- Two substances are used to measure GFR:
  - **Inulin**: a polysaccharide which is not metabolized by the body or reabsorbed from the urine.
    - Inulin is not found in the body and must be injected.
    - This substance gives the most accurate results and is used for research purposes.
  - **Creatinine**: a breakdown product from creatine phosphate, which is naturally found in the blood.
    - Not quite as accurate as inulin (about 10% is reabsorbed), but often used in medicine, since no injection is required.

Using Inulin in Measuring GFR

- Is only filtered by the kidney; it is neither reabsorbed nor secreteted
- Since no inulin is reabsorbed from or secreted into the tubule, the amount filtered into the tubule at the glomerulus must equal the amount appearing in the urine

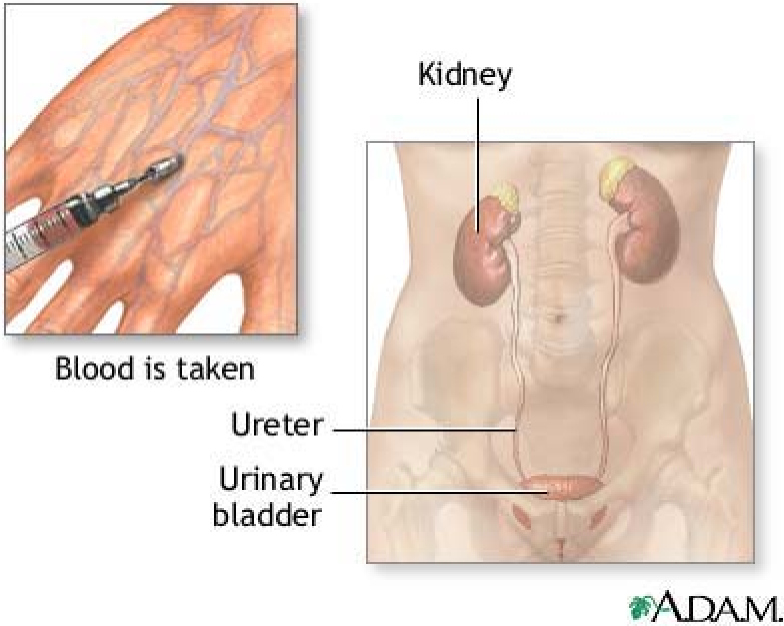
$$P \times GFR = U \times V$$

- P = plasma concentration of inulin, in mg/mL
- GFR = glomerular filtration rate of plasma, in mL/min
- U = urine concentration of inulin, in mg/mL
- V = rate of urine production, in mL/min
- Solving the equation for GFR will give:

$$GFR = (U \times V)/P$$

Kidney Function Tests

- Blood or urine is commonly collected to test for how the kidneys are functioning.
- Some kidney function tests include:
  - Blood test
    - Serum creatinine
    - Blood urea nitrogen (BUN)
  - Urine test
    - Protein
    - Glucose
  - Creatinine clearence test



Creatinine

- Creatinine is a by product of muscle metabolism
- Serum creatinine level and "creatinine clearance" are different ways of determining kidney function.
- The amount produced is relatively stable in a given person and is dependent on muscle mass
- The creatinine level in the serum is therefore determined by the rate it is being removed, which is roughly a measure of kidney function.
  - If kidney function falls (say a kidney is removed to donate to a relative), the creatinine level will rise.
  - Normal is about 1 for an average adult.

Creatinine Clearance Test

- Used to evaluate kidney function
- Creatinine clearance is the amount of blood that is "cleared" of creatinine per time period.
- It is usually expressed in ml per minute. Normal is 120 ml/min for an adult.
- A blood sample is drawn and the amount of creatinine concentration is compared with the amount of creatinine excreted in the urine during a 24-hour period
- Clearance of less than 10 ml/min will cause the symptoms of renal failure and nessitates dialysis

For substances which are reabsorbed and/or secreted the formula is slightly different:

$$P \times C = U \times V$$

- C = clearance rate of the substance (takes into account secretion and reabsorption)
- P = plasma concentration, in mg/mL
- U = urine concentration, in mg/mL
- V = rate of urine production, in mL/min

$$C = (U \times V)/P$$

Clearance measurements tell you how the kidney handles the substance

- Filtered + reabsorbed: C will be less than the GFR
- Filtered only: C = GFR (about 120 mL/min)
- Filtered + secreted: C will be higher than the GFR

Regulation of Glomerular Filtration

GFR must be finely controlled

- If it is too high
  - Fluid flows through the renal tubules too rapidly for them to reabsorb the usual amount of water and solutes
  - Urine output rises and creates a threat of dehydration and electrolyte depletion
- If it is too low
  - Fluid flows sluggishly through the tubules and they reabsorb wastes that should be eliminated and azotemia may occur
- GFR is adjusted by three homeostatic mechanisms
  - **Renal autoregulation**
  - **Sympathetic control**
  - **Hormonal control**

Renal Autoregulation

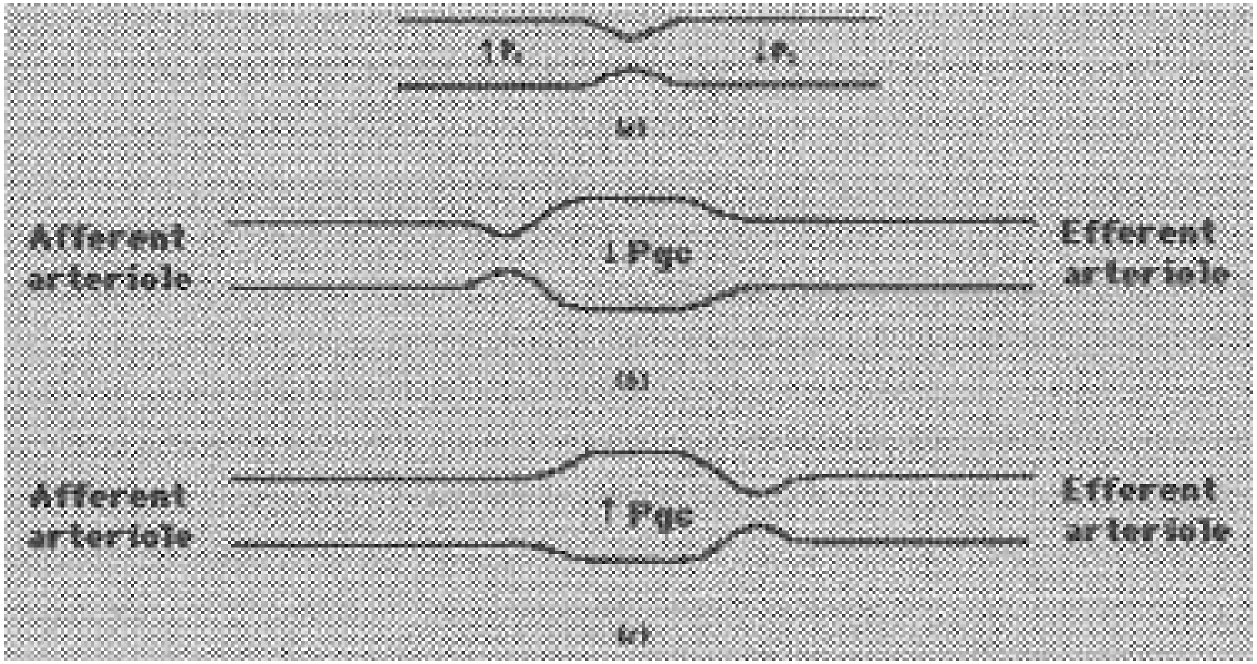
- The ability of the nephrons to adjust their own blood flow and GFR without external (nervous or hormonal) control.
- Allows stable fluid and electrolyte balance in spite of alterations in mean arterial pressure.
- Therefore, a primary role of the renal autoregulatory mechanism is to regulate intrarenal hemodynamics and intrarenal pressures to levels that maintain an optimal balance with tubular metabolic functions.
- There are two mechanisms of autoregulation
  - **Myogenic mechanism**
  - **Tubuloglomerular feedback**

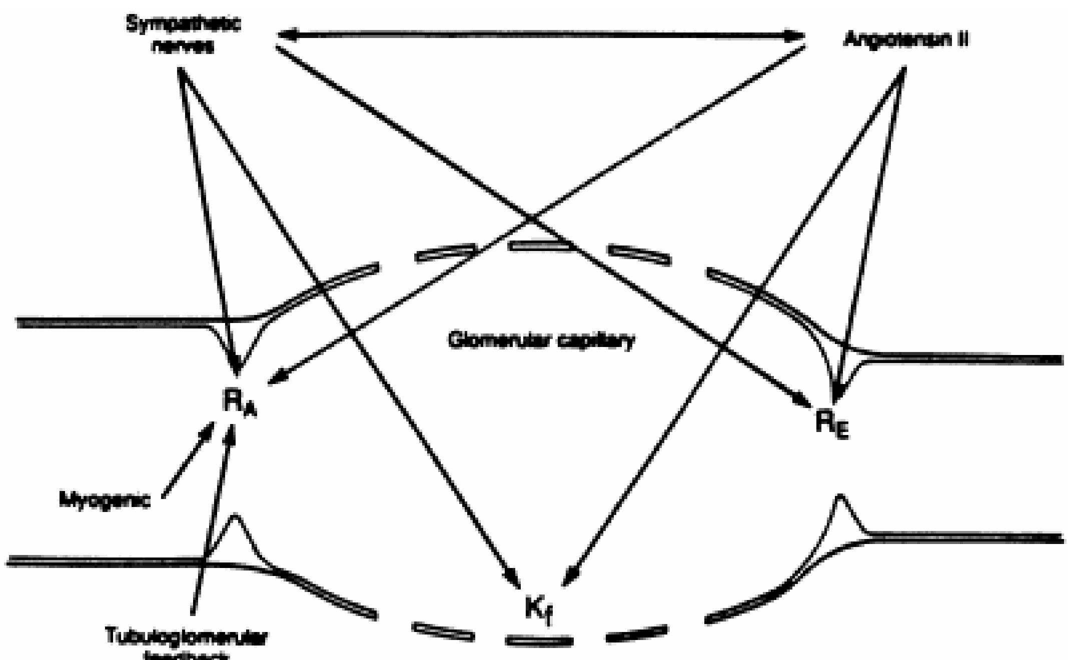
Myogenic Mechanism

- Keeping mind that

GFR = Pgc (filtration pressure) **x Kuf** (ultrafiltration coefficient) and filtration pressure is a matter of blood pressure (or glomerular capillary pressure)

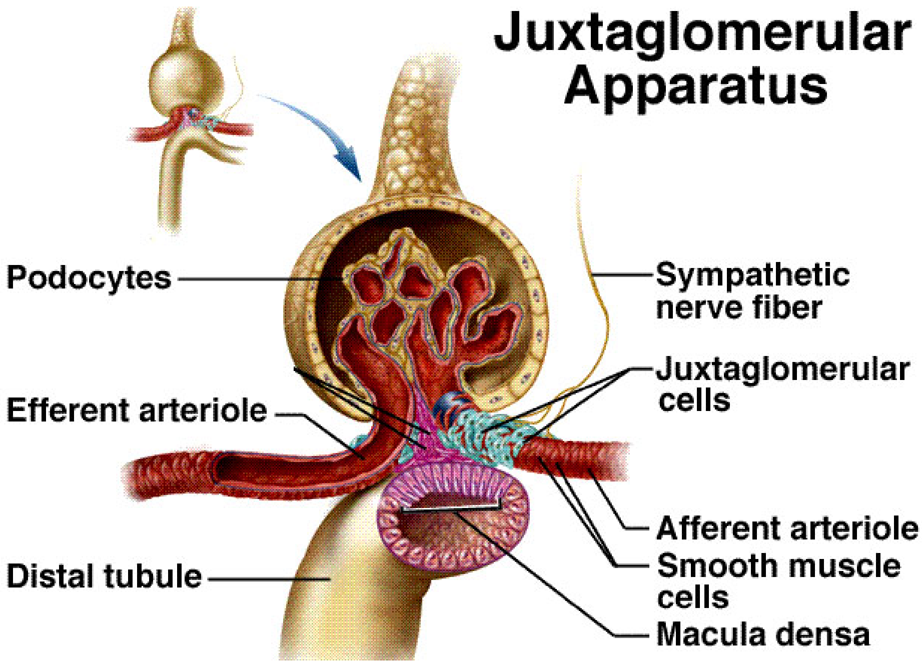
- Blood pressure changes are sensed through stretch receptors and respond accordingly through relaxation or constriction.
  - **afferent arteriolar vasoconstriction** would serve to protect the glomerulus from uncontrolled systemic hypertension,
  - while **afferent arteriolar vasodilatation** would allow for greater blood flow into the glomerulus in times of hypotension
- The autoregulatory system accomplishes this by maintaining the glomerular capillary pressure around 60-70 mm Hg
- This ability to maintain renal perfusion pressure and glomerular capillary pressure is impaired when mean arterial pressure drops below 70 mmHg.


Afferent arteriole
↓Pgc
Efferent arteriole
Afferent arteriole
↑Pgc
Efferent arteriole


Sympathetic nerves
Angiotensin II
Glomerular capillary
R_A
R_E
Myogenic
K_f
Tubuloglomerular feedback

Tubuloglomerular Feedback

- Juxtaglomerular apparatus is made up of specialized cells in the wall of the afferent arteriole and granular cells in the wall of the distal tubule (the **macula densa**).
- This area is innervated by adrenergic fibers and the granular cells carry **renin** in intracellular granules



Tubuloglomerular Feedback

- The principle function of the JGA is adapting the GFR to early distal tubule fluid characteristics by modulating renin synthesis and release: this is known as the **tubuloglomerular feedback (TGF) loop.**
- Afferent arteriolar caliber is principally controlled by TGF
- Besides **altered sodium concentration** at the macula densa of the distal tubule, release of renin can also be induced by **changes in the blood flow** patterns of the afferent arteriole, or by **adrenergic stimulation**.

Renin-Angiotensin Mechanism

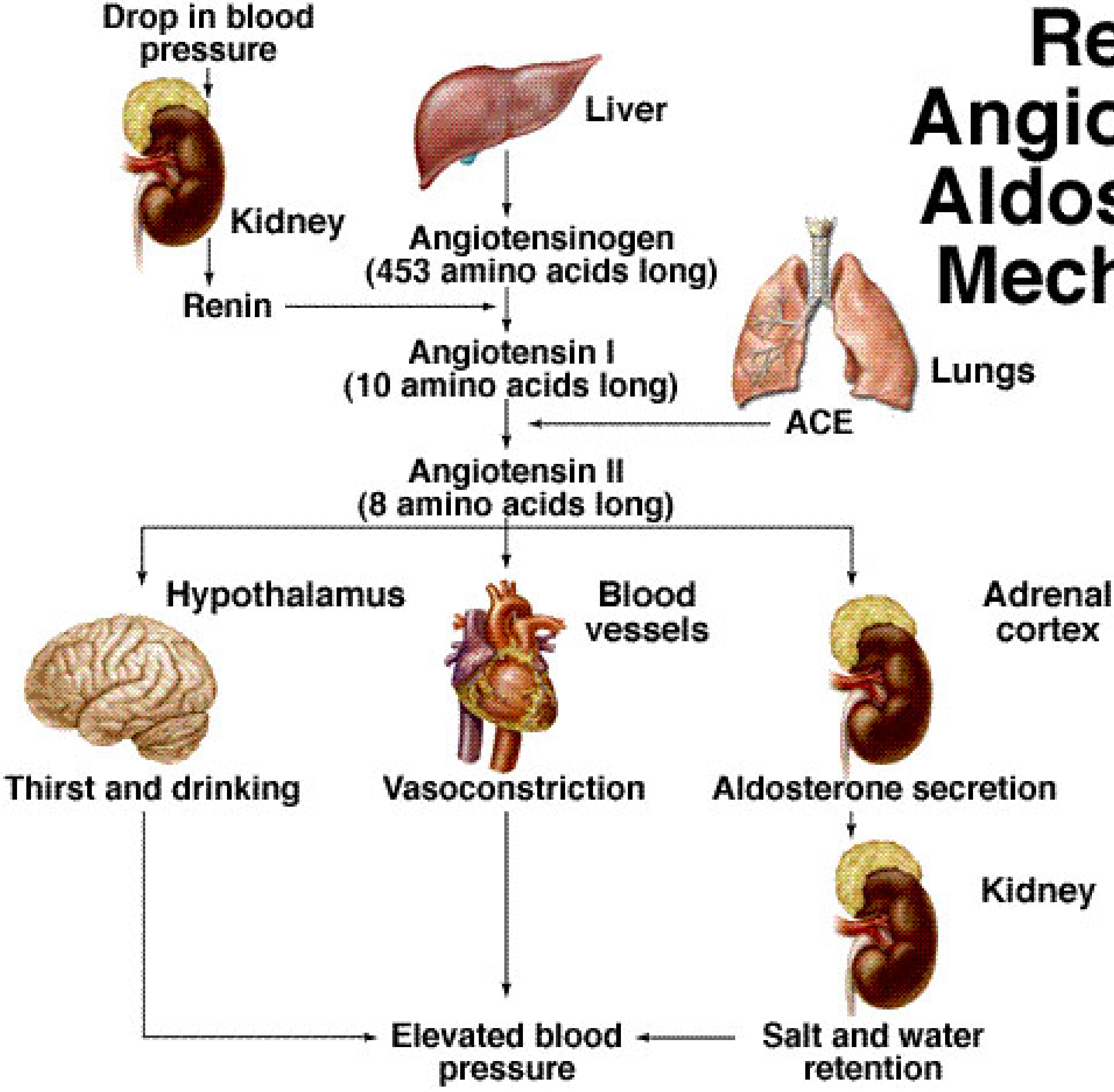
- When blood pressure drops, the sympathetic nerves stimulate the JGA cells to secrete renin
- Renin acts on angiotinsinogen to create angiotensin.
- Angiotensin is converted to angiotensin II by the action of angiotensin-converting enzyme (ACE) from the lungs and kidneys
- Angiotensin II has multiple effects

Renin-Angiotensin Mechanism

- Stimulates widespread vasoconstriction which raises the Mean Arterial Pressure throughout the body
- Constricts both the afferent and <u>efferent arterioles</u> (more prominent here because of greater concentration of A II receptors) which reduces GFR and water loss
- Stimulates the secretion of antidiuretic hormone which promotes water reabsorption
- Stimulates the adrenal cortex to secrete aldosterone, which in turn promotes sodium and water retention
- Stimulates the sense of thirst and encourages water intake

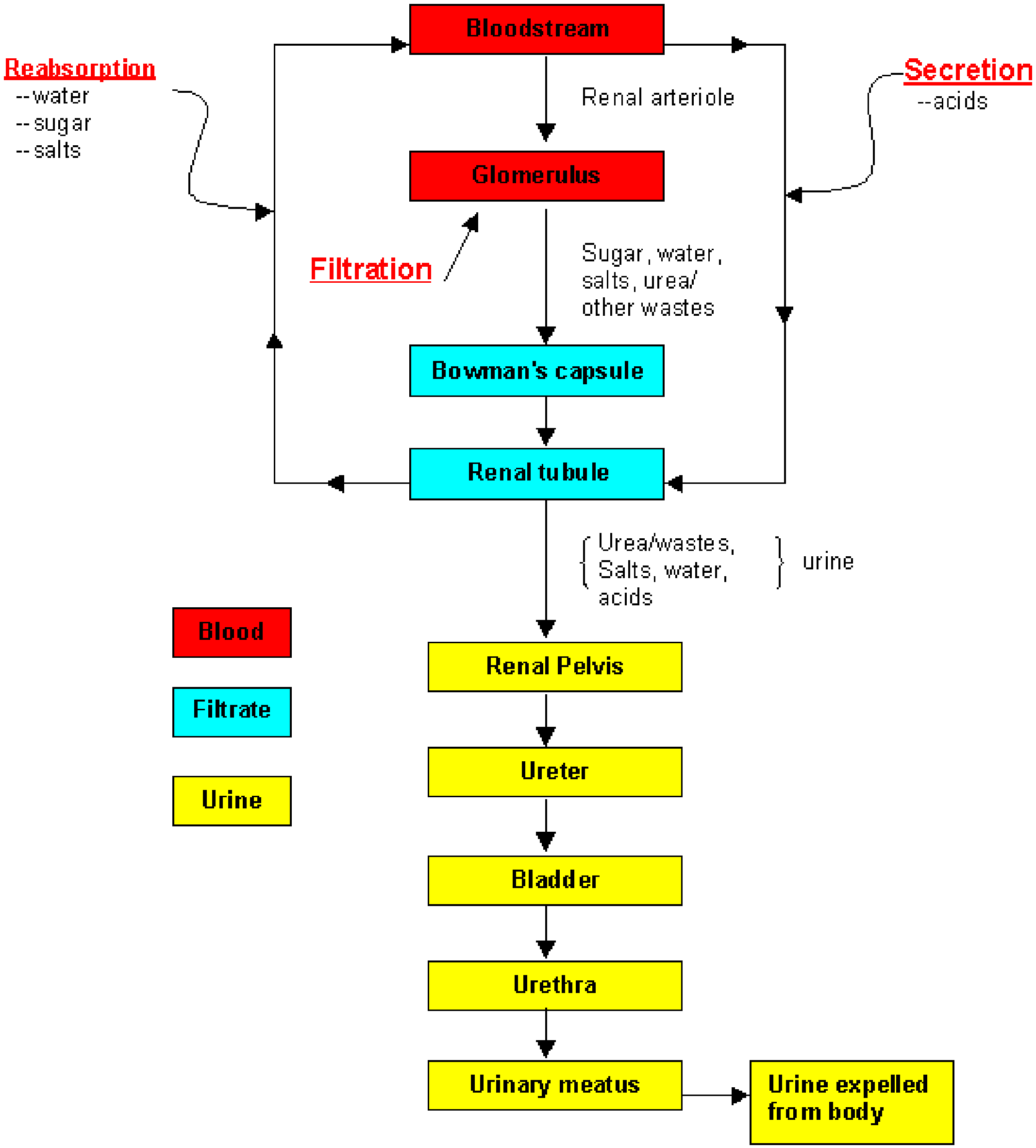
- In summary, renal vascular resistance controlled by
- **Intrinsic mechanisms**
  - Stretch receptors in wall of afferent and efferent arterioles
- **Extrinsic mechanisms**
  - Hormones – renin-angiotensin II axis
- AII acts to increase efferent arteriolar tone
  - **Sympathetic innervation**- in strenuous exercise of acute conditions such as circulatory shock
- Norepinephrine directly increases afferent arteriolar tone causing a reduction in GFR and urine production, while redirecting blood from the kidneys to the heart, brain, and skeletal muscles
- Angiotensn II release is dependent on renin release which results from
  - blood flow changes in the afferent arteriole
  - adrenergic stimulation
  - solute changes at the macula densa

Renin-Angiotensin-Aldosterone Mechanism



Urine Formation II: Tubular Reasorption and Secretion

- Conversion of glomerular filtrate to urine involves the removal and addition of chemicals by tubular reabsorption and secretion.
- This modification occurs as the filtrate flows through the nephron, from the PCT through the DCT



Proximal Convoluted Tubule

- Reabsorbs about 65% of the glomerular filtrate
  - Relatively great length and prominent microvilli, which increases absorptive surface area
  - Cells contain abundant large mictochondria that provide ATP for active transport
- 6% of resting ATP and calories are consumed by the PCTs

- Tubular reabsorption-the process of reclaiming water and solutes from the tubular fluid and returning them to the blood
- Two routes of absorption

Proximal Convoluted Tubule

- Tubular reabsorption-the process of reclaiming water and solutes from the tubular fluid and returning them to the blood
- Two routes of absorption
  - Transcellular- substances pass through the cytoplasm and out the base of the epithelial cell
  - Paracellular- substances pass between the cells
    - Tight junctions are quite leaky and allow for significant amounts of water, minerals, urea, and other matter to pass

Sodium Reabsorption

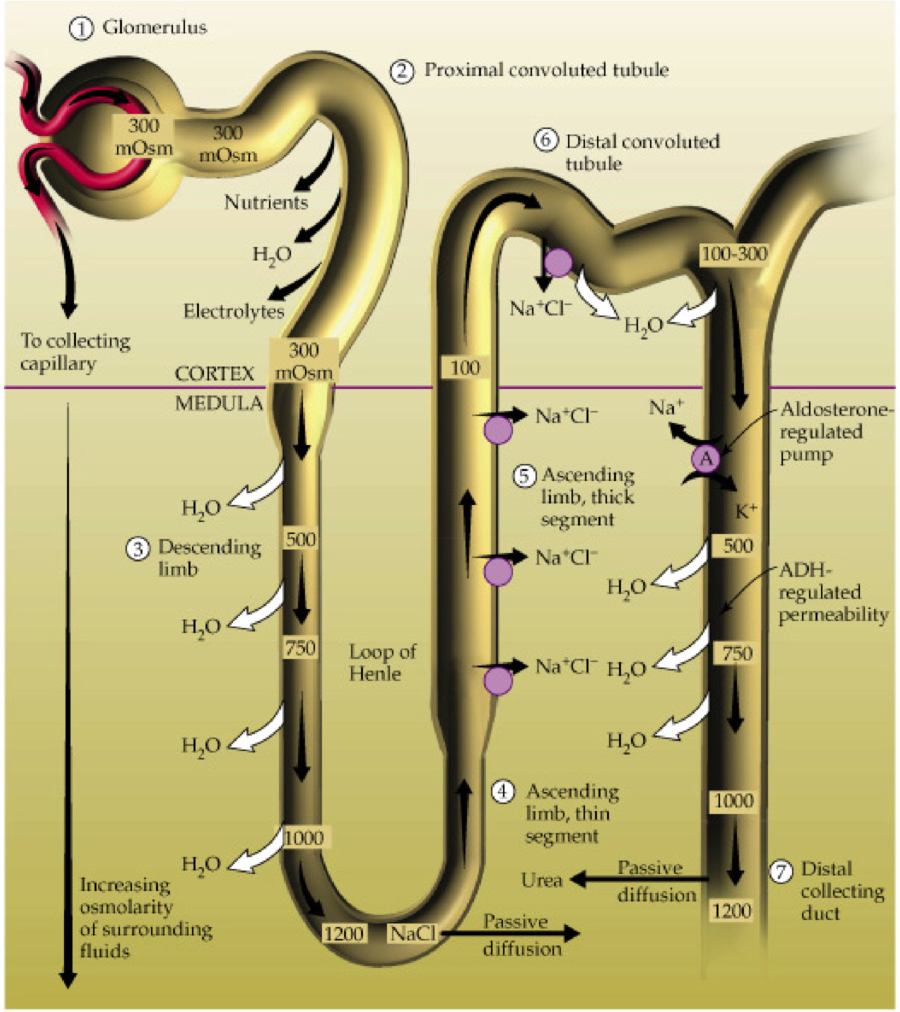
- Sodium reabsorption is the key to everything else, because it **creates an osmotic and electrical gradient** that drives the reabsorption of water and other solutes
- Is reabsorbed by both transcellular and paracellular routes

DCT & Collecting Ducts

- **Controls fluid and sodium/potassium balance because cells are subject to hormonal control** (esp. aldosterone, atrial natriuretic peptide, ADH, and parathyroid hormone)
- Has two kinds of cells
  - **Principal cells**-
    - Are more abundant
    - Have receptors for the above hormones and are involved chiefly in salt and water balance
  - **Intercalated cells**-
    - Are fewer in number
    - Reabsorb K+
    - secrete H+ into the tublule lumen
    - involved mainly in acid-base balance

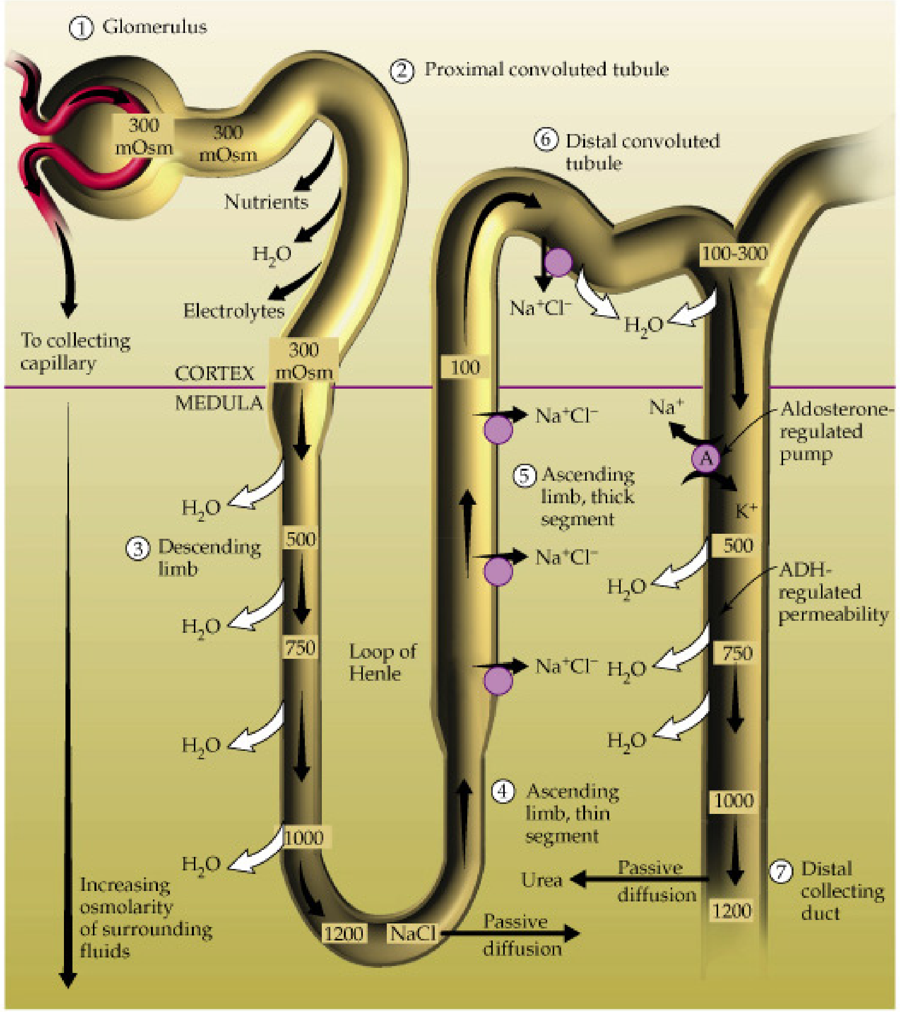
Countercurrent Mechanism Establishes Sodium Gradient From Cortex to Medulla

- The Kidney Has an Osmotic Gradient From Cortex to Medulla
- Osmotic gradient is produced by a countercurrent mechanism located in the loop of Henle
- The countercurrent mechanism is based upon the Na pump; by pumping large quantities of Na into the interstitial fluid in the medulla a very high concentration is built up



Countercurrent Mechanism Establishes Sodium Gradient From Cortex to Medulla

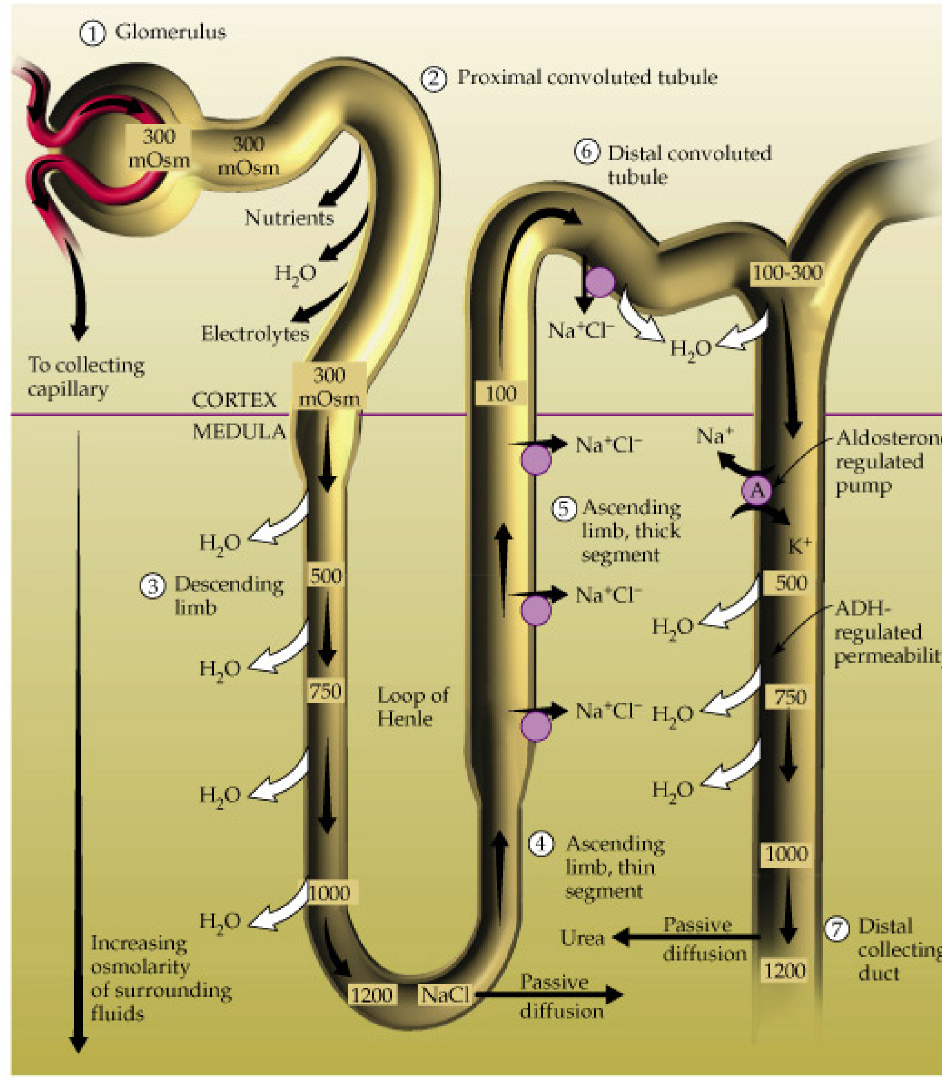
- The Kidney Uses Osmosis in the Collecting Duct to Control the Concentration and Volume of Urine
- •The concentration of the urine is adjusted in the collecting ducts of the kidney.
- •The collecting ducts pass through tissue with a very high osmotic pressure in the medulla.
- •Water will be sucked out of the tubules by osmosis if the tubules are permeable.



User:

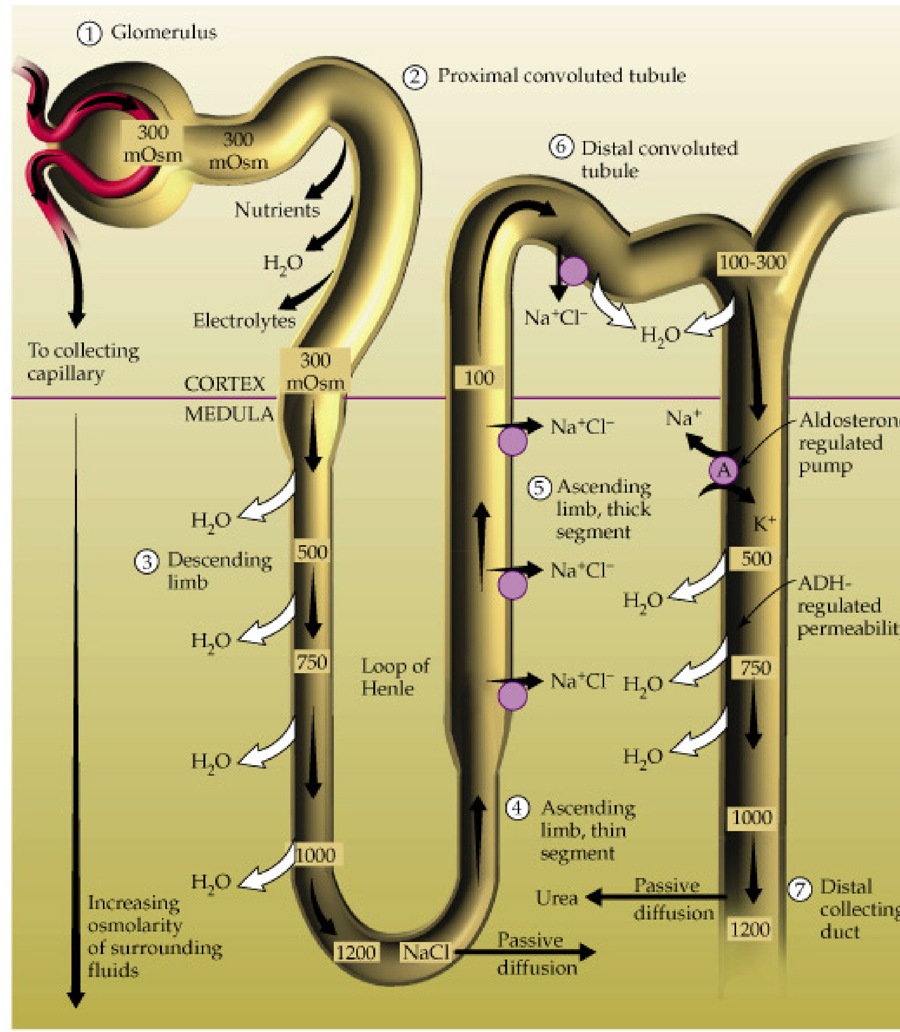
ng Duct & Urine Production

- •As the urine passes into the collecting duct it first passes through a region of isotonic osmotic pressure (300 milliosmoles/liter) and then through a region of hypertonic osmotic pressure (up to 1200 milliosmoles/liter)



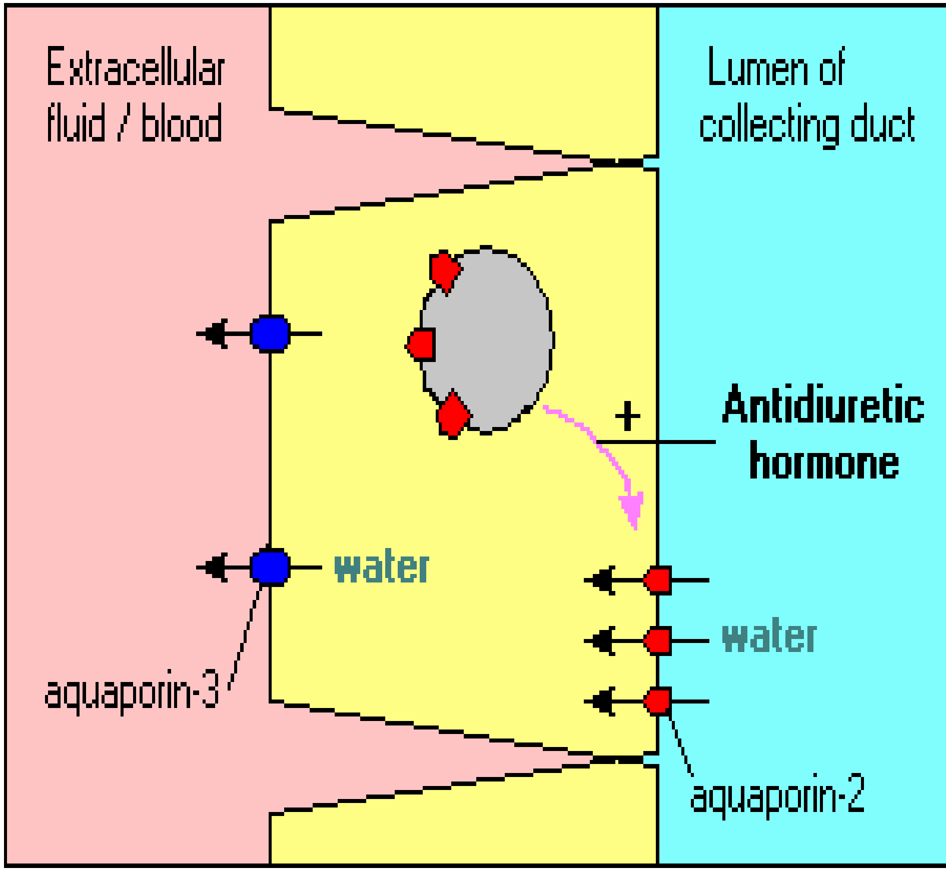
Collecting Duct & Urine Production

- If the collecting duct has low water permeability the dilute urine in the kidney tubule passes through with little uptake of water
  - This produces large amounts of dilute urine (diuresis)
- If the collecting duct has high water permeability much of the water will be reabsorbed from the collecting duct into the interstitial fluid
  - This produces small amounts of concentrated urine (antidiuresis)



ADH Controls Kidney Osmosis by Inserting Water Pores into the Collecting Duct

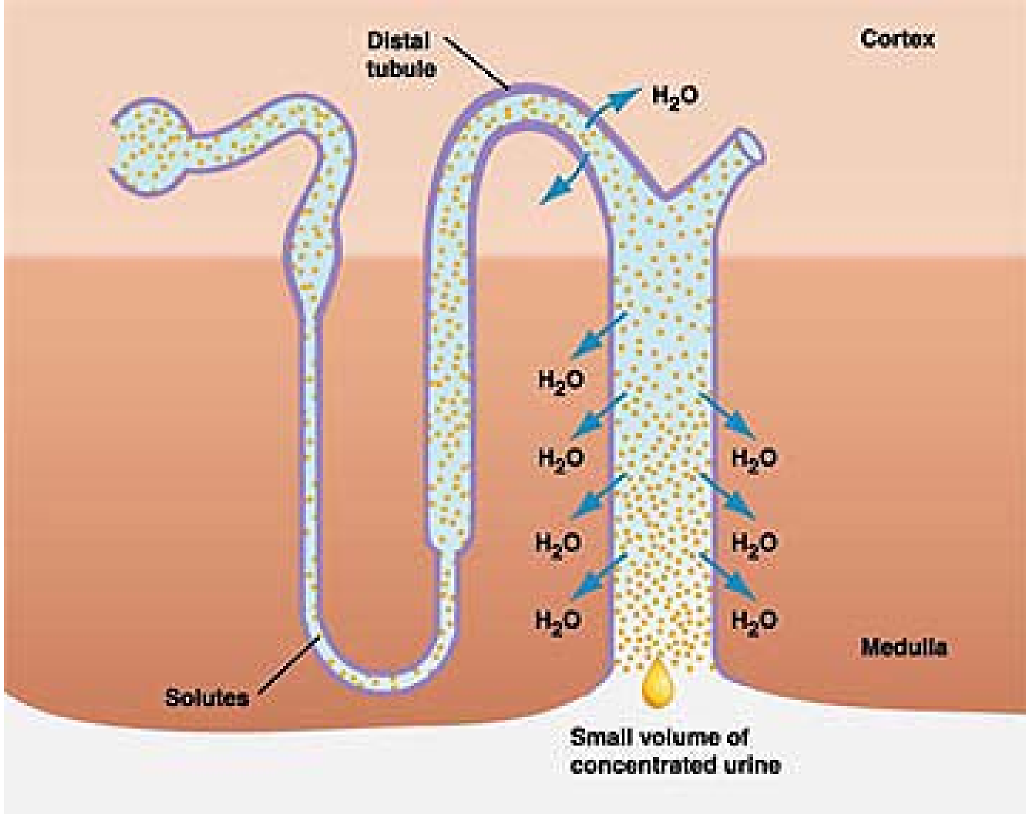
- The permeability of the collecting duct is determined by water pores (**aquaporin-2**) which are under the control of **antidiuretic hormone** (ADH- also called vasopressin) from the posterior pituitary
- The water pores are made by the cells lining the collecting duct
- Pores are stored in vesicles called endosomes and are inserted when needed
- If ADH is present they are inserted into the cell membranes facing the tubule
- If ADH is low the channels are removed from the membranes (down-regulated)



Effects of Antidiuretic Hormone

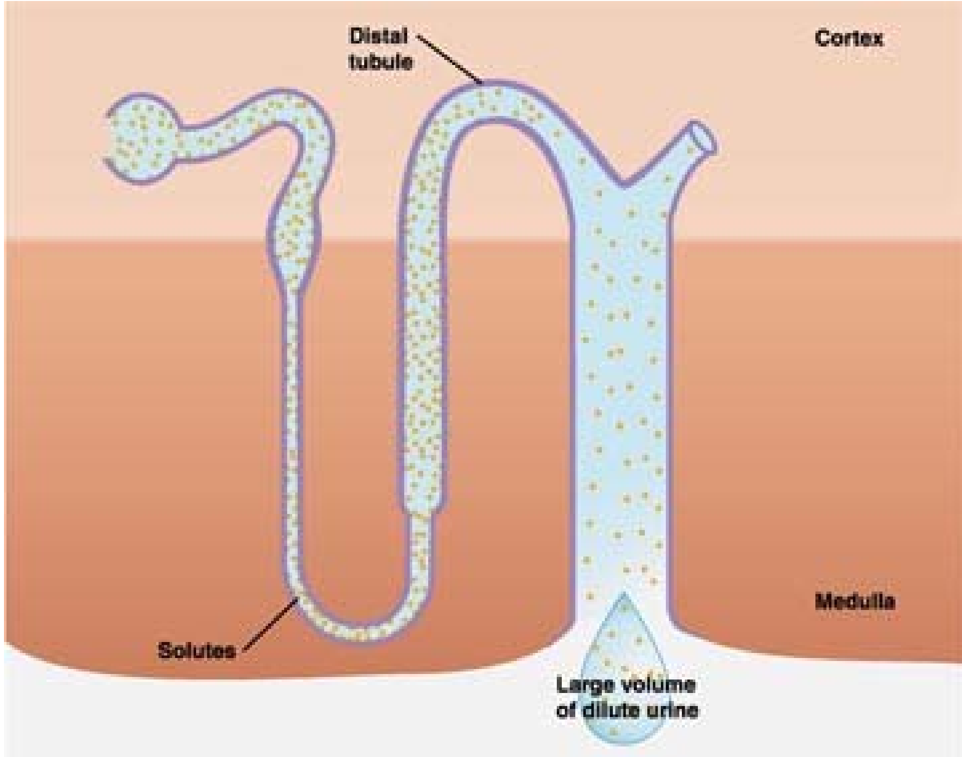
- If ADH is High the Kidney Makes Concentrated Urine and Conserves Water
- When a person is dehydrated the blood osmotic pressure rises
- Under these conditions osmoreceptors in the hypothalamus fire, causing the posterior pituitary to secrete large amounts of ADH
- The ADH will cause the kidney collecting ducts to insert water pores
- More water will be conserved, preventing further dehydration
- The dehydration will also make the person thirsty and drinking will

  restore the water volume



Effects of Antidiuretic Hormone

- If ADH is Low the Kidney Makes Large Volumes of Dilute Urine
- If a person has recently consumed a lot of water the ADH secretion will be low
- Water channels will be down-regulated from the collecting duct
- Less water will be reabsorbed
- The increased urine production will remove the excess water



Defects in the ADH Mechanism Cause Diabetes Insipidus

- Diabetes insipidus is the continuous production of large amounts of watery urine (5-10 L/day)
- The urine does not contain sugar, as it does in diabetes mellitus
- ADH mechanism can fail in 2 ways:
  - Posterior pituitary does not secrete enough ADH (blood ADH will be low)
  - Kidney does not respond to ADH (nephrogenic: blood ADH will be normal)

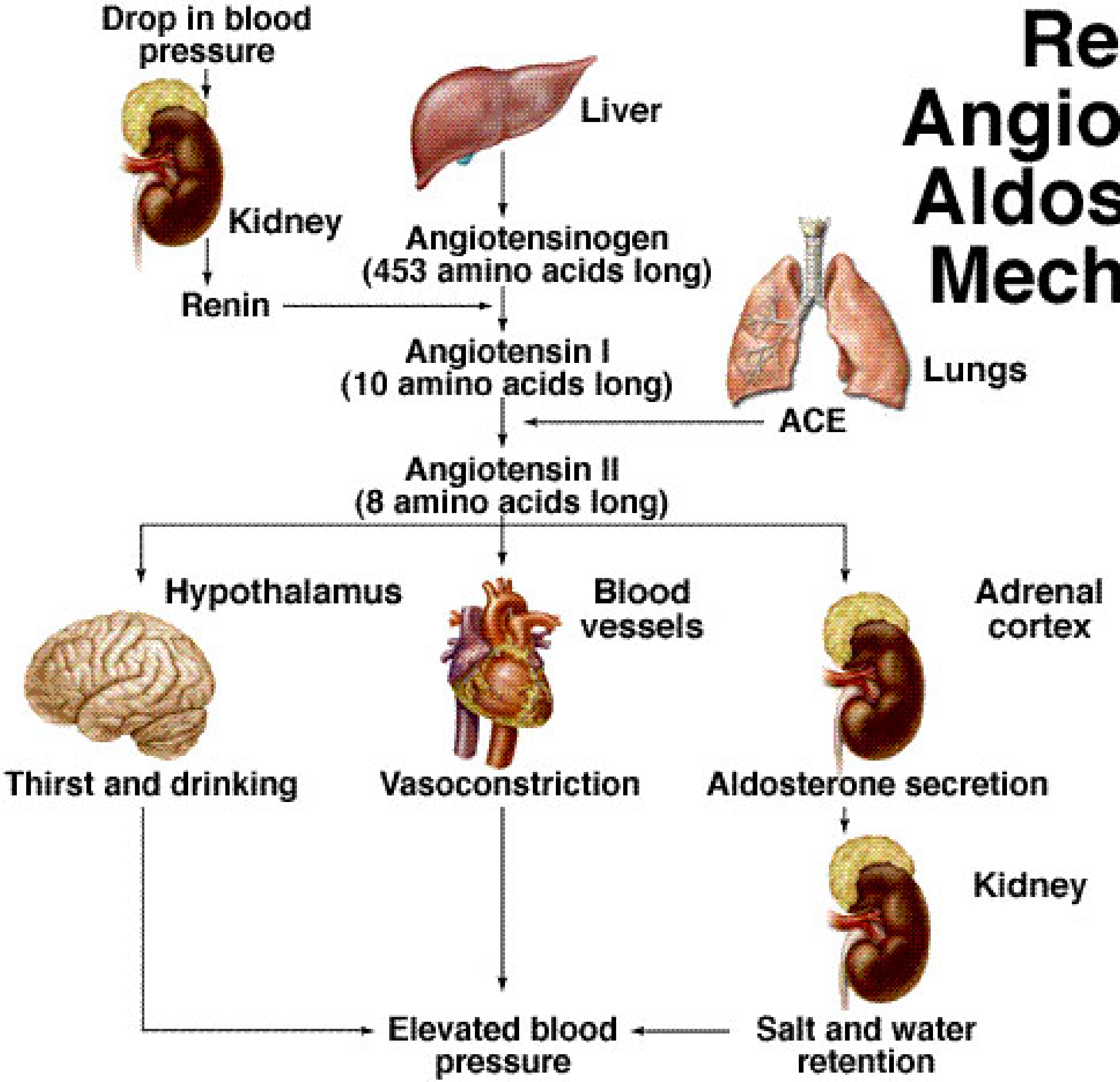
Aldosterone Allows the Kidney to Make a Separate Adjustment of the Na Level

- The kidney can also adjust urine Na concentration by reabsorption in the distal tubule
- This activity is under control of the adrenal cortical hormone **aldosterone**
- Aldosterone acts by turning on genes (transcription), so its stimulation of Na retention is relatively slow
- Causes production of Na pump molecules
- Secretion from adrenal cortex caused by
  - Low sodium blood concentration
  - Rise in Potassium concentration
  - Indirect release by the renin-angiotensin mechanism

In Addition to Aldosterone, Renin and Angiotensin are Involved in Na Retention

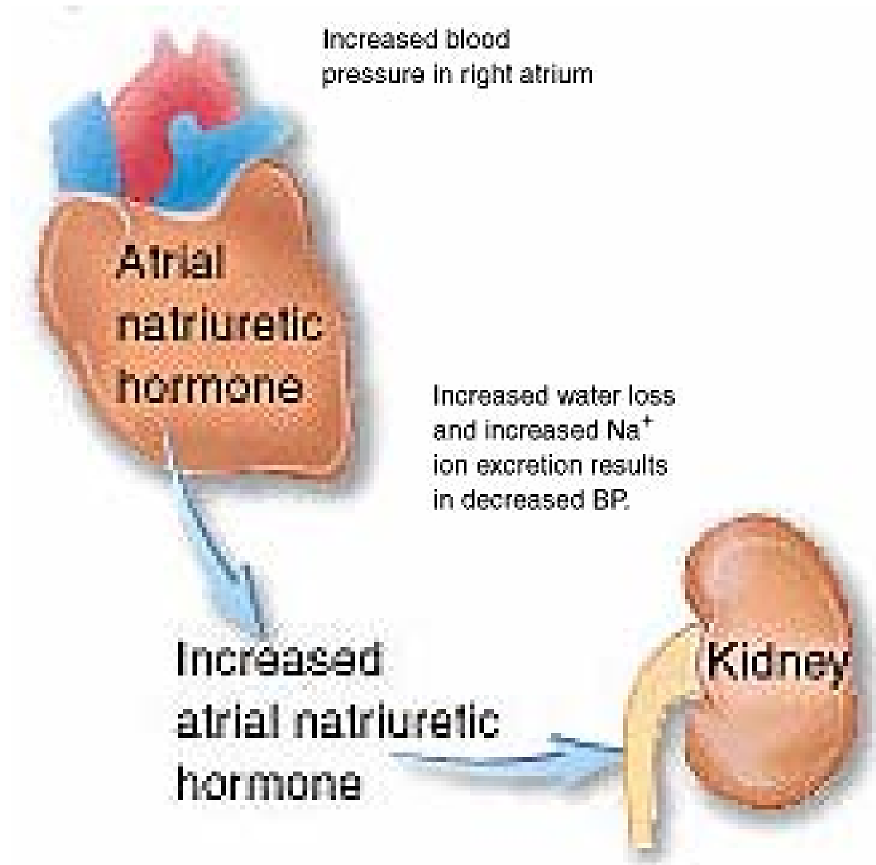
- Aldosterone is released from the adrenal cortex mainly in response to a lowered blood pressure
- Renin-angiotensin mechanism:
  - Low blood pressure causes the juxtaglomerular cells of the kidney to secrete an enzyme called renin into the blood
  - Renin converts a protein called angiotensinogen (produced by the liver) into angiotensin I
  - Angiotensin I is converted to angiotensin II by angiotensin converting enzyme (ACE), which is found in capillary walls
    - ACE inhibitors are used to lower blood pressure
- Angiotensin II causes the adrenal cortex to secrete more aldosterone into the blood

Renin-Angiotensin-Aldosterone Mechanism



Atrial Natriuretic Peptide (ANP) Causes Loss of Both Sodium and Water

- If the blood volume is too high blood pressure goes up and the atria are stretched more than normal as blood enters the heart
- This causes the release of a peptide, ANP, by atrial cells
- ANP causes the body to lose both Na and water, restoring the blood volume to normal
- Increases GFR
- Inhibits aldosterone, renin and ADH secretion



Parathyroid Hormone Effects on the Kidney

- Promotes calcium reabsorption by the ascending limb and the DCT
- Secreted when the plasma Ca+ concentration falls below normal
- Also inhibits phosphate reabsorption by the PCT, thus increasing urinary phosphate
  - This prevents phosphate from binding with plasma calcium and precipitating in the bone and other tissues
- Promotes magnesium reabsorption
- Stimulates the kidney to complete the synthesis of calcitriol (Vit. D)

Diuretics

Chemicals that increase urine volume

- Used for treating hypertension and congestive heart failure because they reduce the body’s fluid volume and blood pressure
- Work by two mechanisms
  - Increasing glomerular filtration
  - Reducing tubular reabsorption

Diuretics

- Caffeine
  - increases glomerular filtration rate
    - Dilates afferent arteriole
- Alcohol
  - Reduces tubular reabsorption
    - Inhibits ADH secretion
- Osmotic diurectis
  - Reduces water reabsorption by increasing the osmolarity of the tubular fluid
- Furosemide (Lasix)
  - Produce osmotic diuresis by inhibiting sodium reabsorption

Diabetes

Diabetes Mellitus

- A metabolic disorder exhibiting chronic polyuria and glycosuria
- Polyuria results form high concentrations of glucose in the renal tubule as a result of hyperglycemia
  - Tubules are not able to reabsorb all of the glucose resulting in large quantities left in the tubules
  - Glucose opposes the osmotic reabsorption of water, so more water is passed in the urine (osmotic diuresis)
  - As a result, a person can become severely dehydrated

Gestational diabetes

- Pregnancy reduces the mother's insulin sensitivity resulting in hyperglycemia and glycosuria

Renal diabetes

- Blood glucose levels are not elevated, but there is a hereditary deficiency of glucose transporters in the PCT, which causes glucose to remain in the tubular fluid

Urinalysis

The examination of the physical and chemical properties of urine

- **Appearance**- varies from almost colorless to deep amber, depending on the body's state of hydration and normal metabolic end products such as urochrome, urobilin and uroerythrin in the urine.
  - Yellow color due to urochrome, a pigment produced by the breakdown of hemoglobin from expired erythrocytes
- Abnormal colors include red, beer-brown, black, orange and blue-green
  - A red urine can be caused by red blood cells or hemoglobin in the urine or by the red pigments found in beets
  - A beer-brown or yellow-brown urine is most often seen when bilirubin is present
  - a black urine occurs when melanin is found in the specimen
  - orange, blue and green are often associated with the presence of drug, dye or food metabolites.

Urinalysis

Cloudy urine-

- upon standing can develop bacteria growth
- Pyuria- pus in the urine, suggesting infection

Odor

- Fresh urine has a distinctive but not a repellent odor
- As it stands, bacteria multiply, degrade urea to ammonia, and produce a pungent odor.
- Foods can give a distinct odor
  - Asparagus
- Diabetes gives it a sweet, fruity odor of acetone
- Rotten order may indicate infection

Urinalysis

Specific gravity

- Is the ratio of the density of a substance to the density of distilled water
  - Distilled water has a density of 1.000, and urine ranges from 1.001 when it is very dilute to 1.028 when it is very concentrated
- **correlates with urine osmolality** and gives important insight into the patient's hydration status.
  - measures the kidney's ability to concentrate or dilute urine in relation to plasma
- There are two primary reasons why the kidney produces concentrated urine with a high specific gravity.
  - The first and most common reason for an increase in urine specific gravity is **dehydration.**
  - The second reason for a high specific gravity is an **increased secretion of anti-diuretic hormone (ADH).**
- Trauma, stress reactions, **surgery**, and many drugs cause an increase in ADH secretion.

Urinalysis

Specific gravity (cont)

A low specific gravity occurs in three situations.

- In **diabetes insipidus**, there is an absence or decrease of anti-diuretic hormone
  - Without anti-diuretic hormone, the kidneys produce an excessive amount of urine, often up to 15 to 20 liters per day with a low specific gravity.
- Glomerulonephritis and pyelonephritis cause a decreased urine volume and low specific gravity.
  - In these diseases, damage to the kidney's tubules affects the ability of the kidney to re-absorb water. As a result, the urine remains dilute.
- Renal failure
  - results in a fixed specific gravity between 1.007 and 1.010, regardless of water intake.

Surgical Diuresis

- After a major surgical procedure that produces high physiologic and psychological stress, increased secretion of antidiuretic hormone causes fluid retention within the vascular space.
- As stress after surgery decreases, ADH and other hormones, such as glucocorticosteroids, begin to drop to normal values, and the fluid that was held in reserve is excreted.
- This increase in urine volume a few days after surgery is sometimes referred to as a surgical diuresis.
- It is important for nurses to consider this type of fluid retention and related increase in urine specific gravity in the immediate post-operative patient to avoid excessive fluid replacement.

Urinalysis

Urinary pH

- Can range from 4.5 to 8 but normally is slightly acidic (i.e., 5.5 to 6.5) because of metabolic activity.
- Ingestion of proteins and acidic fruits (e.g., cranberries) can cause acidic urine, and diets high in citrate can cause alkaline urine.
- Urinary pH generally reflects the serum pH
- Is useful in the diagnosis and management of UTIs and calculi

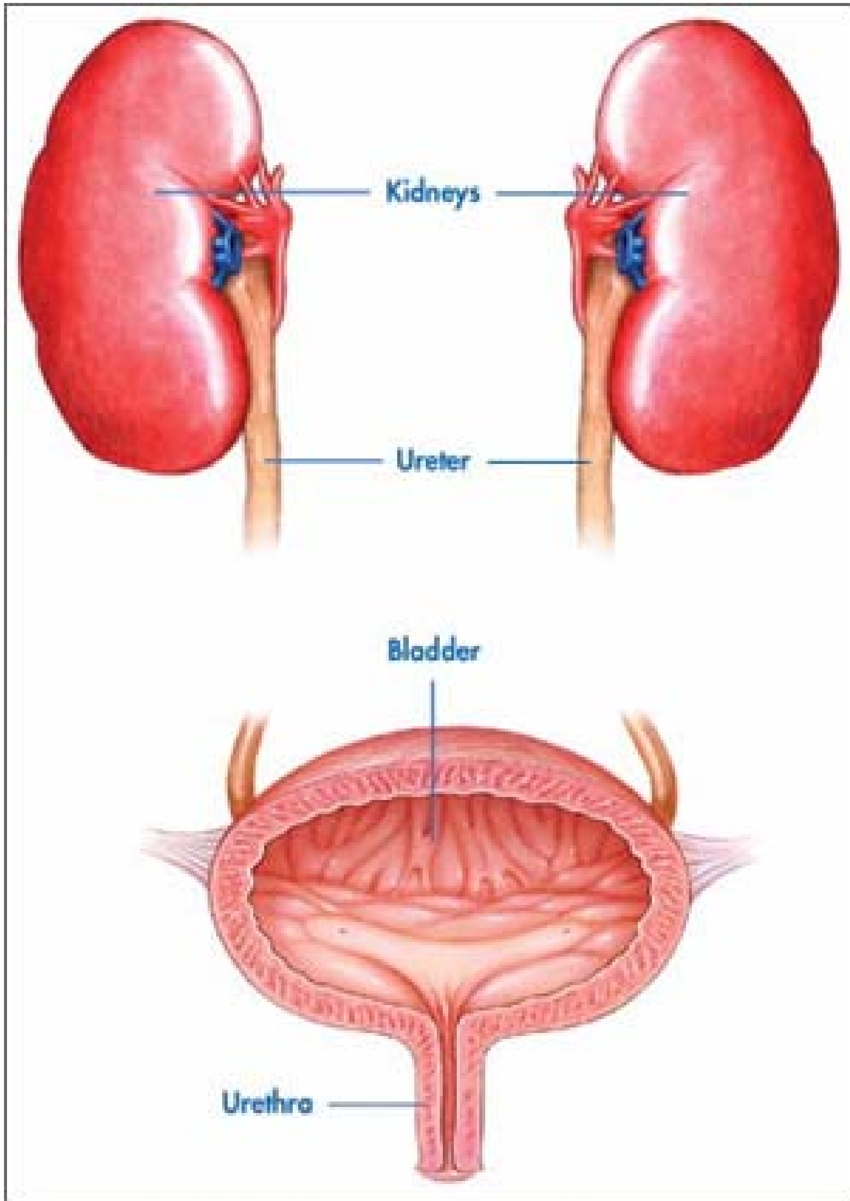
Urine Volume

- Average adult produces 1-2 L of urine per day
  - An output in excess of 2 L per day is called diuresis or **polyuria**
  - **Oliguria**- an output of less than 500ml/day
  - Anuria- output of 0-100ml/day
  - Azotemia- A higher than normal blood level of urea or other nitrogen containing compounds in the blood due to low urine output
- The hallmark test is the serum BUN (blood urea nitrogen) level.
  - Abnormal values usually caused by the inability of the kidney to excrete these compounds.

Urine Storage and Elimination

Ureters

- The renal pelvis funnels urine into the ureters
- Are muscular retroperitoneal tubes that extends to the urinary bladder
- The mucosa has transitional epithelium that is continuous with that of the pelvis and bladder
- The muscular layer consists of two layers of smooth muscle
  – Urine stretches tube causing the muscularis to contract in paristaltic waves, milking urine down to the bladder



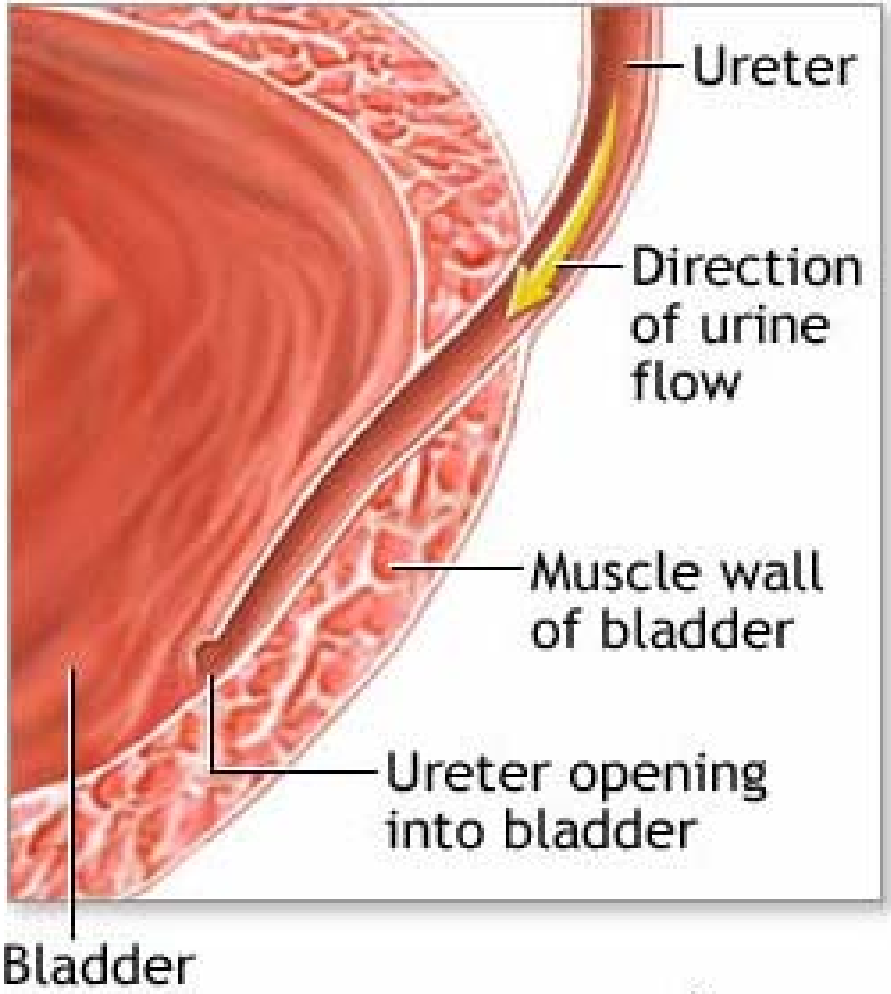
Ureter


Adventitia
Smooth muscle
Transitional epithelium
Lamina propria
0.2 mm

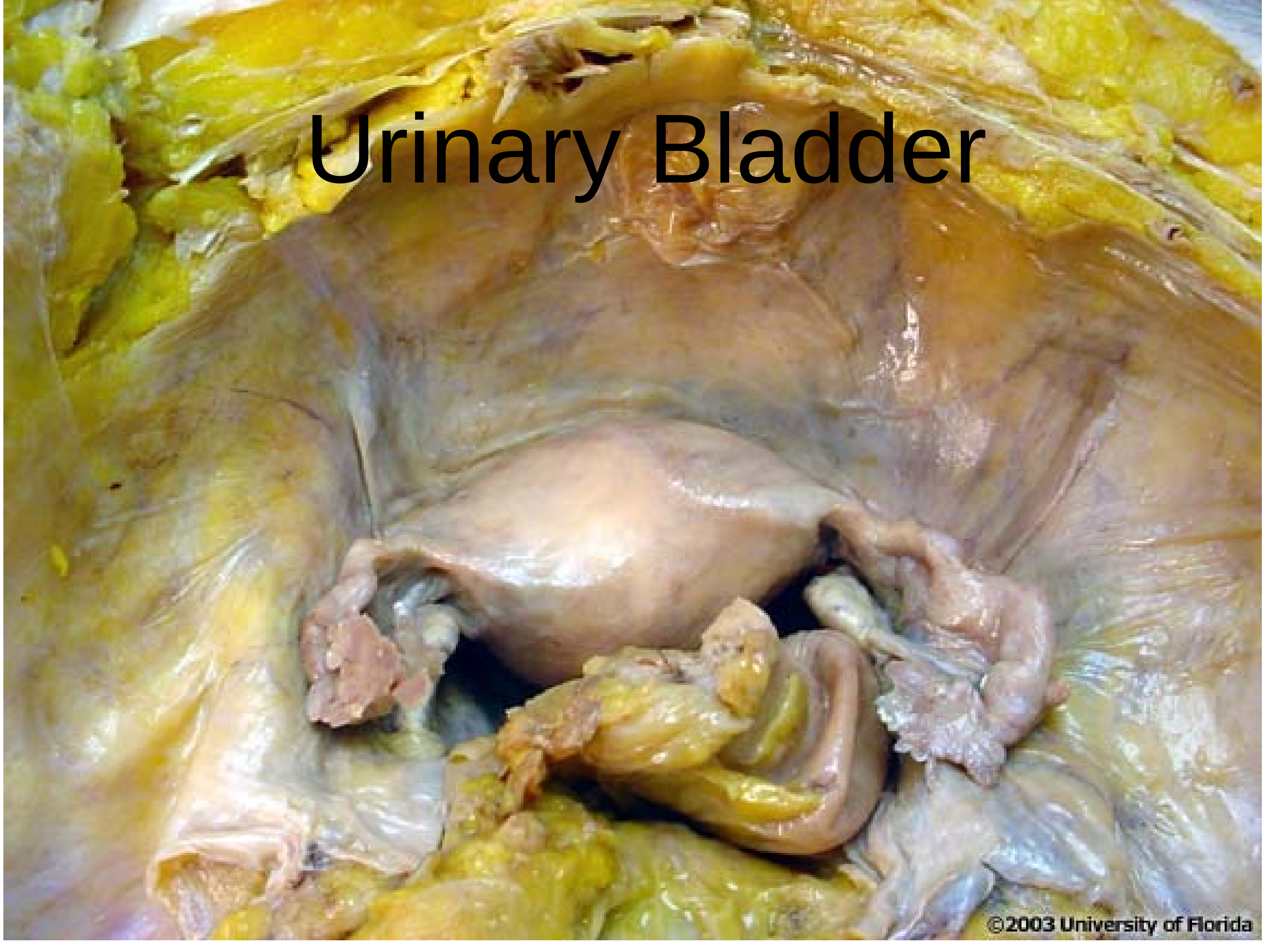
Urine Storage and Elimination

Ureters (cont)

- Enters obliquely through the bladder muscular wall and opening onto is floor
  - Thus as pressure builds in the bladder, it compresses the ureters and prevents urine backflow



Urinary Bladder



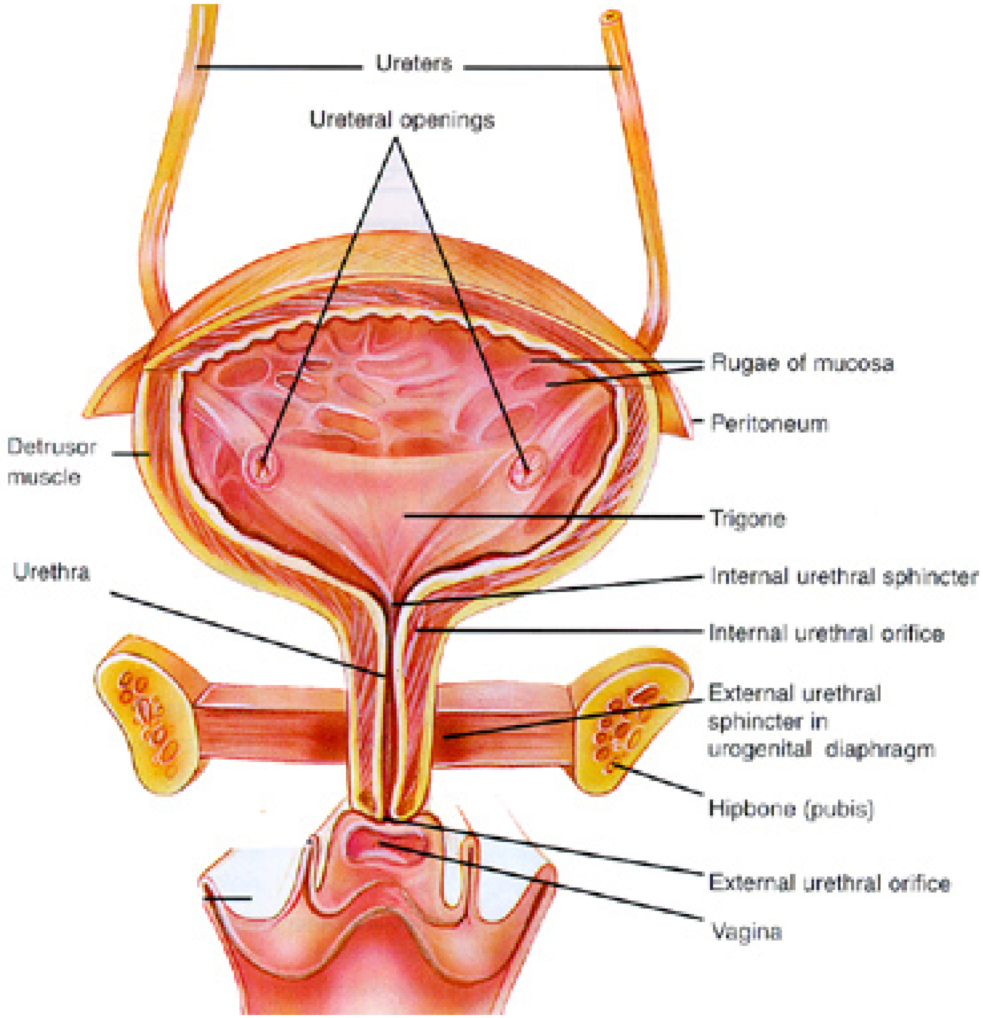
- Muscular sac on the floor of the pelvic cavity
- Is covered by parietal peritoneum on its flattened superior surface and by a fibrous adventitia elsewhere

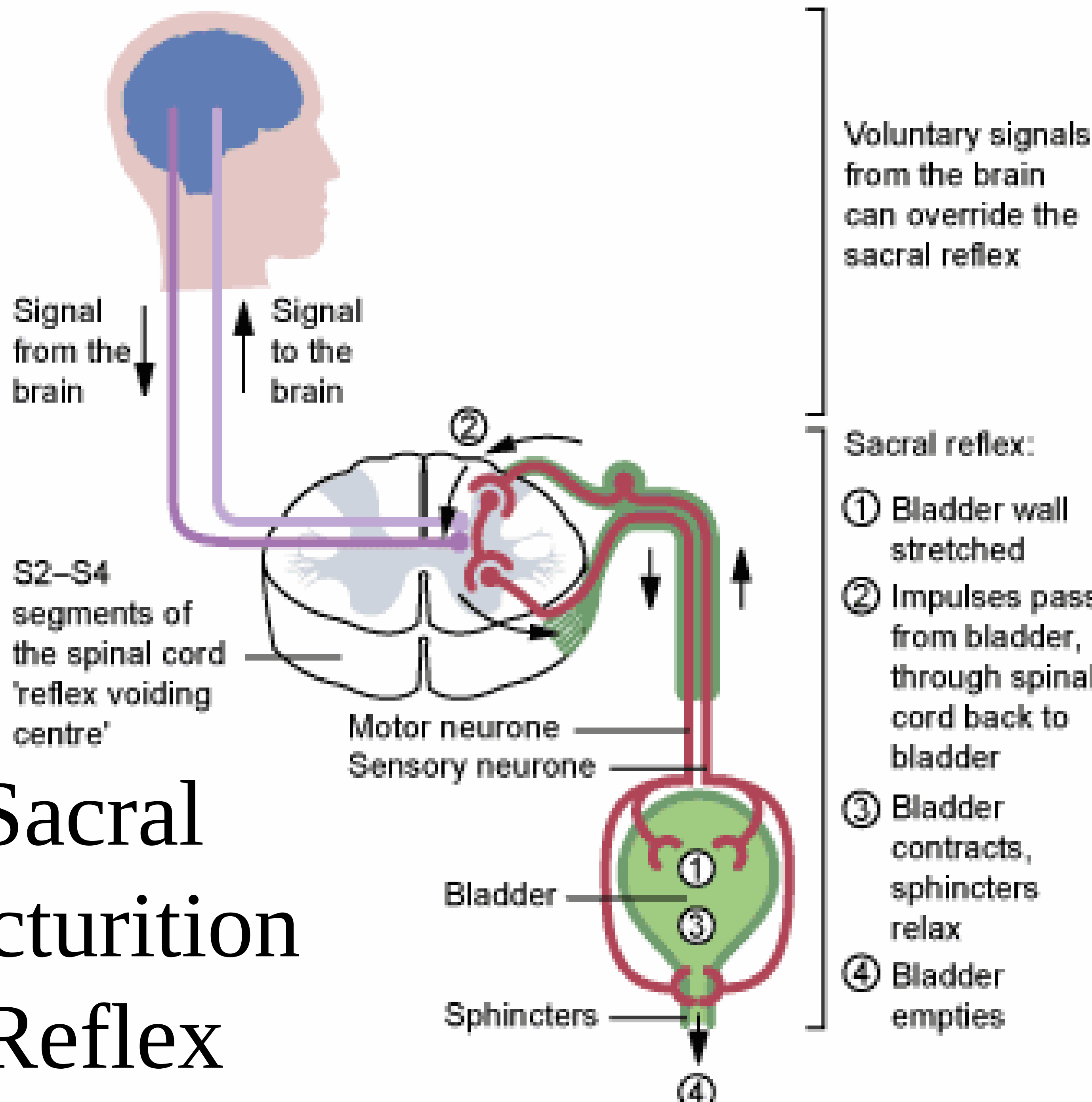
Urinary Bladder

- Its muscularis, called the **detrusor muscle**, consist of three layers of smooth muscle
- The mucosa has transitional epithelium

Urinary Bladder

- Mucosa is wrinkled (rugae) when relaxed.
- The opening of the two ureters and the urethra mark a smooth-surface triangular area called the **trigone** on the bladder floor
- The bladder is highly distensible
  - The maximum capacity is 700 to 800 mL



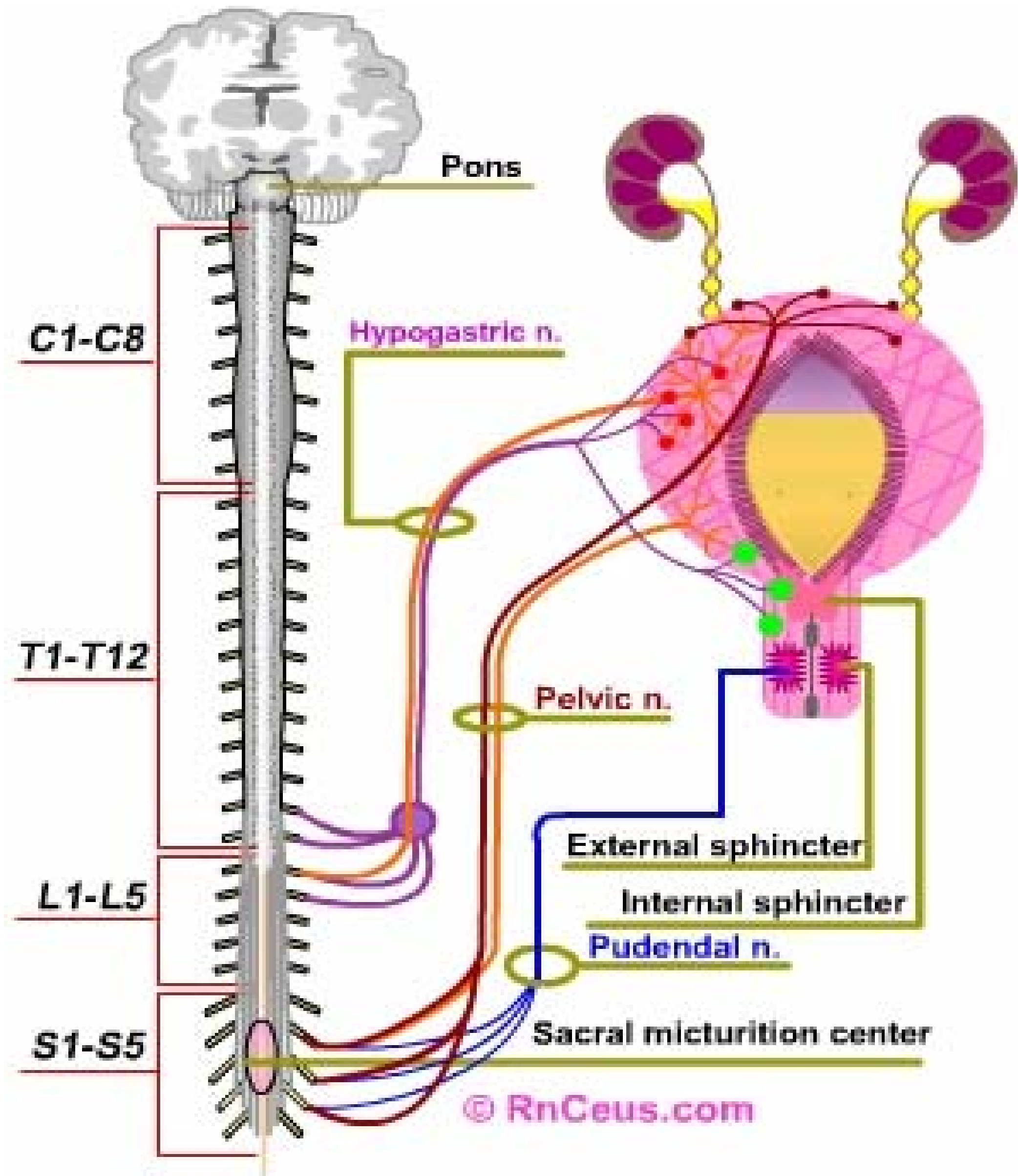


Sacral Micturition Reflex

Voiding reflex center at S2-S4

Micturition Control

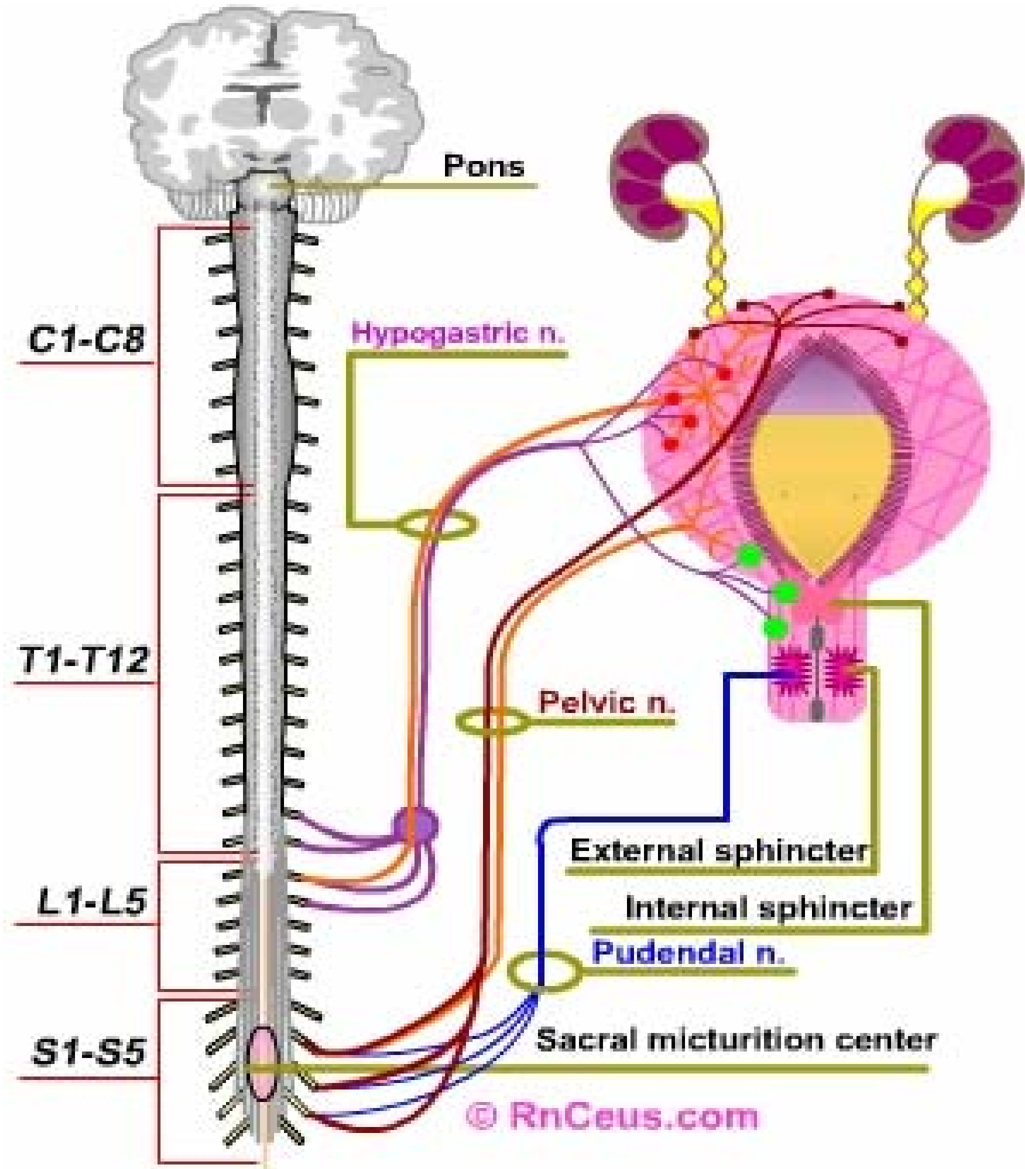
- The body of the bladder is rich in **sympathetic** beta adrenergic receptors whose fibers are via the **hypogastric nerve**
  - Stimulation suppress contractions of the detrusor muscle and internal sphincter
- **parasympathetic** stimulation, by fibers in the **pelvic nerve**, cause the detrusor to contract and relaxation of the internal sphincter.
- **Sympathetic** stimulation is predominant during bladder filling, and the **parasympathetic** causes emptying.



Micturition Control

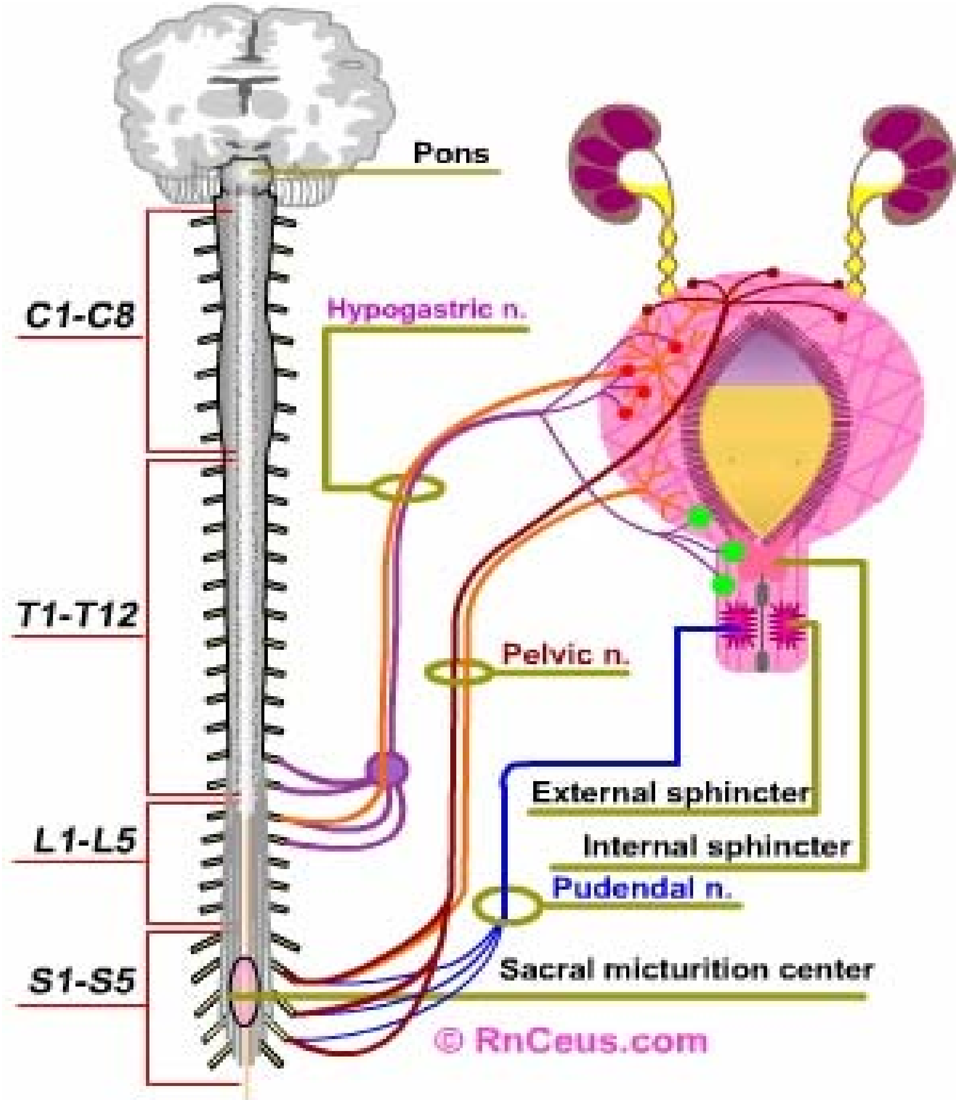
Two sphincters control the bladder outlet.

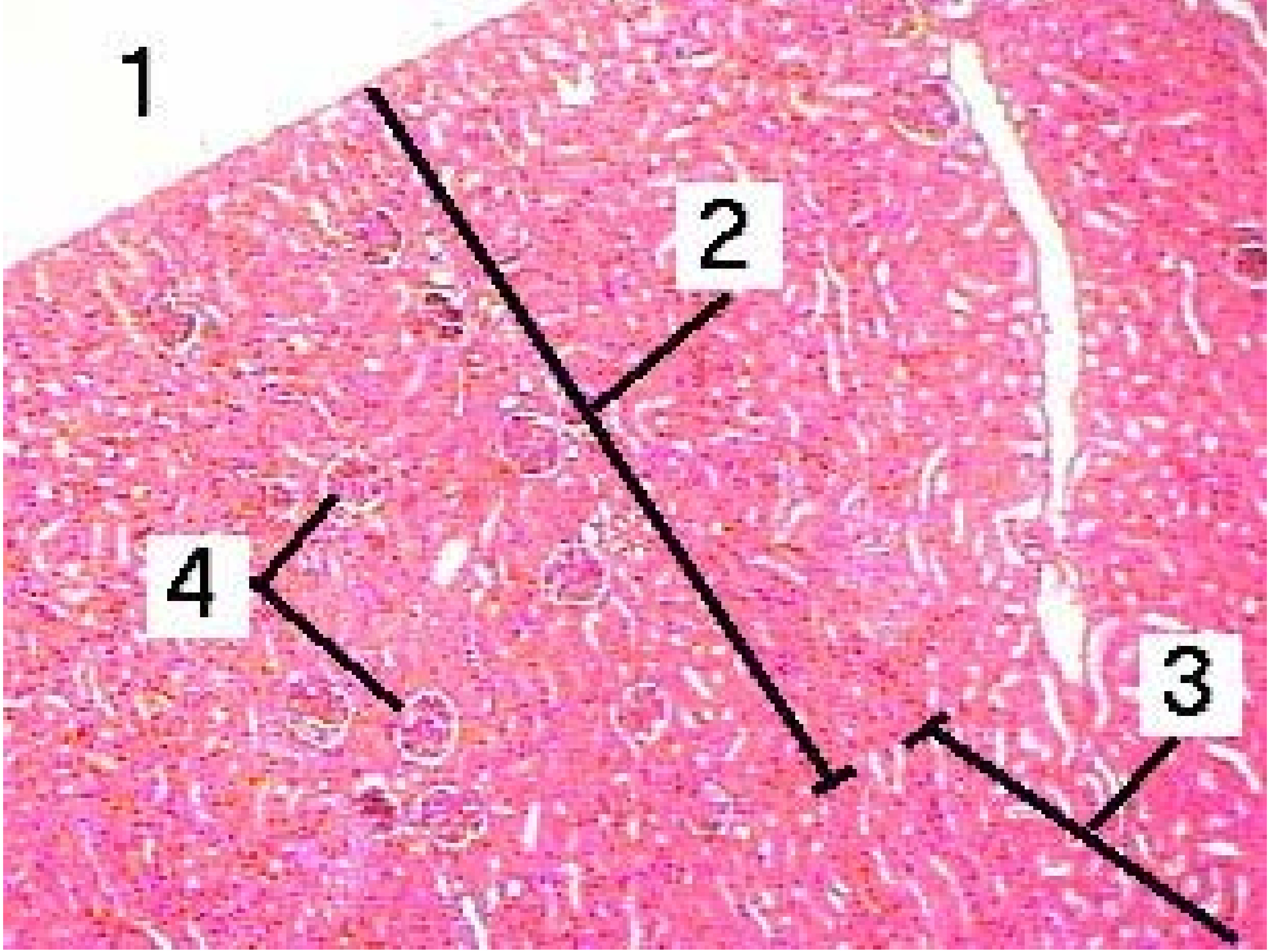
- The **internal sphincter**
  - is composed of smooth muscle like the detrusor and extends into the bladder neck.
  - Also like the detrusor, it is controlled by the ANS and is normally closed.
  - The primary receptors in the bladder neck are **alpha-**adrenergic.
  - **Sympathetic** stimulation of these **alpha** receptors, via fibers in the **hypogastric nerve**, contributes to urinary continence.



The **external sphincter**

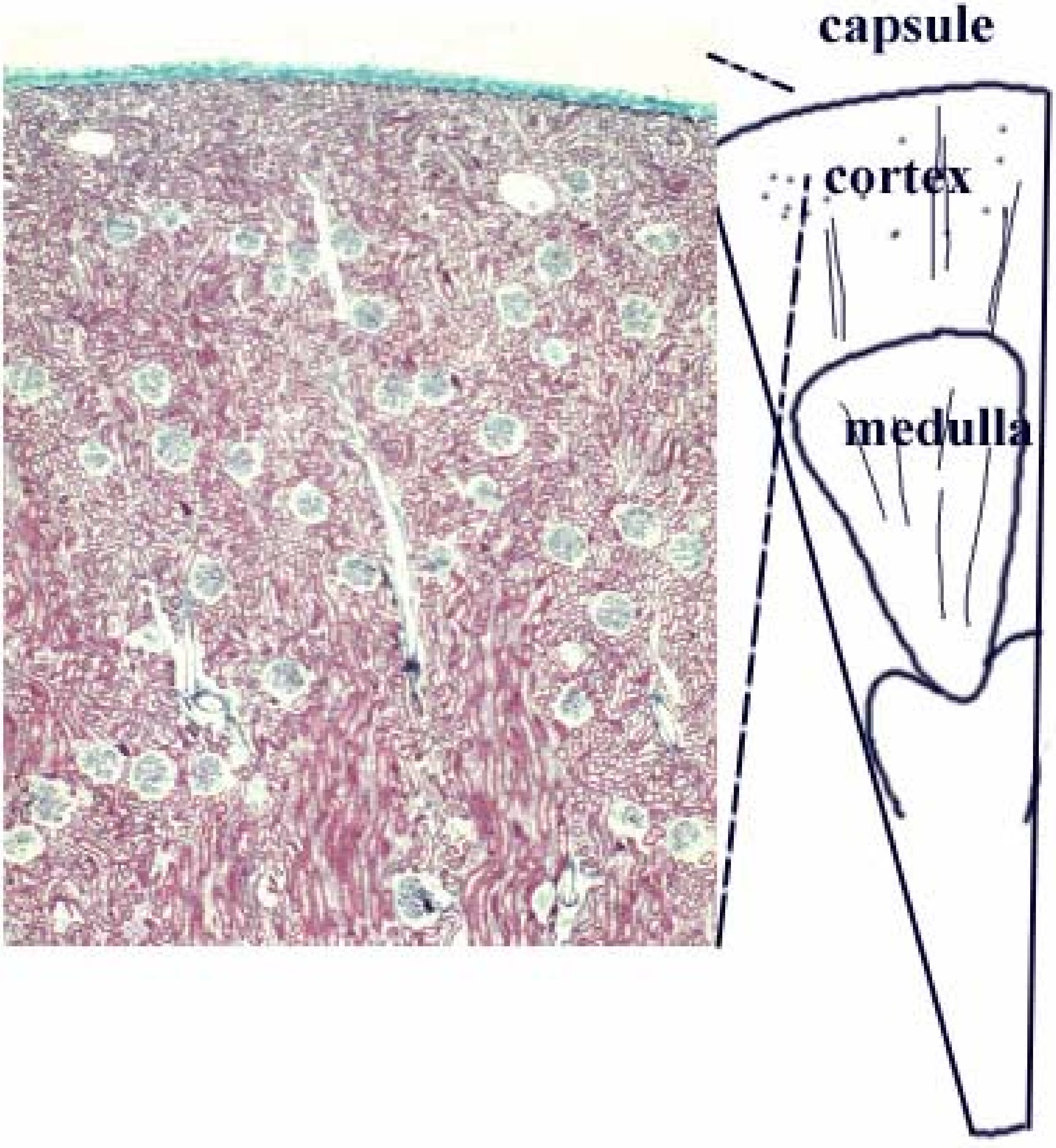
- histologically different from the detrusor and internal sphincter.
- It is striated muscle. And is under voluntary control.
- It receives its innervation from the **pudendal** nerve, arising from the ventral horns of the sacral cord.
- During micturition, **supraspinal centers** (**micturition center** of the pons) block stimulation by the hypogastric and pudendal nerves.
- This relaxes the internal and external sphincters and removes the **sympathetic** inhibition of the **parasympathetic** receptors. The result is contraction of the detrusor.



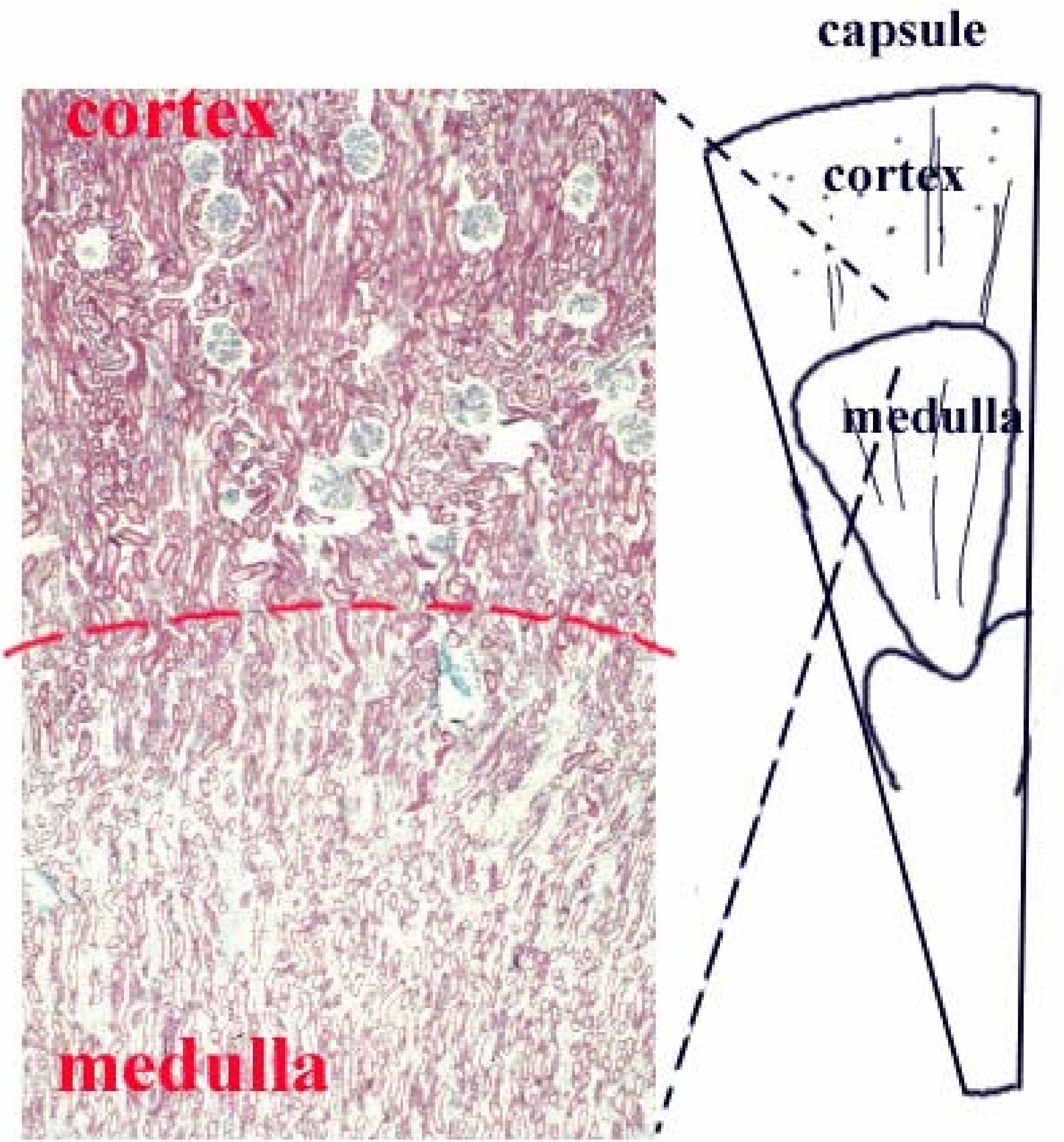


2. Cortex, 3. Medulla, 4. glomeruli

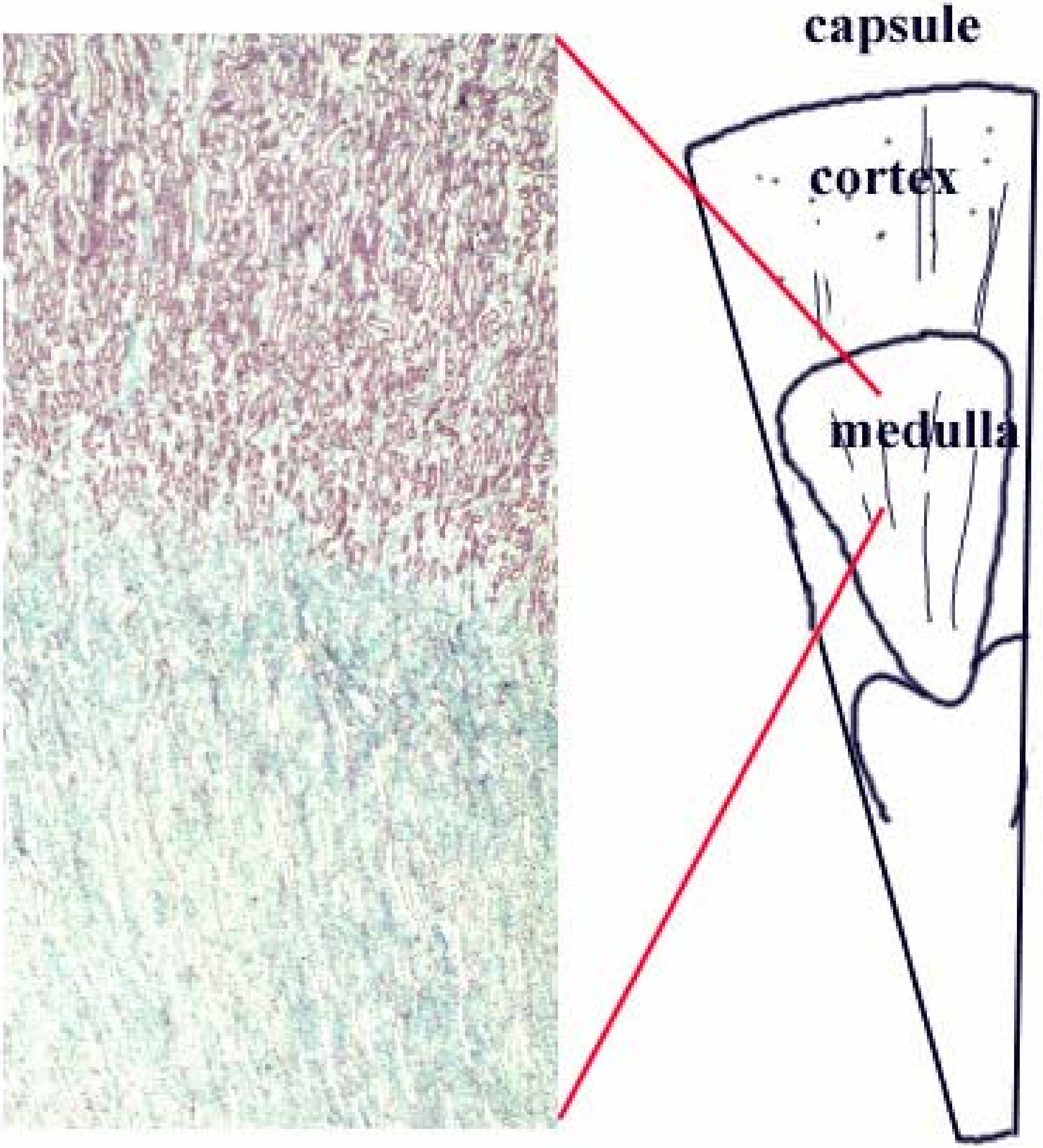
Cortex

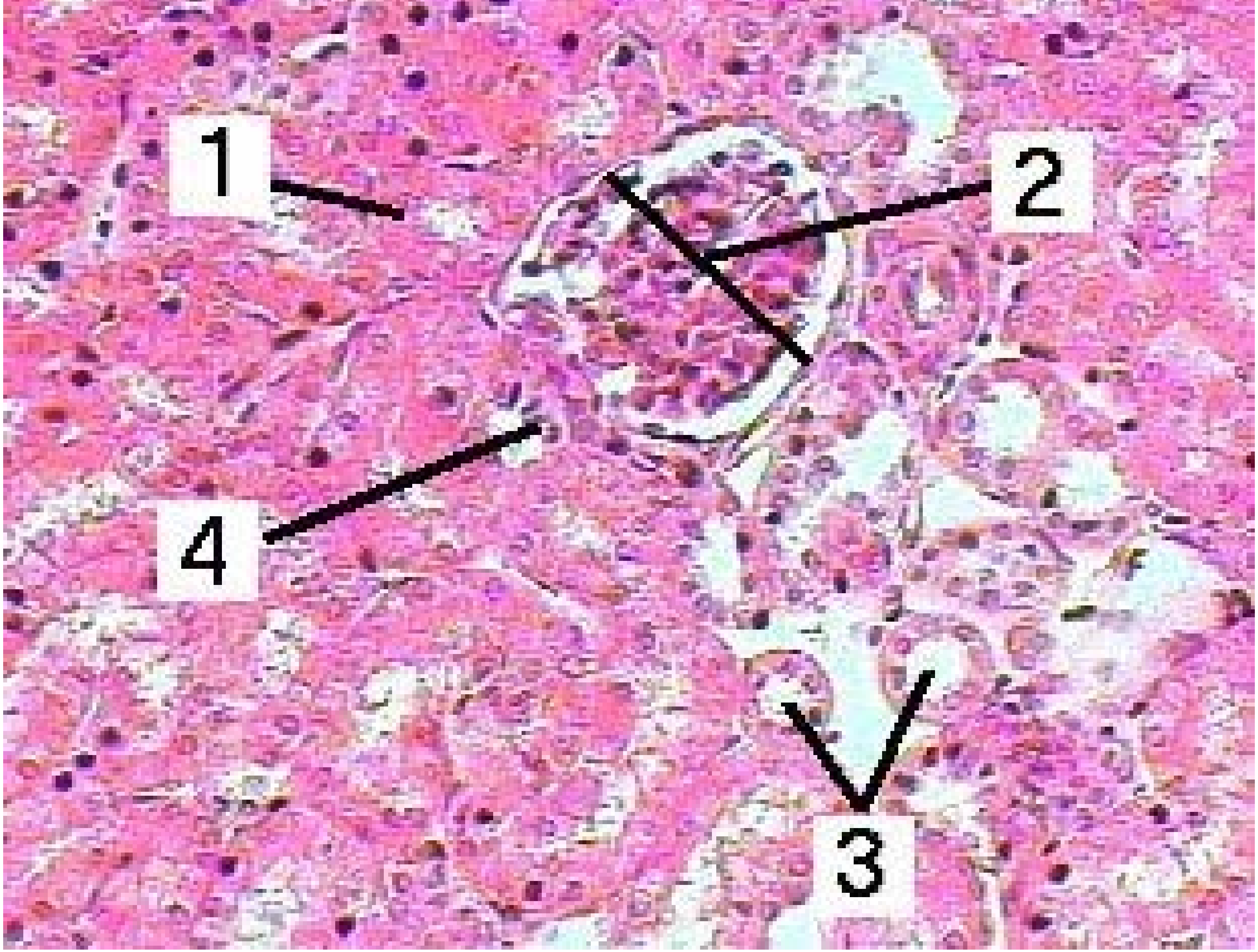


Corticomedullary junction

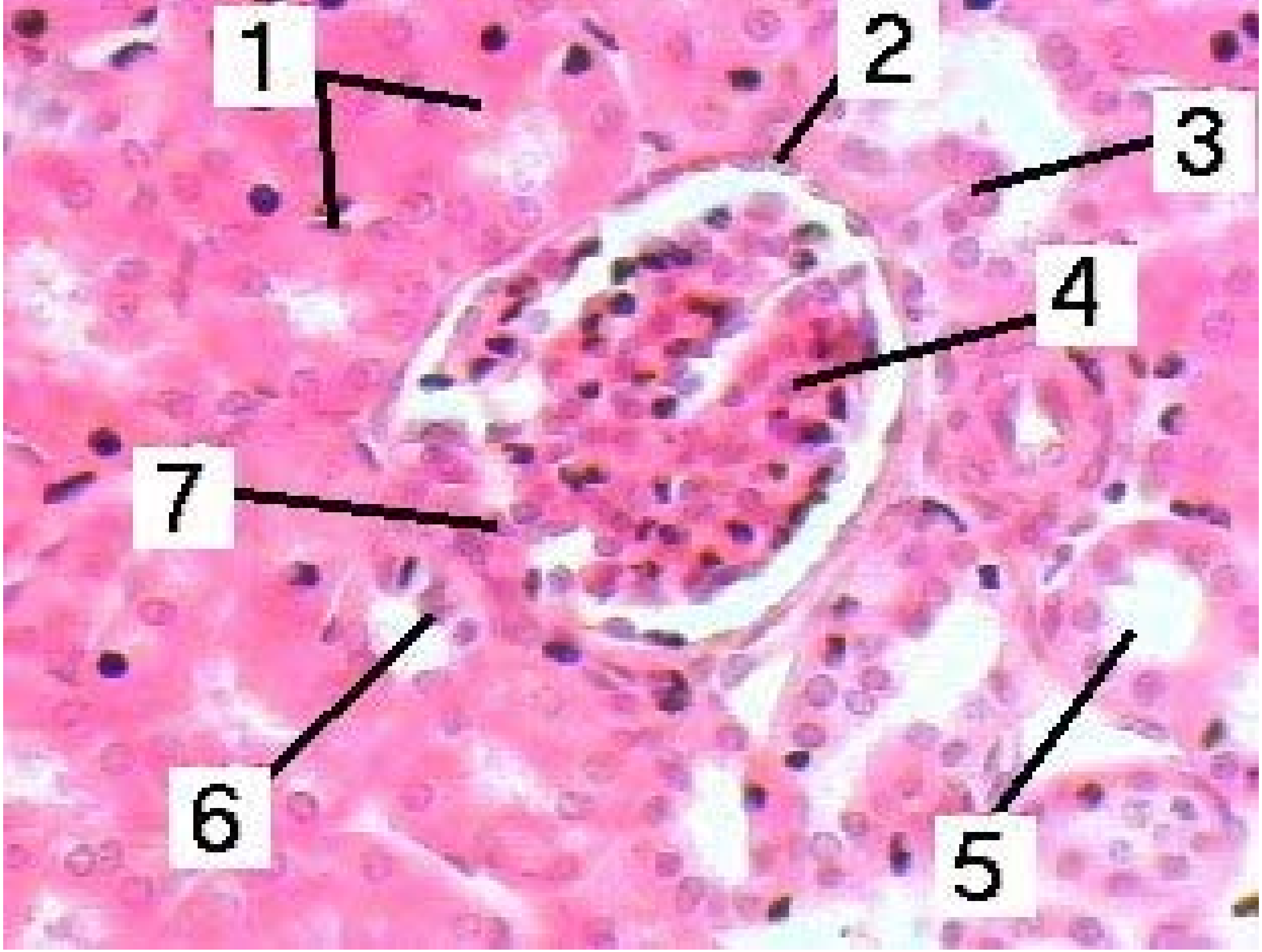


In the pyramids

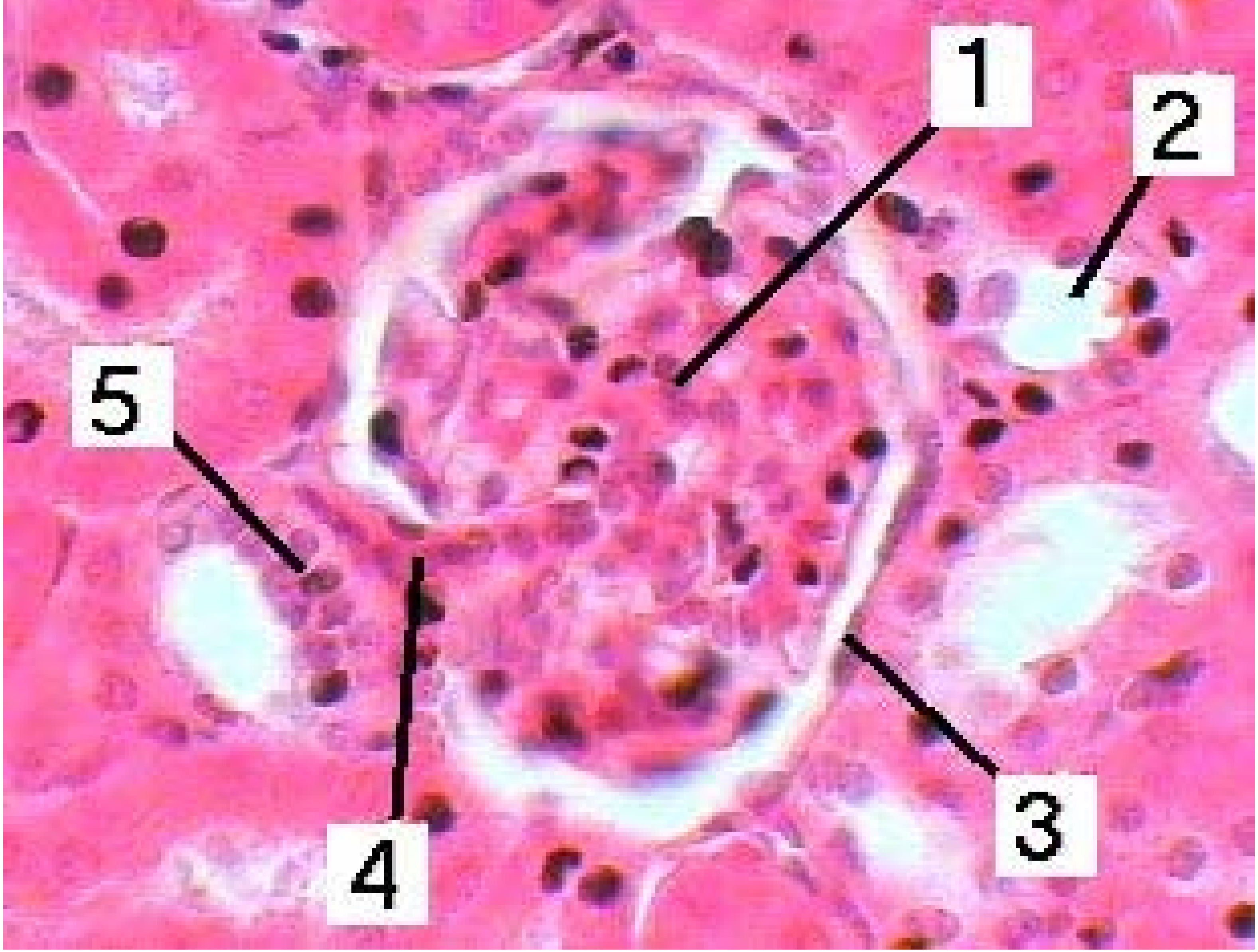




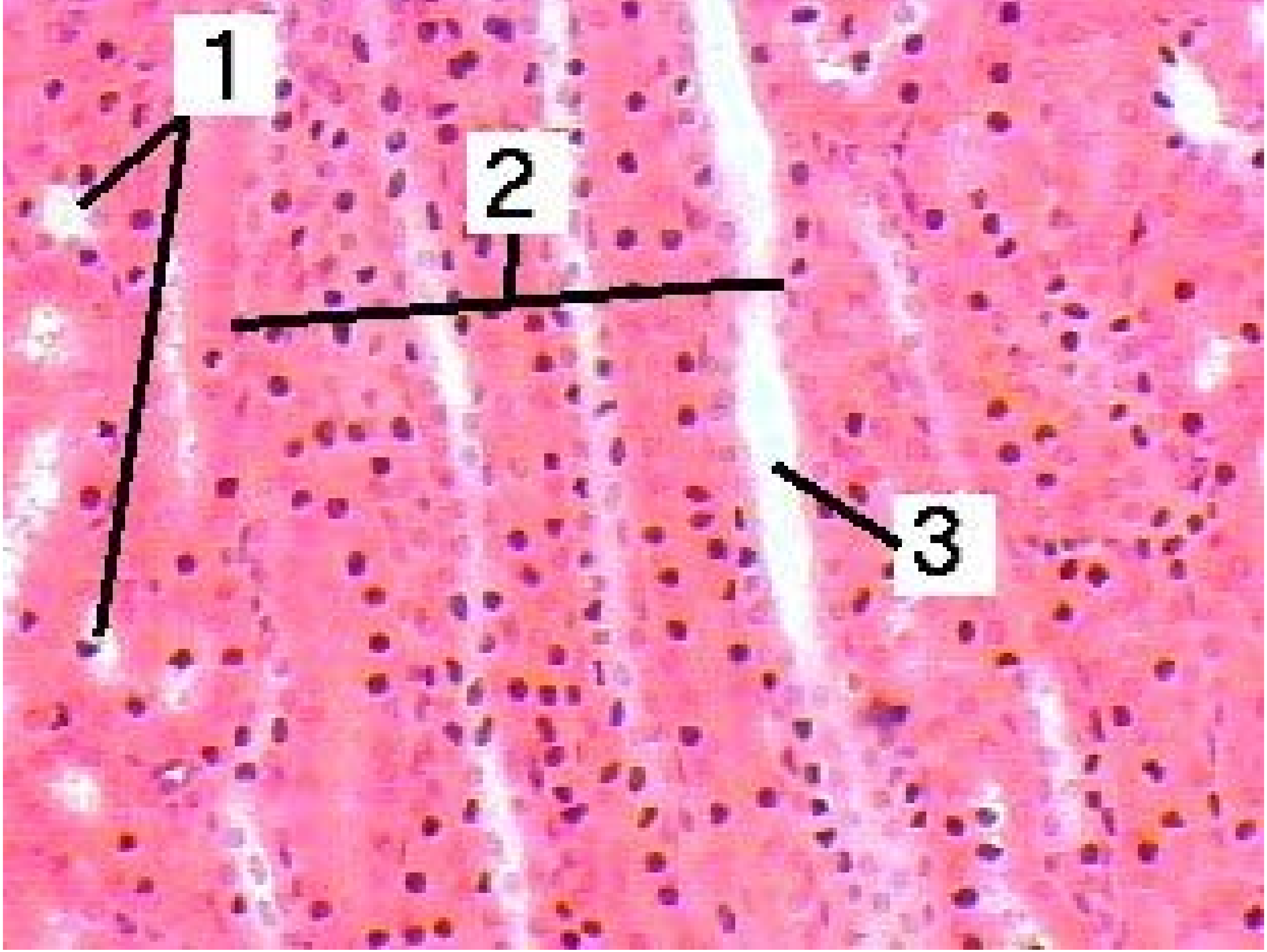
1. Proximal convoluted tube, 2. Glomerulus, 3. Distal convoluted tubes, 4. Macula densa



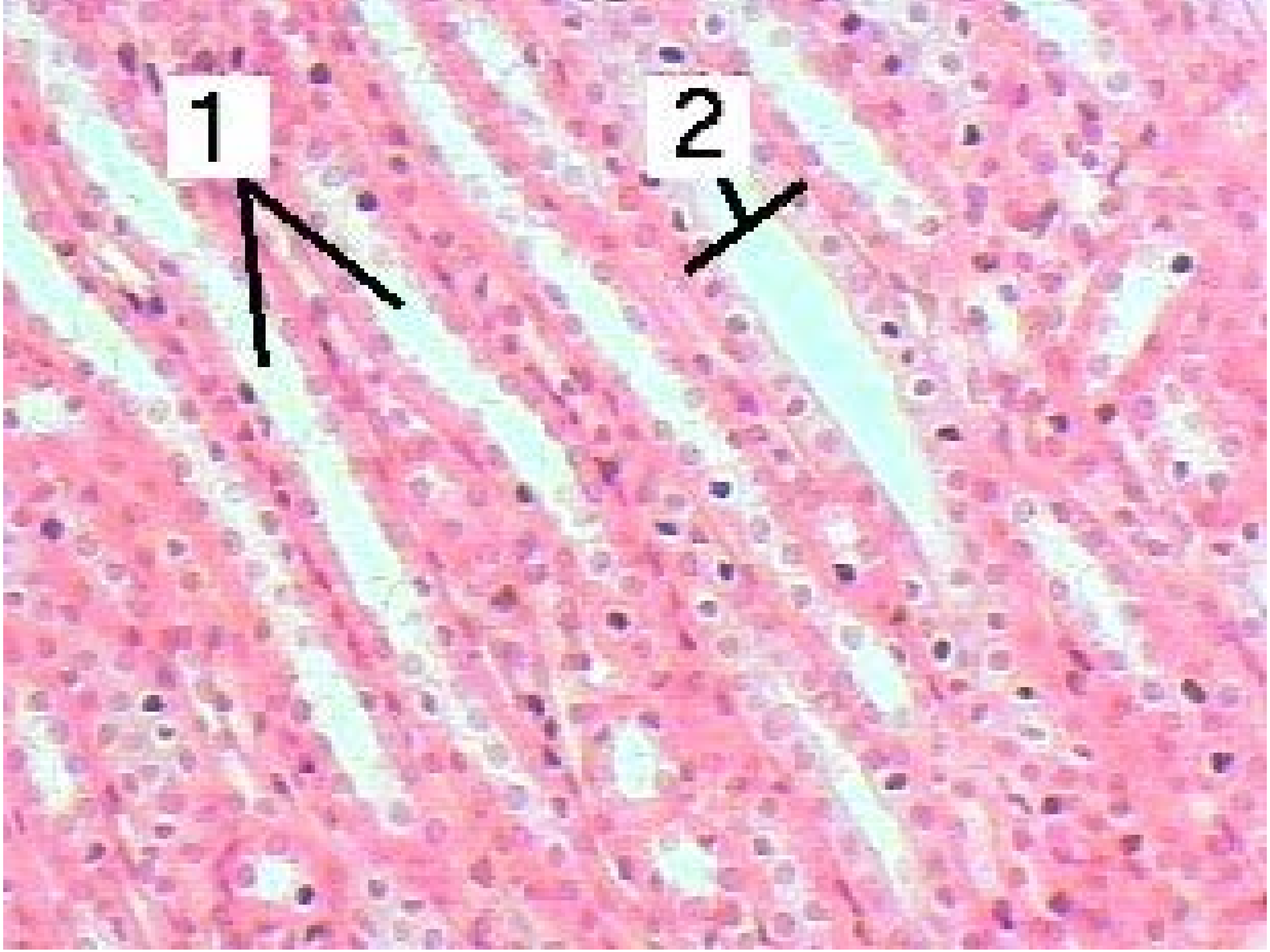
1. Proximal ct., 2 parietal layer of bowmen's capsule, 4. Glomerulus, 5. Distal ct., 6. Macula densa, 7. Afferent or efferent capillary



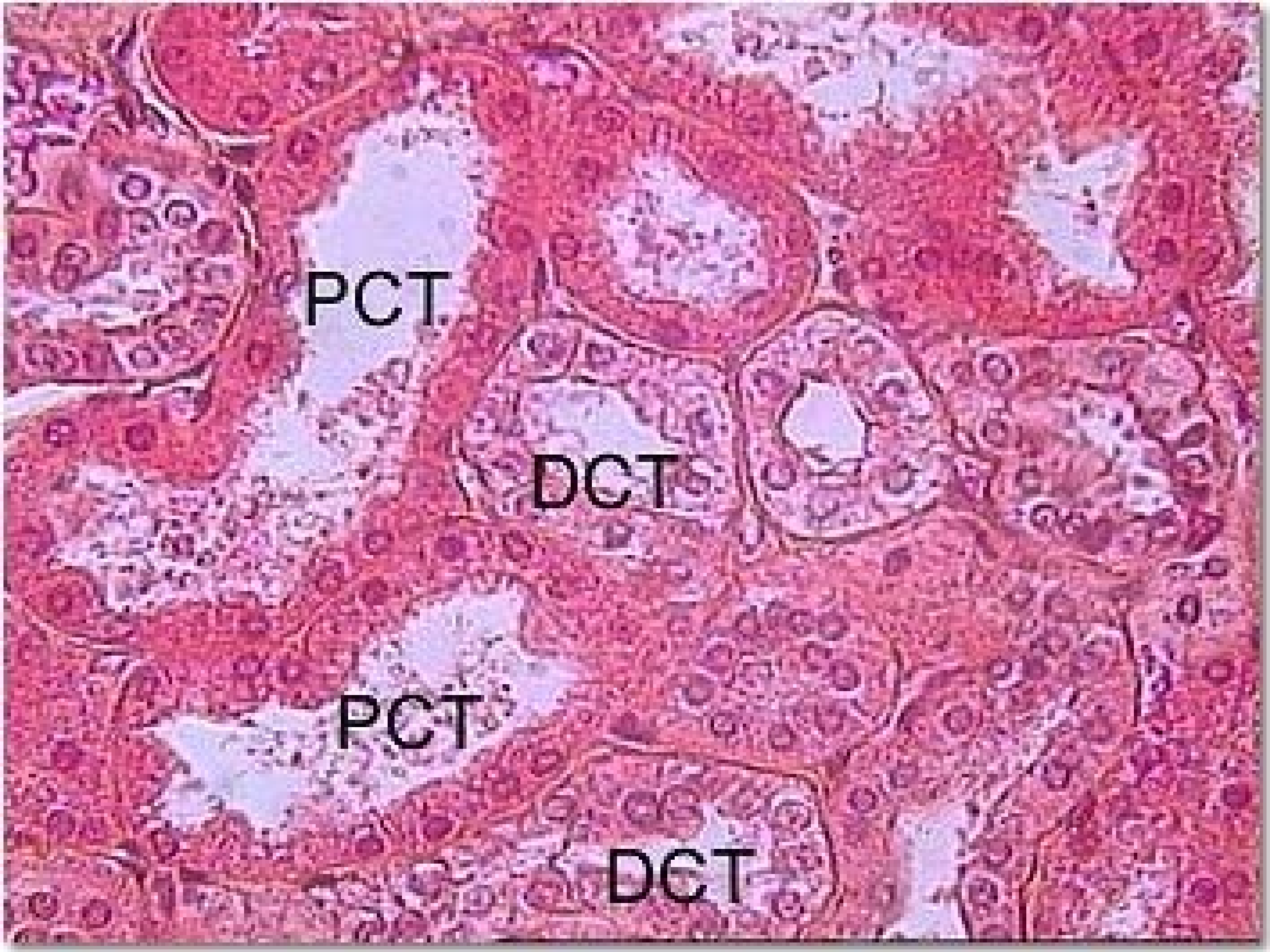
1. Glomerulus, 2. Distal ct., 3. Bowmen’s capsule, 4. Arteriole, 5. Macula densa



1. Proximal ct. 2. Collecting ducts, 3. Tubule lumen

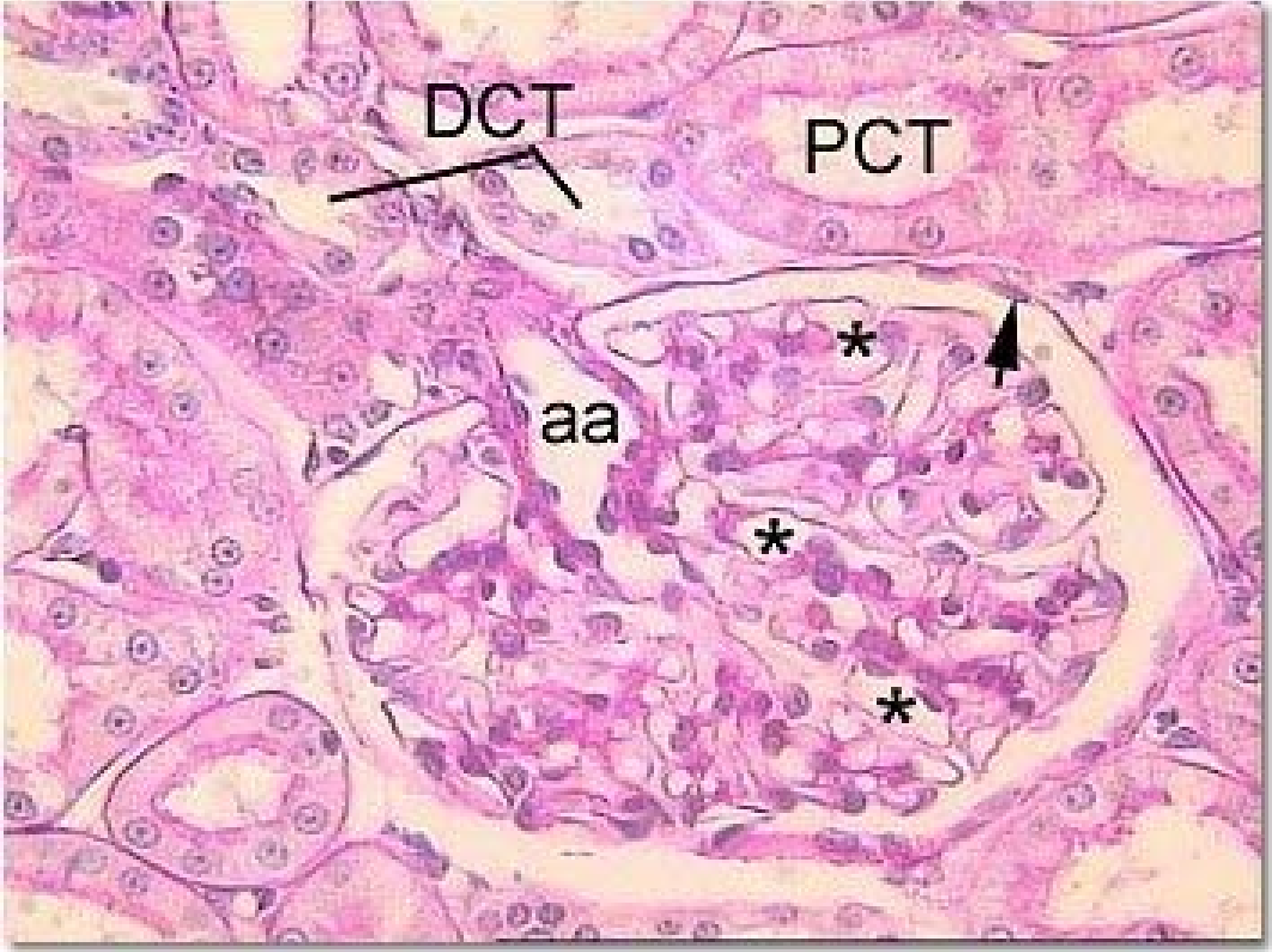


1. Collecting duct lumen, 2. Cuboidal cell wall of duct



DCT = distal convoluted tubule

PCT = proximal convoluted tubule



aa = afferent arteriole **DCT** = distal convoluted tubule

PCT = proximal convoluted tubule **arrowhead** = nucleus of capsular epithelial cell

asterisks = capillaries within glomerulus