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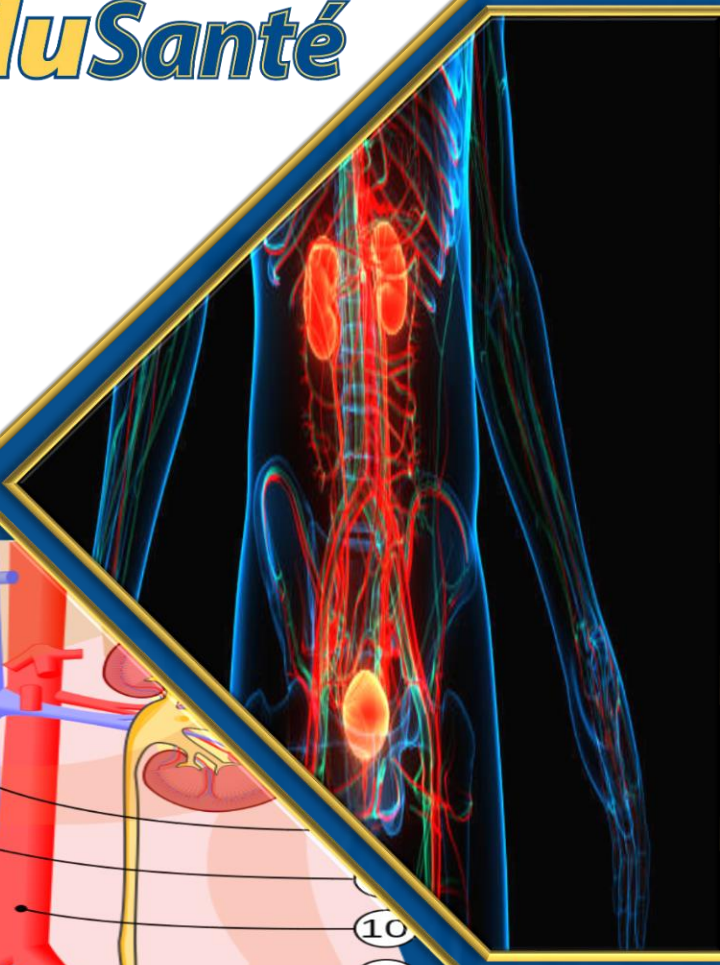
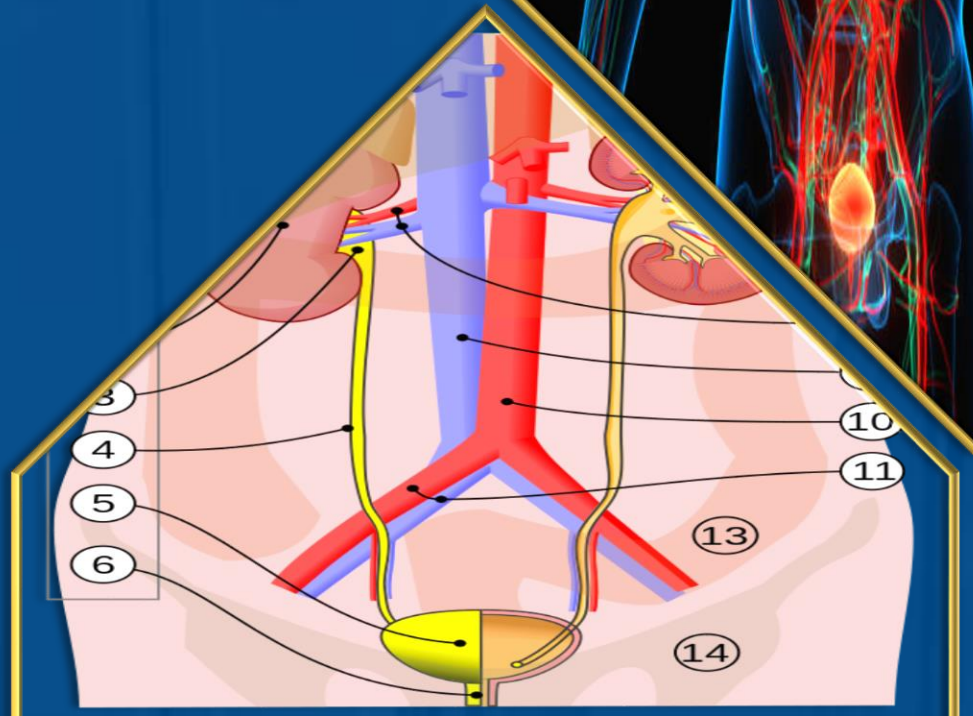
Genitourinary Anatomy

Primary Care Paramedicine





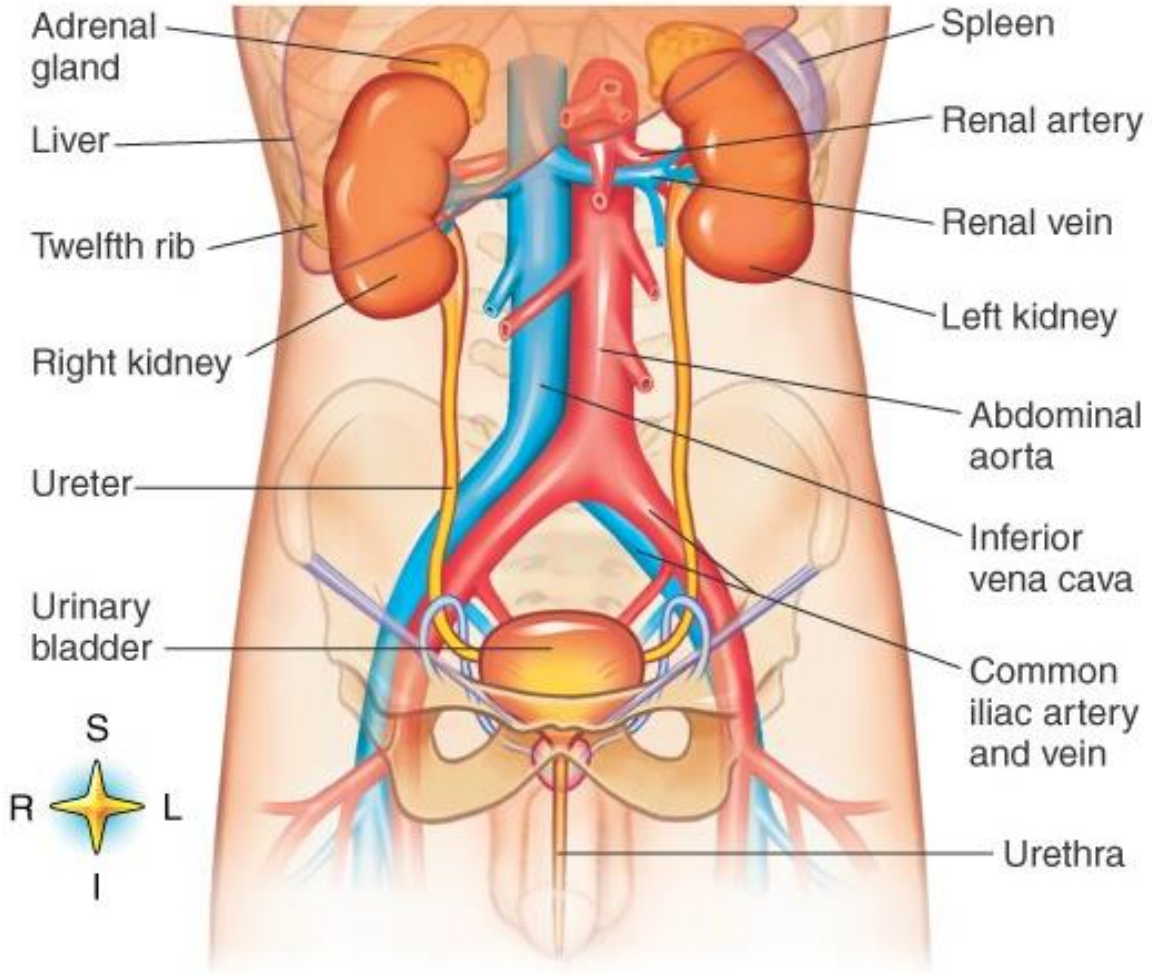
Module: 17

Section: 02

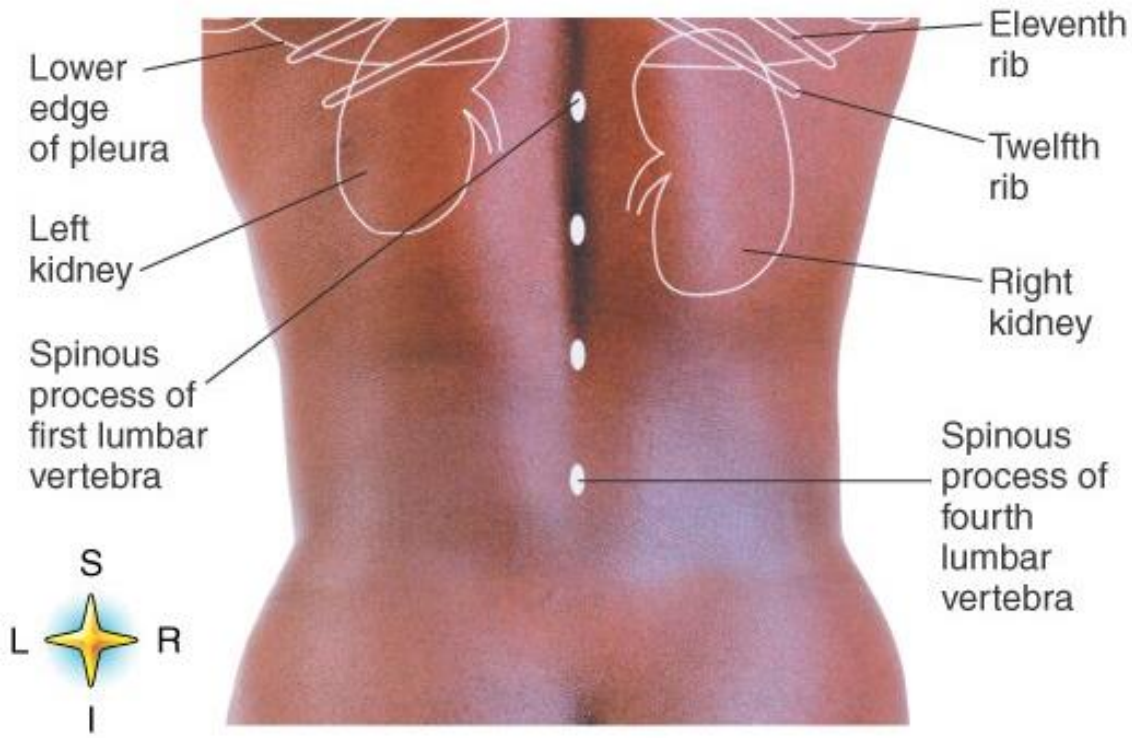
The Urinary System

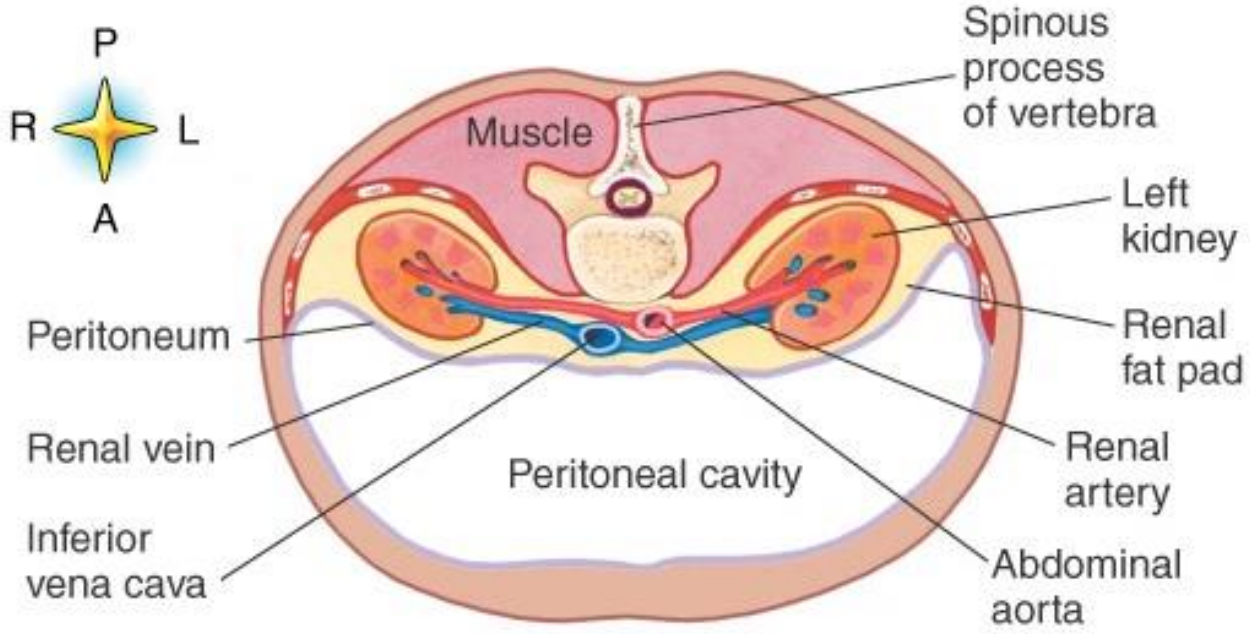
- The urinary systems consists of the kidneys, ureters, bladder and urethra, along with its associated nerves and blood vessels.
- The system maintains homeostasis by:
  - Regulating blood volume, pressure, pH and concentration (osmolarity) of electrolytes (Na^+, K^+, Ca^{2+}, Cl^-, HPO_4^{-3}, Mg^{2+}, HCO_3^-)
  - Reabsorbing glucose and excreting wastes
  - Releasing certain hormones like renin and EPO

Frontal View



Other Views


Lower edge of pleura
Left kidney
Spinous process of first lumbar vertebra
Eleventh rib
Twelfth rib
Right kidney
Spinous process of fourth lumbar vertebra
S
L
R
I


P
R
L
A
Spinous process of vertebra
Muscle
Left kidney
Renal fat pad
Peritoneum
Renal vein
Inferior vena cava
Peritoneal cavity
Renal artery
Abdominal aorta

The Kidneys

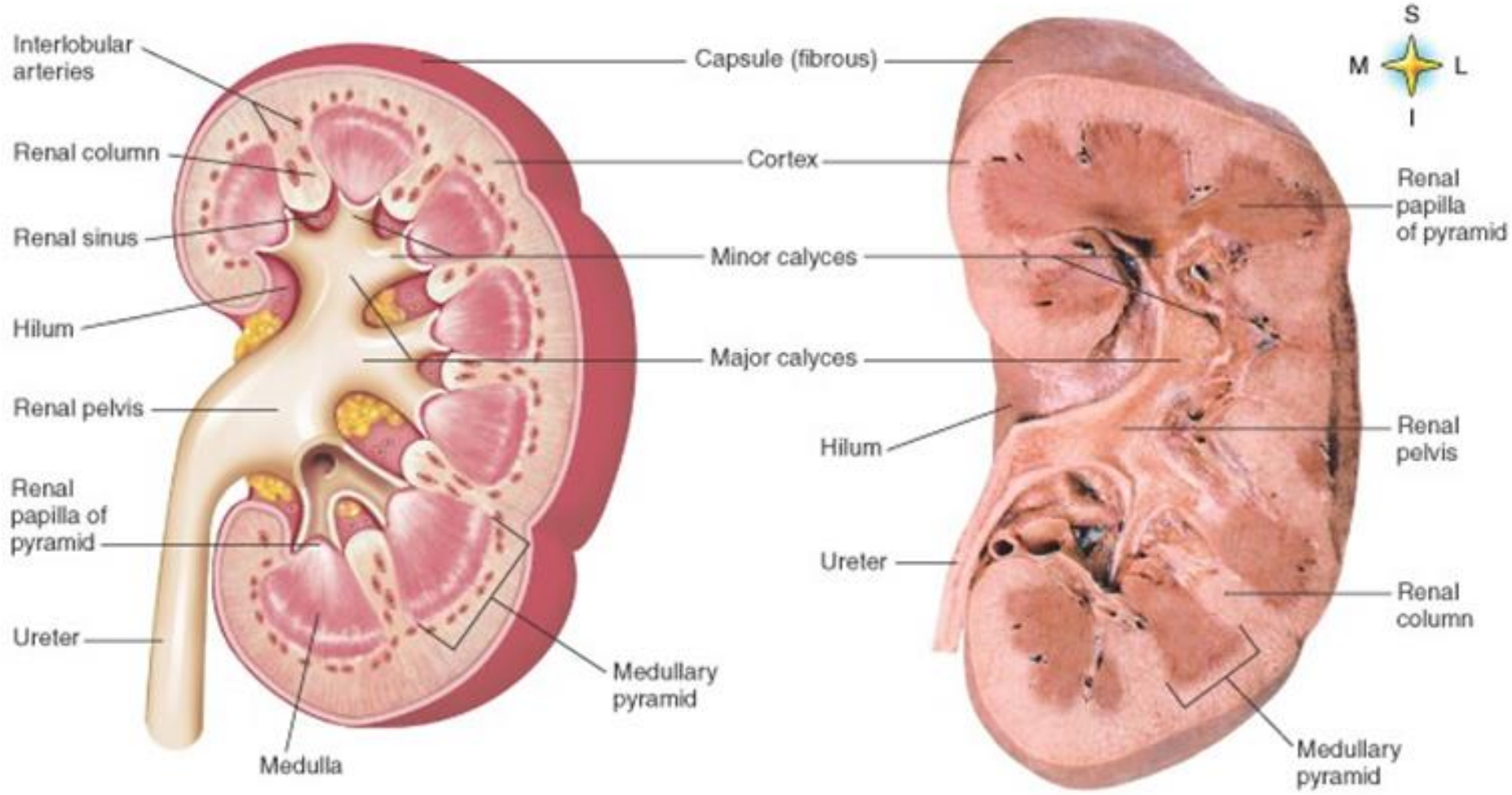
- Found in the retroperitoneal space on either side of the vertebral column (T12 - L3)
- Left usually slightly larger then right
- Right is usually lower
- Protected by fat
- Nephron is the functional unit of the kidneys
  - Filtering the blood

The Kidneys

- Excrete wastes through urine formation
- Processes blood plasma for removal of waste
- Synthesize Vit D, erythropoietin and prostaglandins

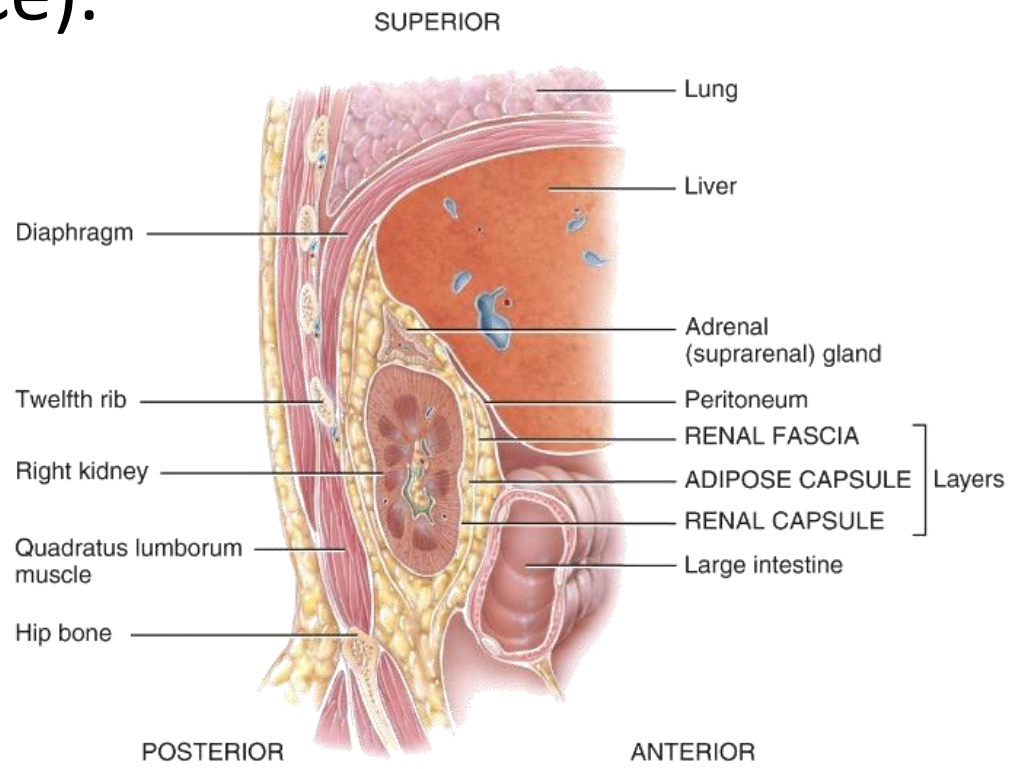
- Maintain body fluids
  - Composition
    - pH
    - Electrolytes
      - Regulate Na+, K+, Cl-, N+, and Urea
  - Controls RBC production
    - Erythropoietin
  - Volume
    - Influence ADH and aldosterone secretion
  - Maintain Blood Pressure
    - Renin

Kidney


Interlobular arteries
Renal column
Renal sinus
Hilum
Renal pelvis
Renal papilla of pyramid
Ureter
Medulla
Capsule (fibrous)
Cortex
Minor calyces
Major calyces
Medullary pyramid
S
M
L
I
Renal papilla of pyramid
Hilum
Renal pelvis
Ureter
Renal column
Medullary pyramid

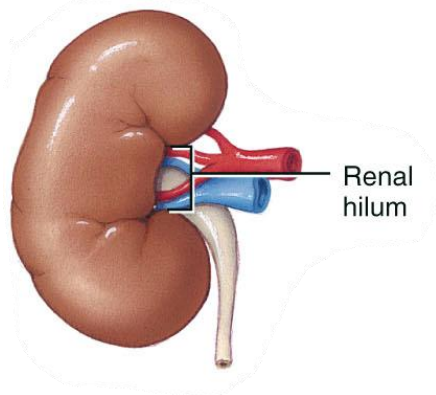
Renal Anatomy

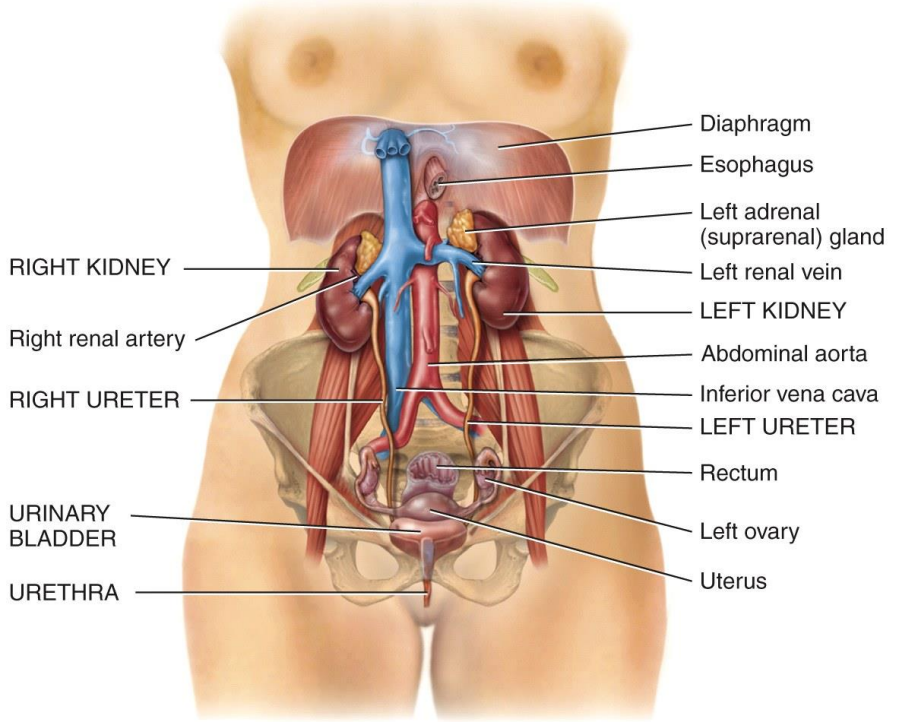
- The kidneys are bean-shaped organs located just above the waist between the peritoneum and the posterior wall of the abdomen (in the retroperitoneal space).
- They are partially protected by the eleventh and twelfth pairs of ribs.
- Because of the position of the liver, the right kidney is slightly lower than the left.



Renal Anatomy

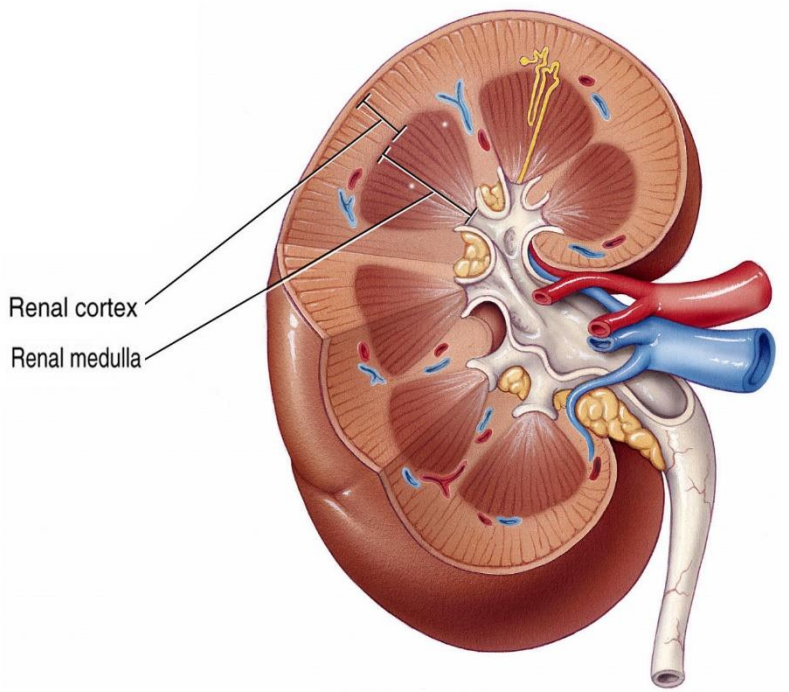
- A ureter (approximately 25 cm long) originates near an indented area of each kidney called the hilum and travels to the base of the bladder. Renal blood vessels also emerge from the hilum.
- From the bladder, the urethra (4 cm in length in women and 24 cm in length in men) allows urine to be excreted.





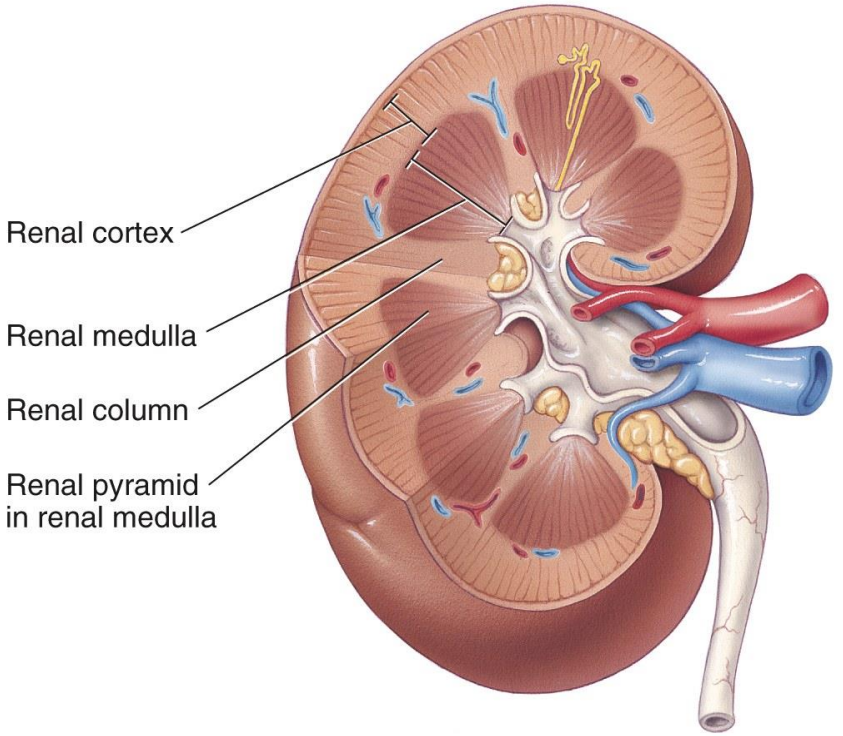
Renal Anatomy

- A frontal section through the kidney reveals two distinct regions of internal anatomy, the cortex and medulla.
  - The main function of the cortex is filtration to form urine.
  - The main function of the medulla is to collect and excrete urine.



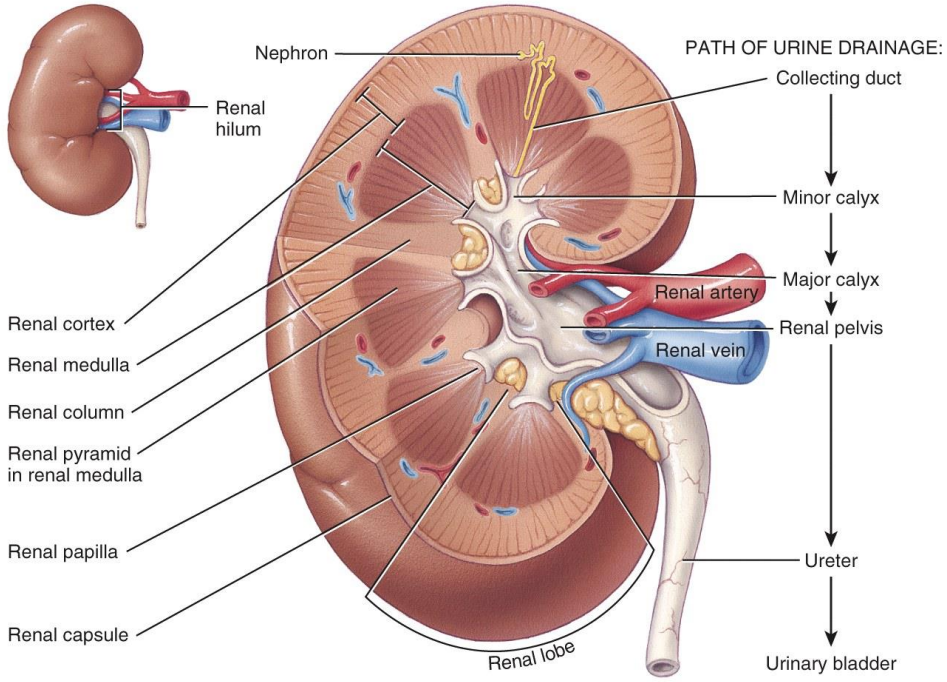
Renal Anatomy

- Renal pyramids
  - consists of 8 to 18 conical subdivisions within the medulla that contain the kidney's secreting apparatus and tubules
- Renal columns
  - are composed of lines of blood vessels and fibrous material which allows the cortex to be better anchored.



Renal Anatomy

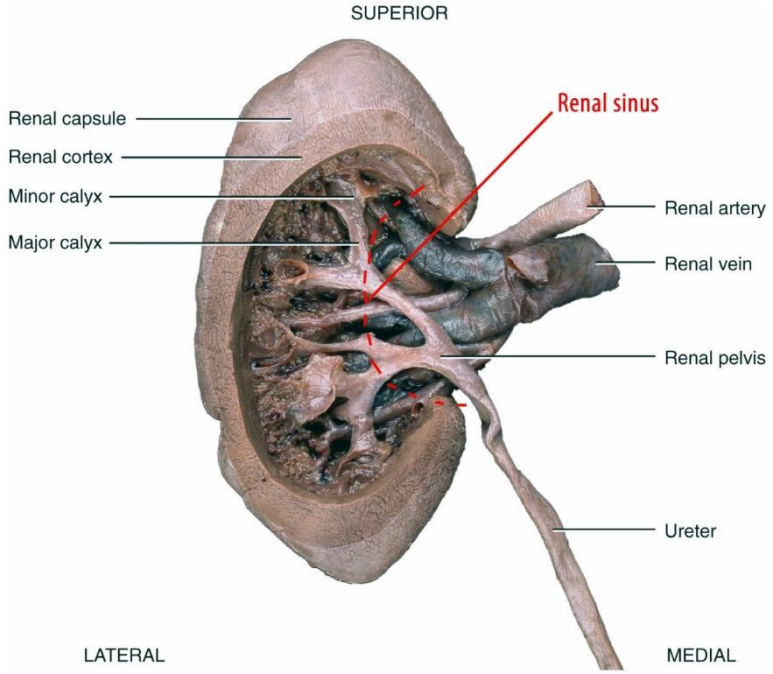
- The renal papilla is the location where the medullary pyramids empty urine into cuplike structures called minor and major calyces.
  - 8-18 minor calyces and 2-3 major calyces receive urine from the papilla of one renal pyramid.
  - Once the filtrate enters the calyces, it becomes urine because no further reabsorption can occur.



(a) Anterior view of dissection of right kidney

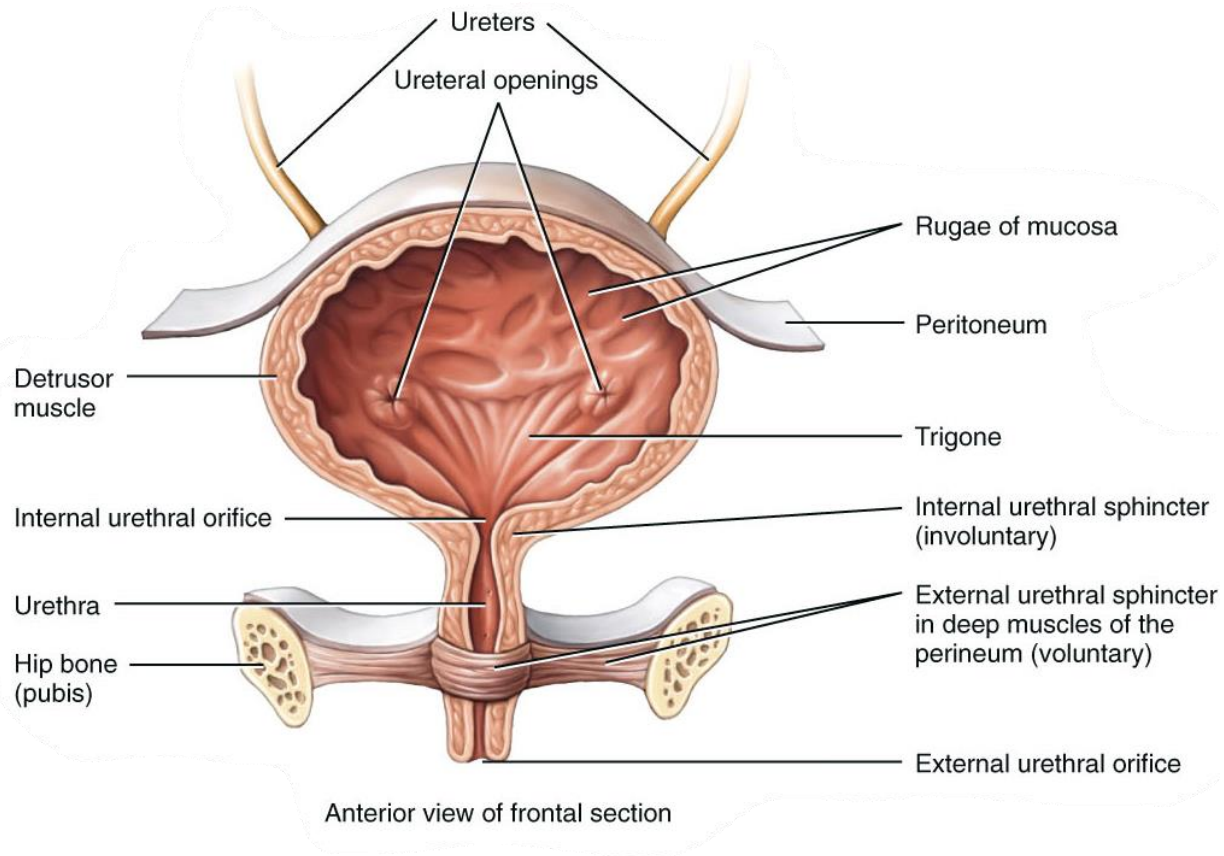
Renal Anatomy

- From the major calyces, urine drains into a single large cavity called the renal pelvis and then out through the ureter.
- The hilum expands into a cavity within the kidney called the renal sinus, which contains part of the renal pelvis, the calyces, and branches of the renal blood vessels and nerves.



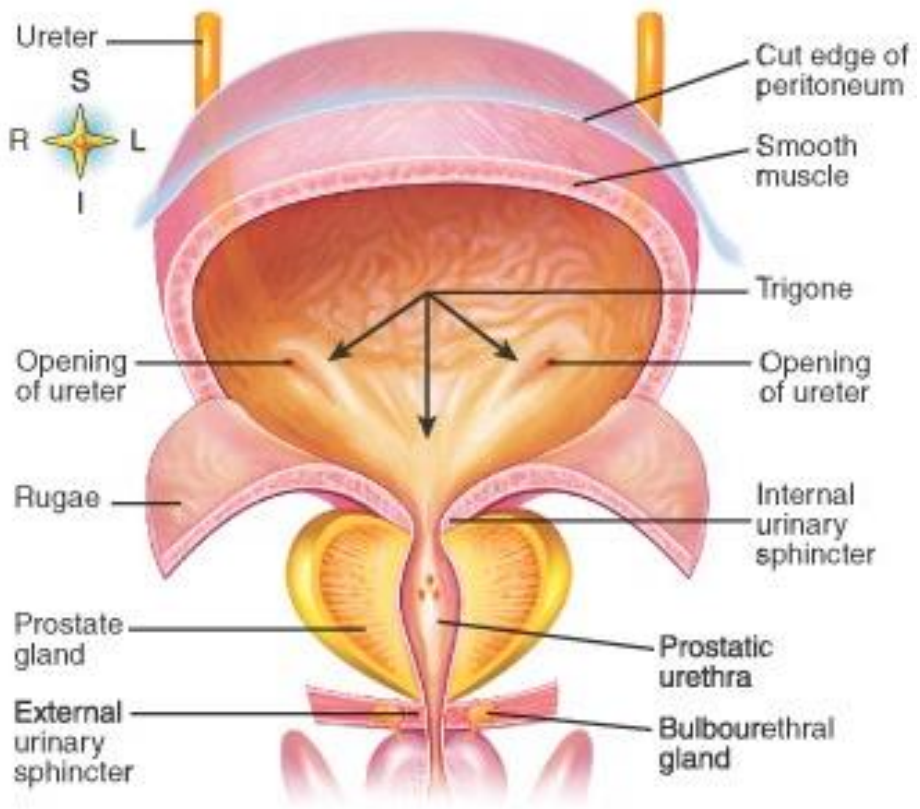
Renal Anatomy

- The ureters transport urine from the renal pelvis of the kidneys to the bladder using peristaltic waves, hydrostatic pressure and gravity to move the urine.
- There is no anatomical valve at the opening of the ureter into the bladder.



Urinary Bladder

- Muscular collapsible sac between symphysis pubis and rectum
- Below parietal peritoneum (covers superior portion)
- Fibrous adventitia covers majority of bladder
- Triangle shaped floor (trigone)
  - Ureter openings posterior/superior corners
  - Urethra opening anterior/inferior corner
- Acts as reservoir and expels urine (with the urethra)

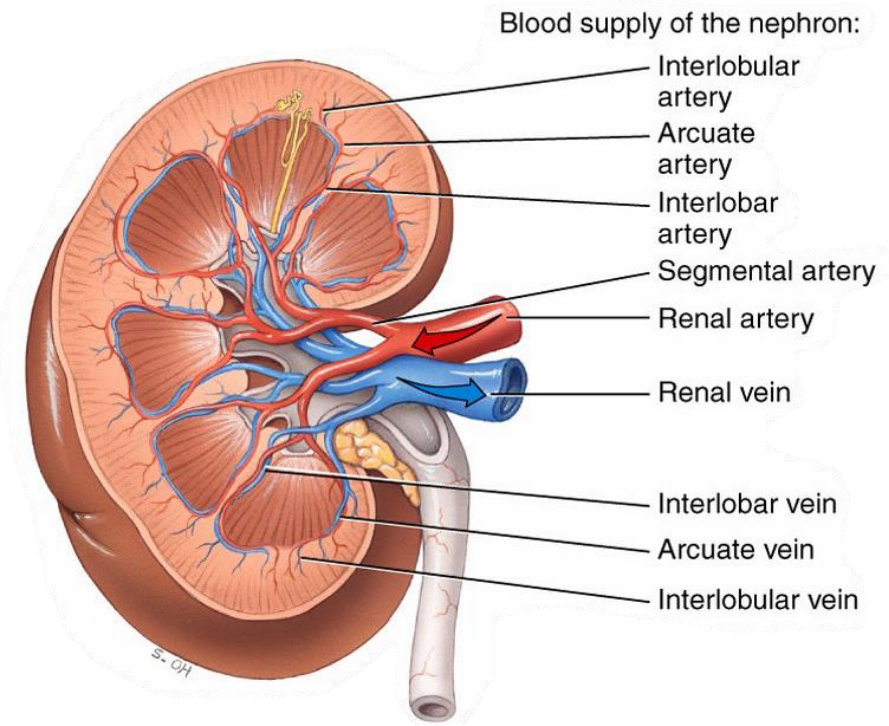


Urethra

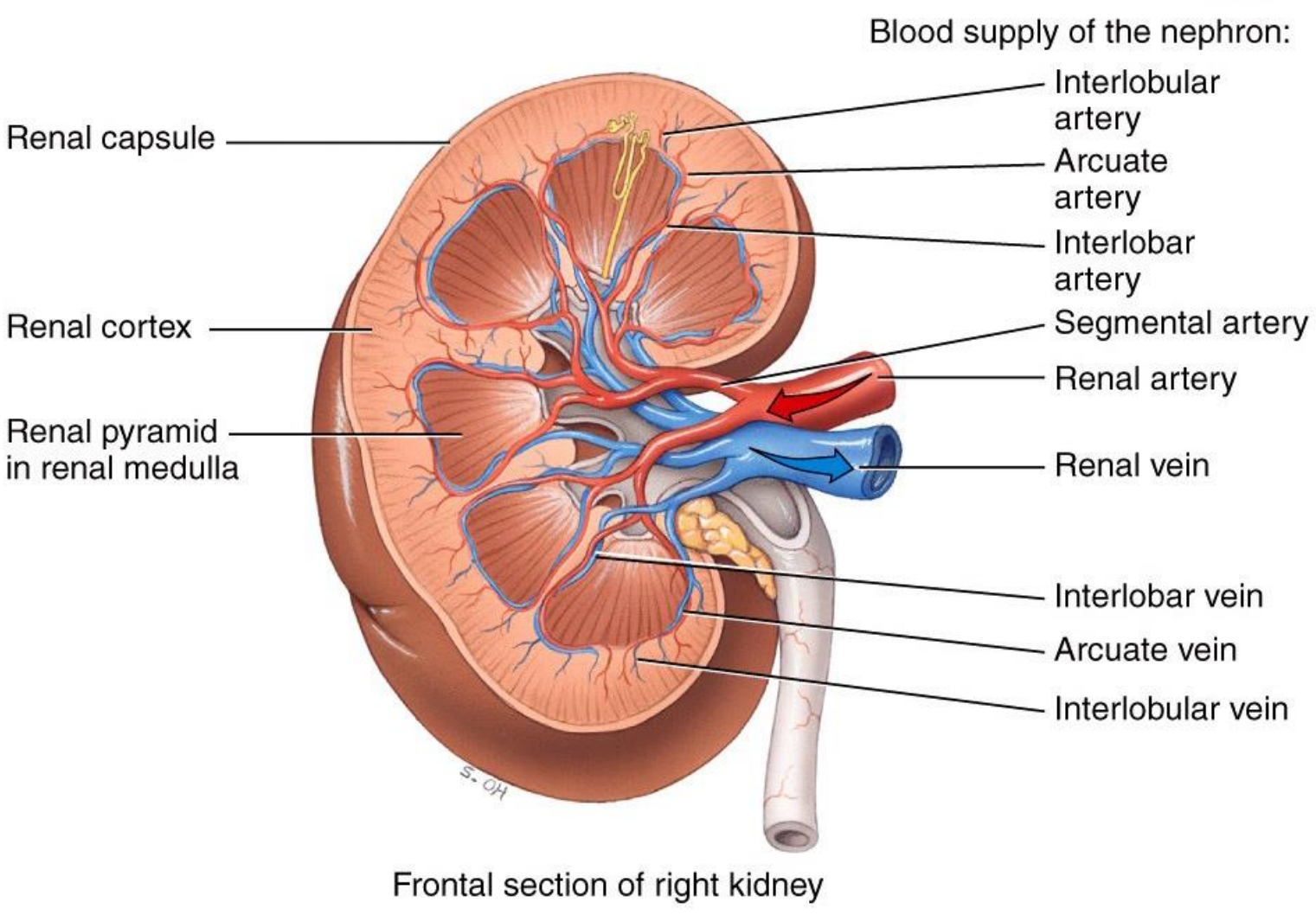
- In females it lies between symphysis and anterior vagina (approx 3 cm in length)
- It extends 20 cm in males, traveling through center of prostate
- Two ejaculatory ducts attach to urethra slightly distal to prostate

Renal Blood Flow

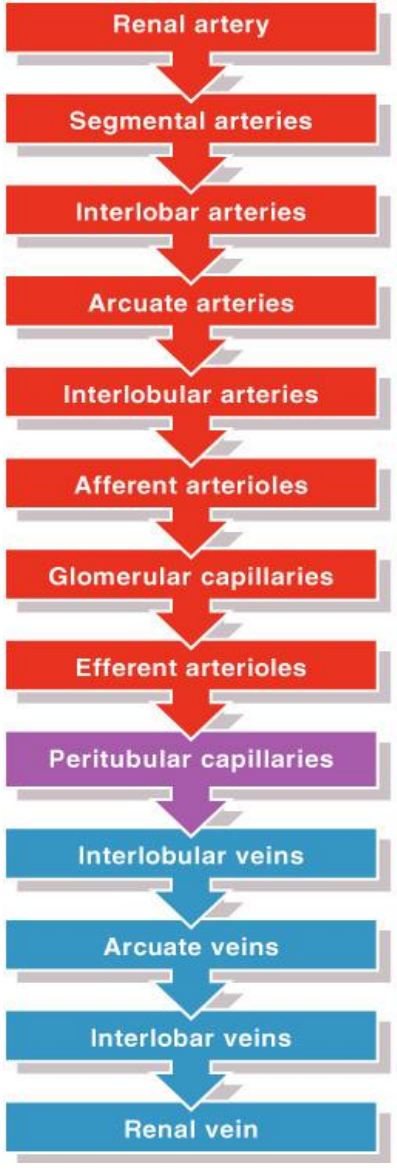
- The renal artery and renal vein pass into the substance of the kidney (the parenchyma) at the hilum.
  - Arterial blood enters via the renal artery and exits the renal vein.
    - The renal arteries are very large branches of the aorta, and up to a third of total cardiac output can pass through them to be filtered by the kidneys.



Renal Blood Flow

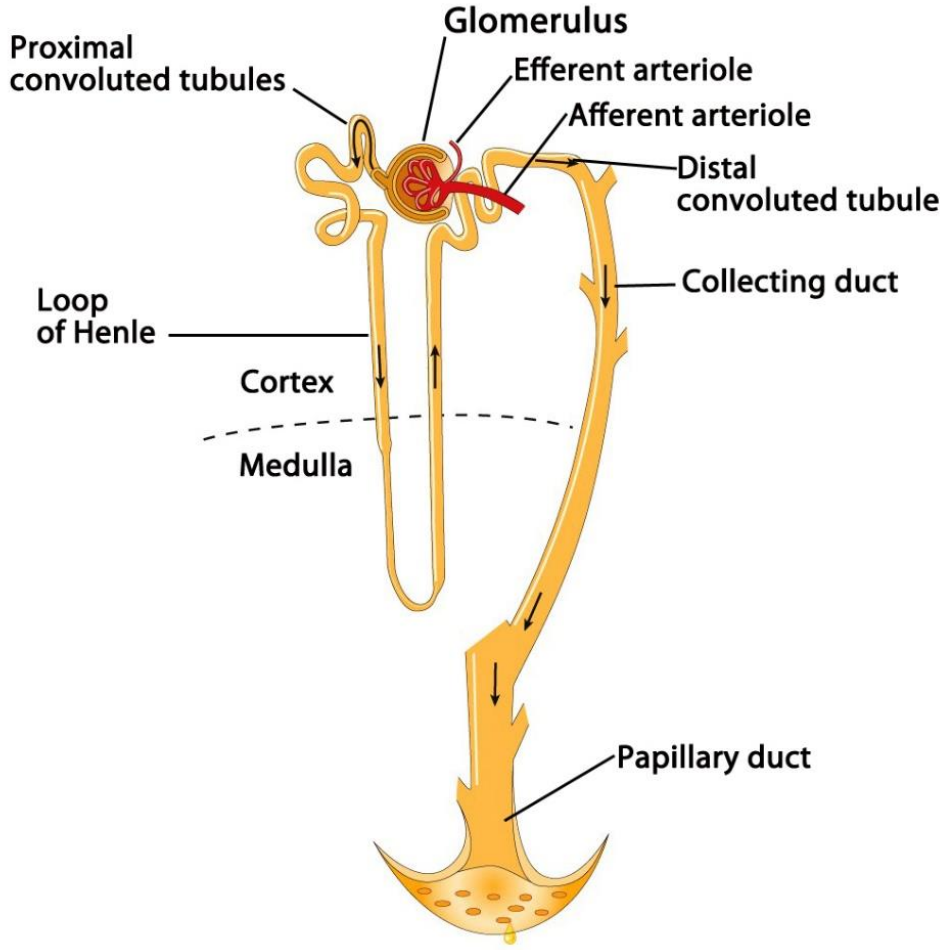


Frontal section of right kidney



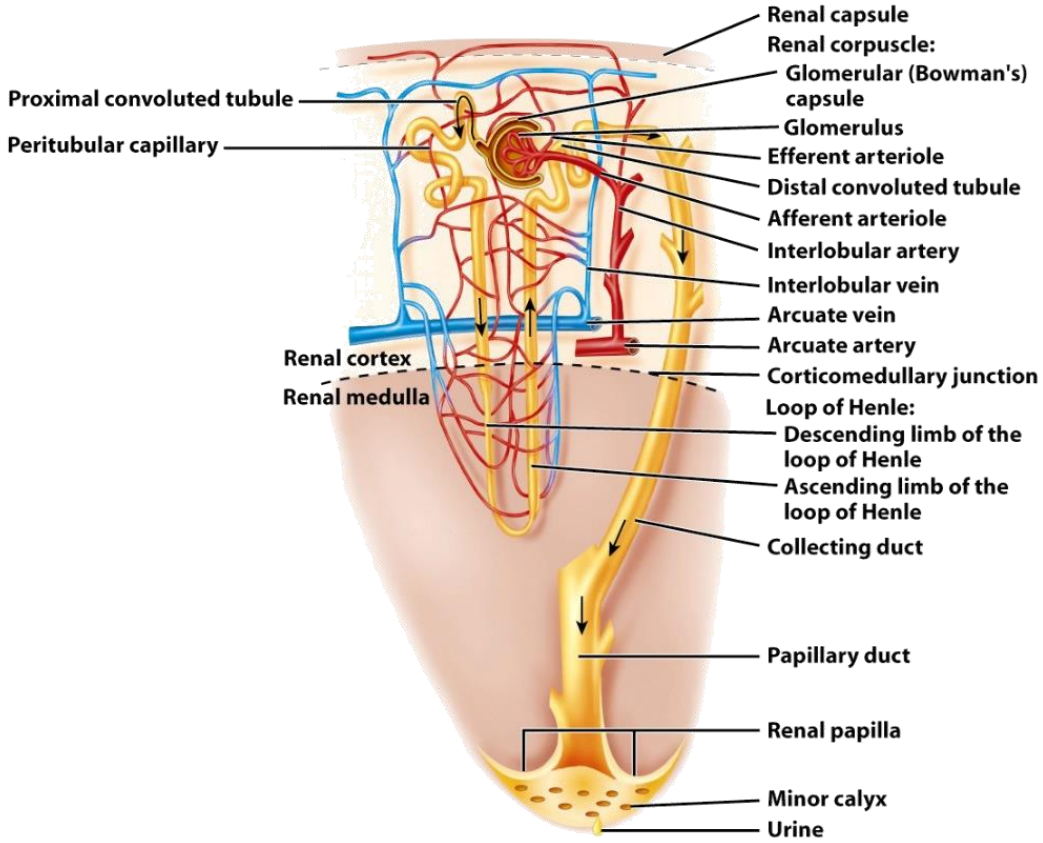
The Nephron

- The nephron is the functional unit of the kidney.
- It is a microscopic structure composed of blood vessels and tubules that collect the filtrate which will ultimately become urine.



The Nephron

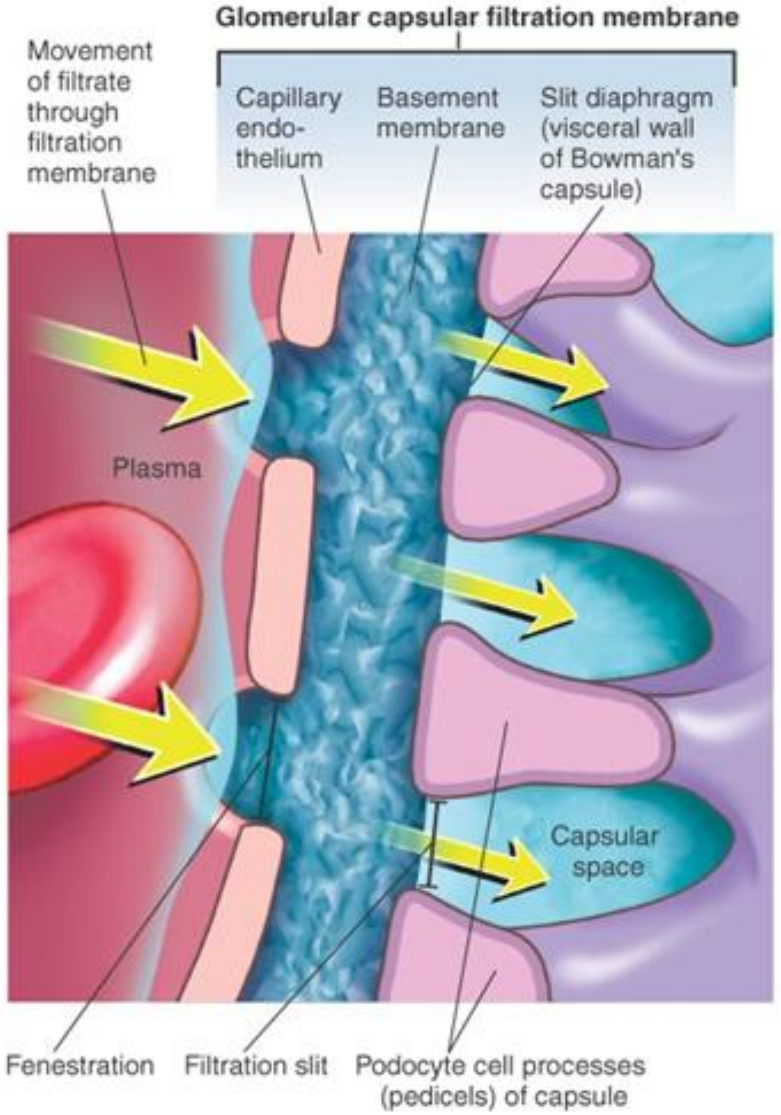
- Each nephron receives one afferent arteriole, which divides into a tangled, ball-shaped capillary network called the glomerulus.
- The glomerular capillaries then reunite to form an efferent arteriole that carries blood out of the glomerulus.



The Nephron

- Glomerular capillaries are unique among capillaries in the body because they are positioned between two arterioles, rather than between an arteriole and a venule.
  - There are venules in the kidney, but they come later.
- The Renal Corpuscle consists of two structures:
  - The glomerular capillaries
  - The glomerular capsule (Bowman's capsule)
    - A double-walled epithelial cup that surrounds the glomerular capillaries.

Renal Corpuscle



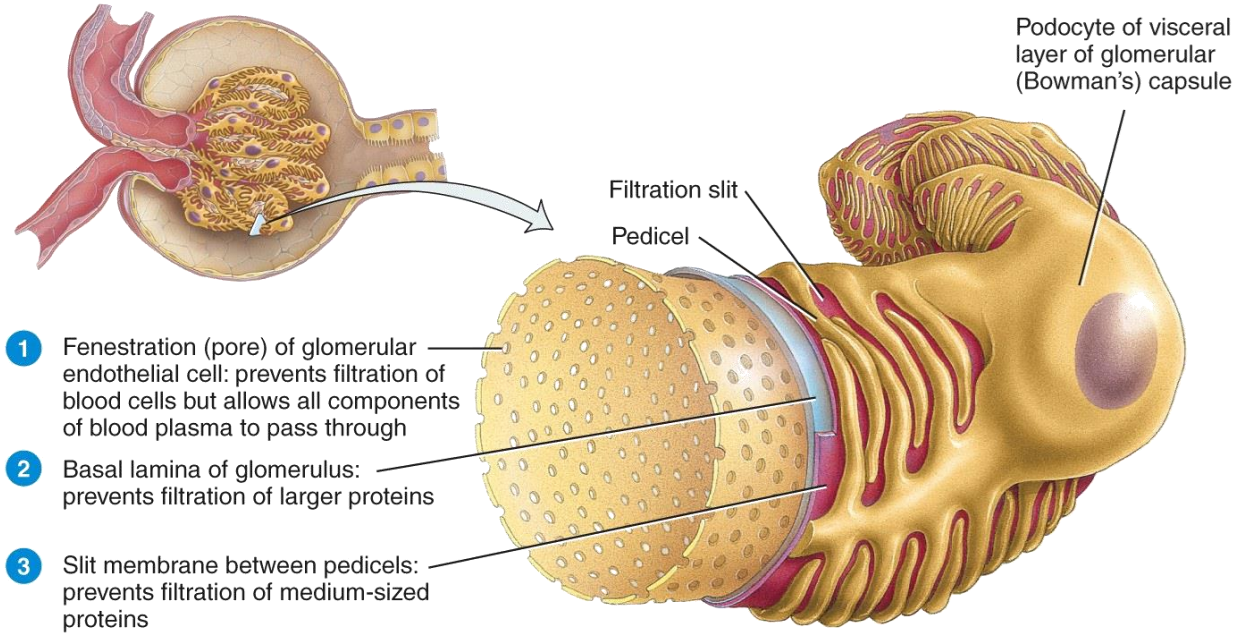
- Basal Lamina (basement membrane) separates the two
- All filtrate must pass through the Glomerular Capsular Filtration Membrane

The Nephron

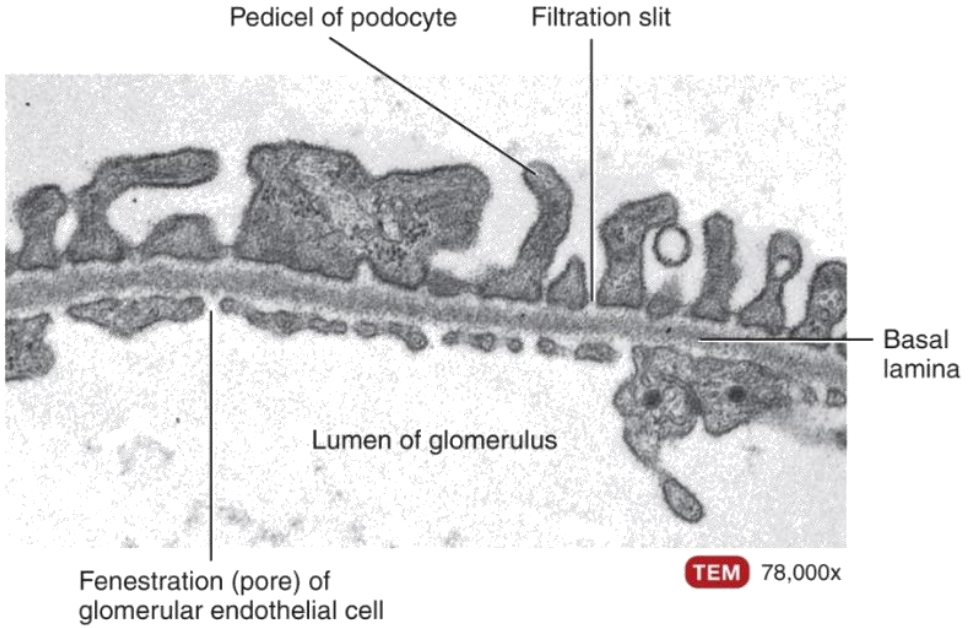
- Bowman's capsule consists of visceral and parietal layers.
  - The visceral layer is made of modified simple squamous epithelial cells called podocytes. The many foot-like projections of these cells (pedicels) wrap around the single layer of endothelial cells of the glomerular capillaries and form the inner wall of the capsule.
  - The parietal layer of the glomerular capsule is a simple squamous epithelium and forms the outer wall of the capsule.

The Nephron

- The epithelium of the visceral and parietal layers of the renal corpuscle form fenestrations (pores) which act as a filtration (dialysis) membrane.



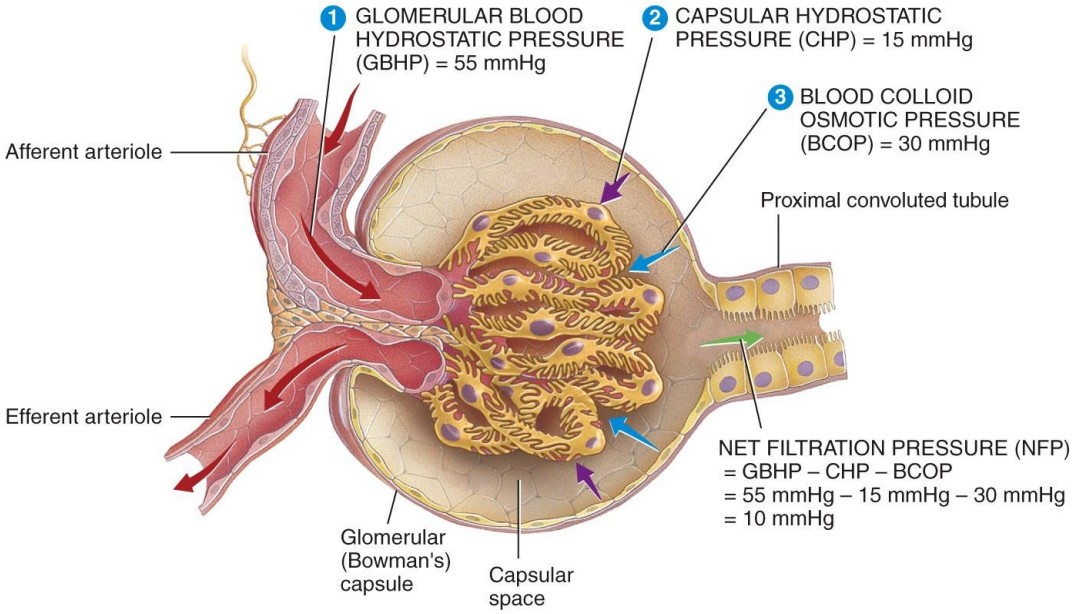
(a) Details of filtration membrane



(b) Filtration membrane

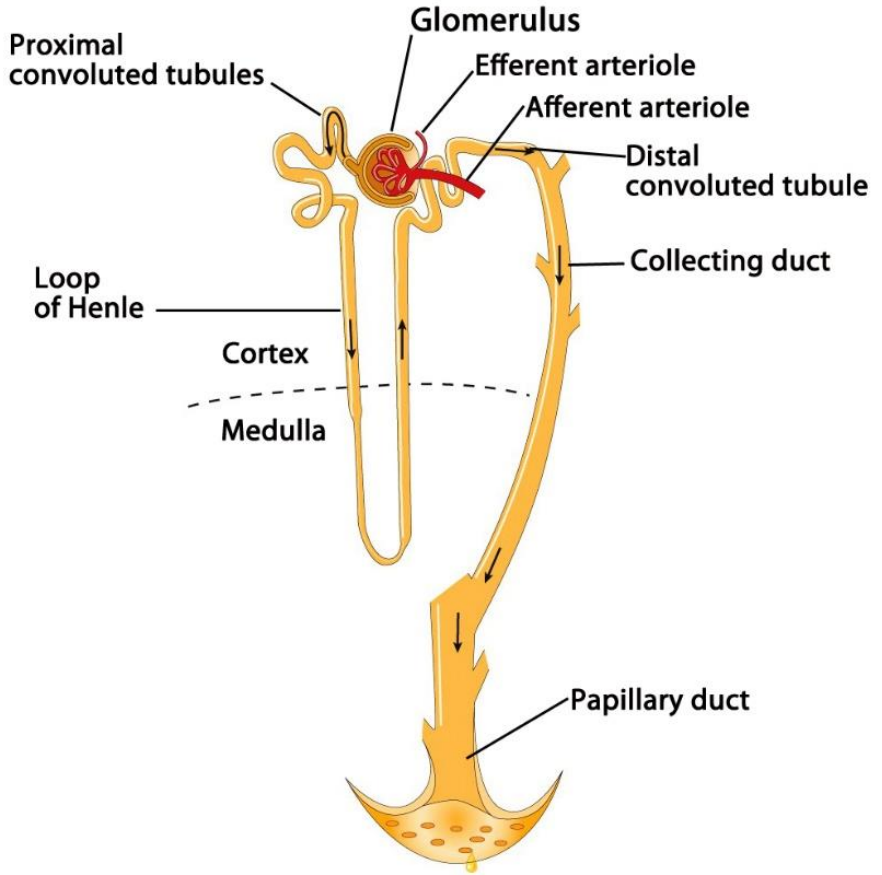
The Nephron

- Fluid filtered from the glomerular capillaries enters Bowman's space, (the space between the two layers of the glomerular capsule), which is the lumen of the urinary tube.



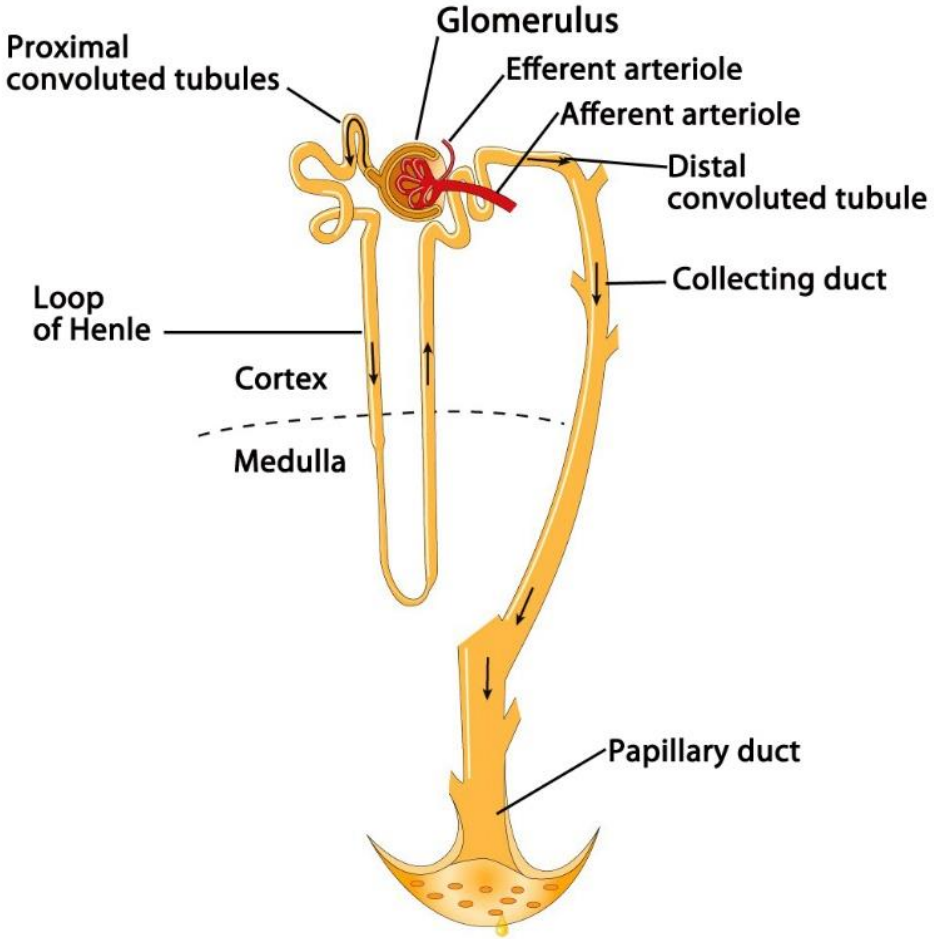
The Nephron

- Blood plasma is filtered through the glomerular capillaries into the glomerular capsule.
- Filtered fluid passes into the renal tubule, which has three main sections:
  - Proximal convoluted tubule (PCT)
  - Loop of Henle
  - Distal convoluted tubule (DCT)



The Nephron

- The distal convoluted tubules of several nephrons empty into a single collecting duct.
- Collecting ducts unite and converge into several hundred large papillary ducts which drain into the minor calyces, major calyces, renal pelvis, and ureters.

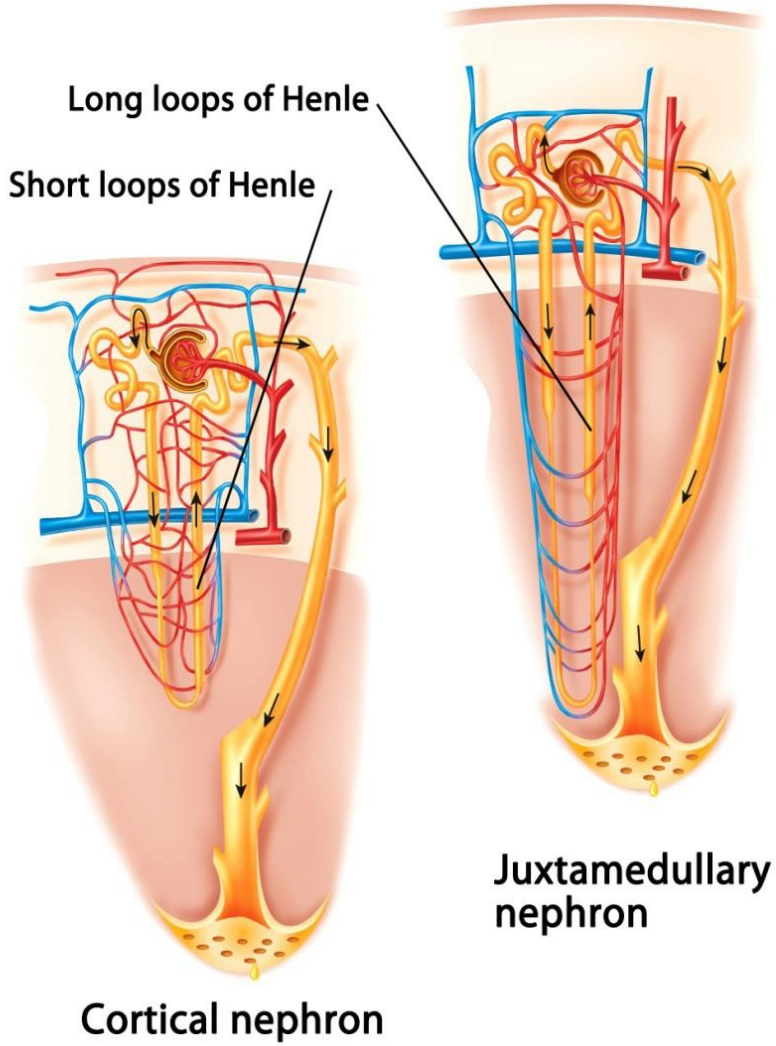


The Nephron

- The first part of the loop of Henle (the descending limb) dips into the renal medulla. It then makes a hairpin turn and returns to the renal cortex as the ascending limb.
  - The descending limb of the loop of Henle is composed of a simple squamous epithelium.
  - The ascending limb of the loop may be either “thin” (composed of a simple squamous epithelium) or “thick” (composed of simple cuboidal to low columnar cells).
    - Some nephrons contain both thick and thin ascending limbs.

The Nephron

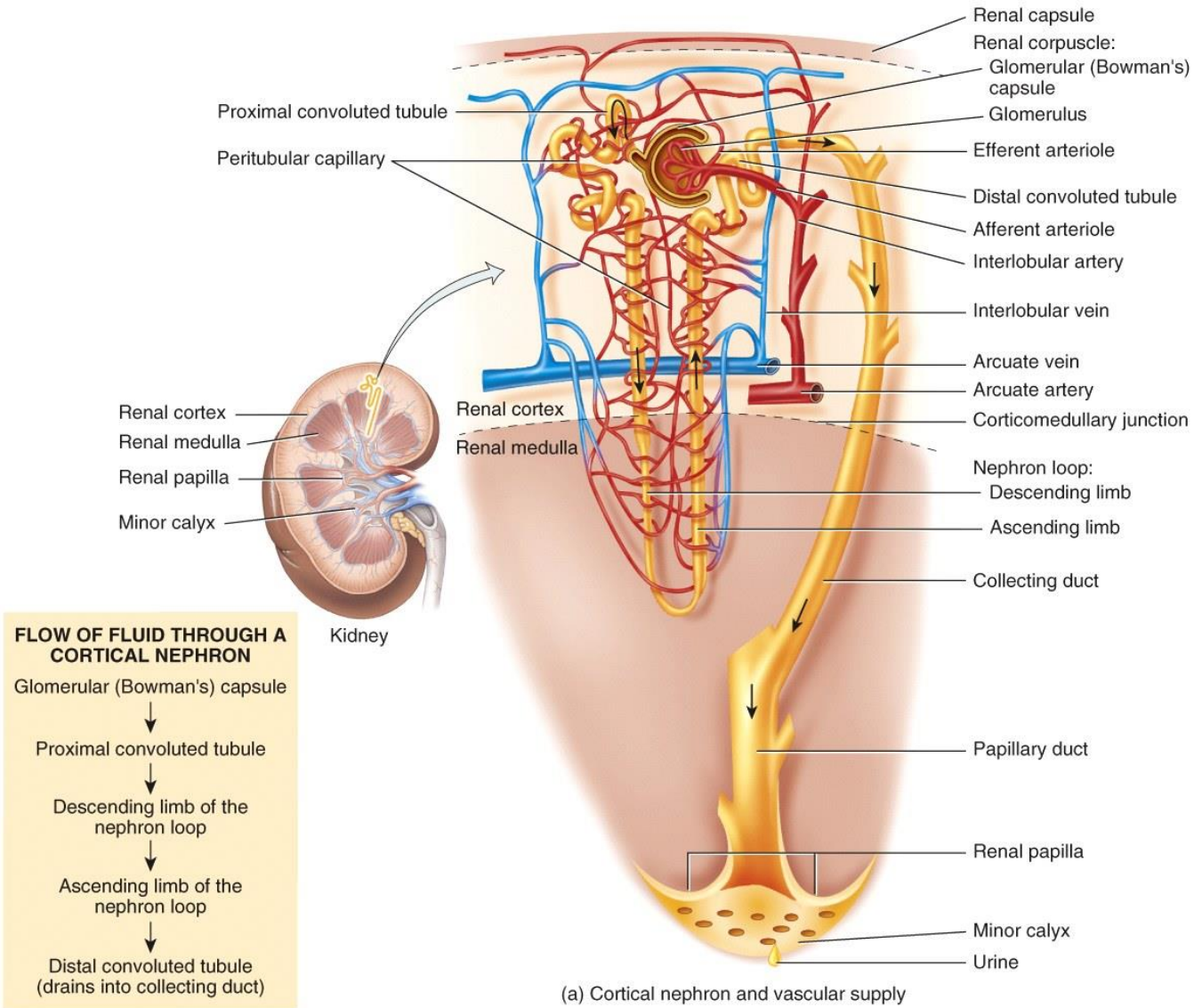
- Based on the length of the Loop of Henle and the presence of thin segments in the ascending limb, nephrons can be sorted into two populations:
  - Cortical
  - Juxtamedullary
- Nephrons with long loops of Henle enable the kidneys to create a concentration gradient in the renal medulla and to excrete very dilute or very concentrated urine.



The Nephron

- Cortical nephrons make up about 80–85% of the 1 million microscopic nephrons that comprise each kidney.
  - Their renal corpuscles are located in the outer portion of the cortex, with short loops of Henle that penetrate only a small way into the medulla.
  - The ascending limbs of their loops of Henle consist of only a thick segment, lacking any thin portions.
  - Nephrons with short loops receive their blood supply from peritubular capillaries that arise from efferent arterioles.

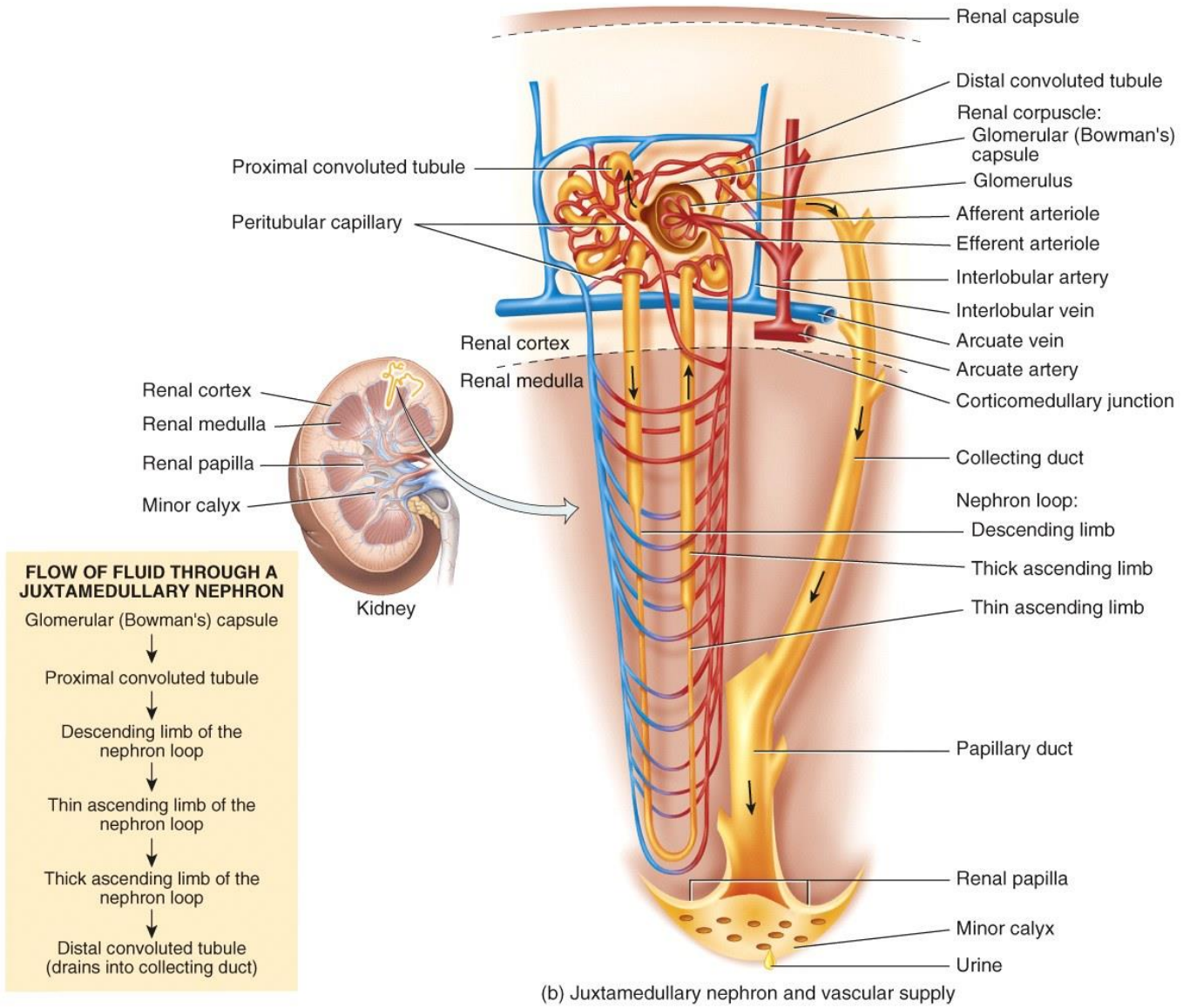
The Nephron


Renal capsule
Renal corpuscle:
Glomerular (Bowman's) capsule
Proximal convoluted tubule
Glomerulus
Peritubular capillary
Efferent arteriole
Distal convoluted tubule
Afferent arteriole
Interlobular artery
Interlobular vein
Arcuate vein
Arcuate artery
Renal cortex
Corticomedullary junction
Renal medulla
Nephron loop:
Descending limb
Ascending limb
Collecting duct
Papillary duct
Renal papilla
Minor calyx
Urine
Renal cortex
Renal medulla
Renal papilla
Minor calyx
Kidney
FLOW OF FLUID THROUGH A CORTICAL NEPHRON
Glomerular (Bowman's) capsule
Proximal convoluted tubule
Descending limb of the nephron loop
Ascending limb of the nephron loop
Distal convoluted tubule (drains into collecting duct)
(a) Cortical nephron and vascular supply

The Nephron

- The other 15–20% of the nephrons are juxtamedullary nephrons .
  - Their renal corpuscles lie deep in the cortex, close to the medulla, and they have long loops of Henle that extend into the deepest region of the medulla.
  - The ascending limbs of their loops of Henle consist of both thin and thick segments.
  - Nephrons with long loops receive their blood supply from the vasa recta that arise from peritubular capillaries before becoming peritubular venules.

Juxtamedullary Nephron

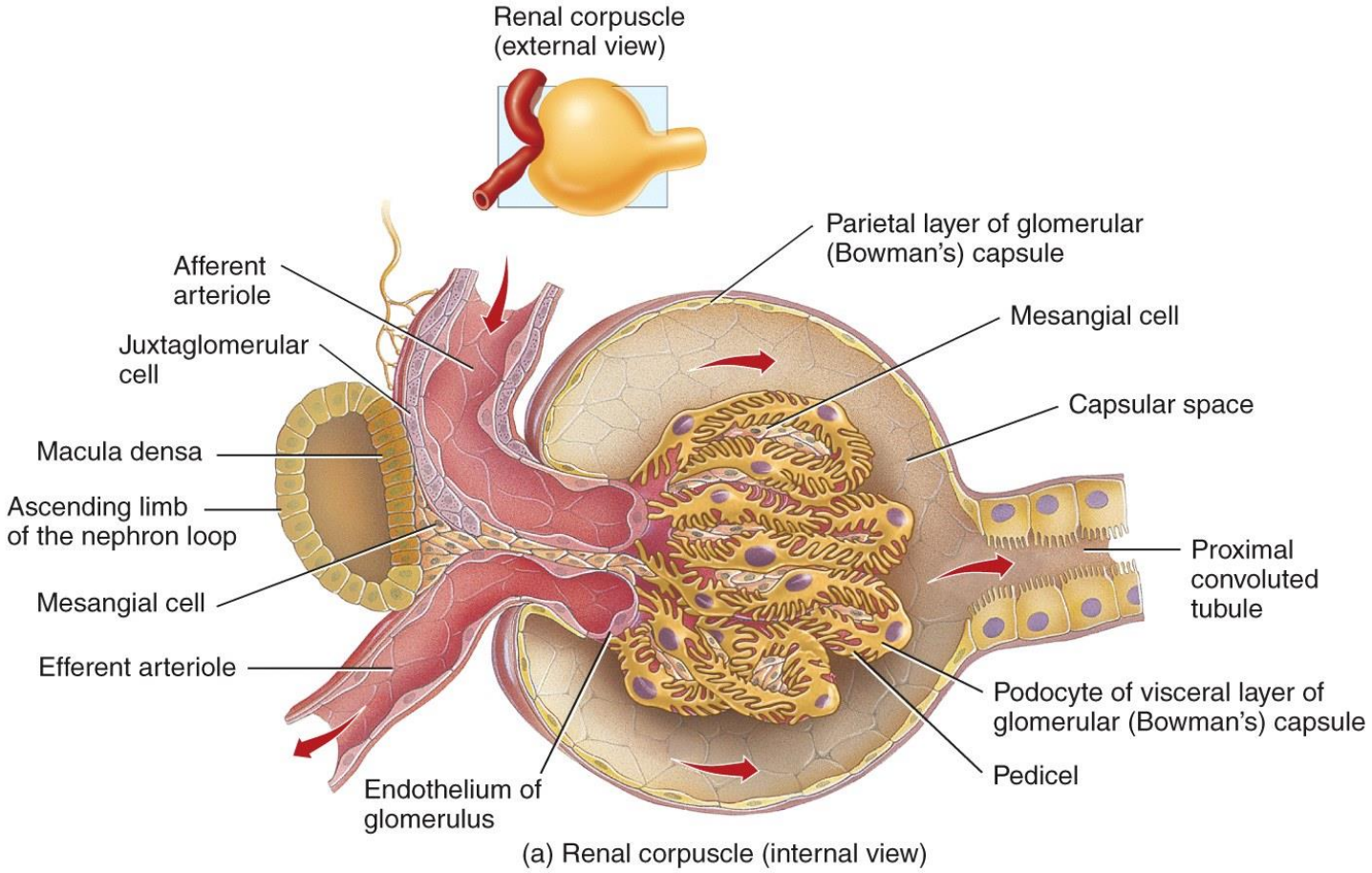


The Nephron

- In each nephron, the final part of the ascending limb of the loop of Henle makes contact with the afferent arteriole serving that renal corpuscle.
- Because the columnar tubule cells in this region are crowded together, they are known as the macula densa.
  - Alongside the macula densa, the wall of the afferent arteriole contains modified smooth muscle fibers called juxtaglomerular (JG) cells.
    - Together with the macula densa, they constitute the juxtaglomerular apparatus (JGA).

The Nephron

- The JGA helps regulate blood pressure within the kidneys.



Juxtaglomerular Apparatus

- Specialized cells are modifications of cells in the distal tubule and afferent arterioles
- Cells of the afferent arterioles (JG cells) contain renin granules
  - Act as mechanoreceptors and are sensitive to increases in pressure
  - Secrete renin when afferent arterial blood pressure drops
- Cells of the distal tubules form macula densa
  - Act as chemoreceptors and are sensitive to concentration of solutes passing through the tubule
  - JG cells stimulate concentrated urine production

Collecting Duct

- Collecting tubules from a number of nephrons connect together to form
- Strait tubule
- Larger collecting ducts of a renal pyramid converge together to form one tube that empties into the minor calyces at the renal papilla

Ureters

- 28 – 34 cm long
- Passages for urine from kidneys to urinary bladder
- Originate from renal pelvis and connect to the bladder on the lateral posterior wall
- Distal end closes on reverse pressure to prevent backflow when bladder is full
- Has three layers
  - Fibrous coat
  - Muscular coat (has circular and longitudinal muscles)
  - Mucosa
- Urine is propelled by peristalsis
  - Rate is directly proportional to urine volume

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Genitourinary Anatomy

PHYSIOLOGY OF THE URINARY SYSTEM

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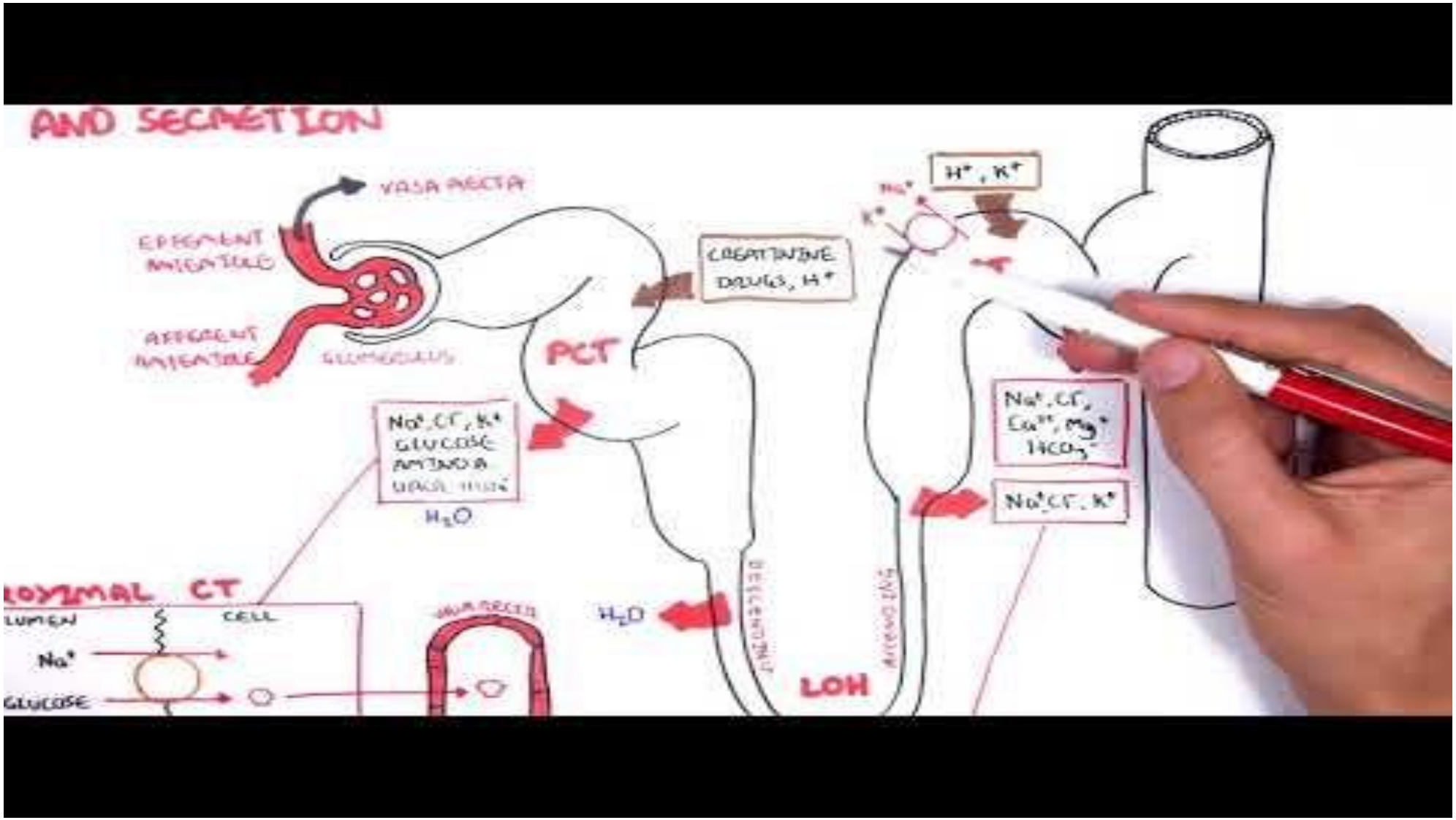
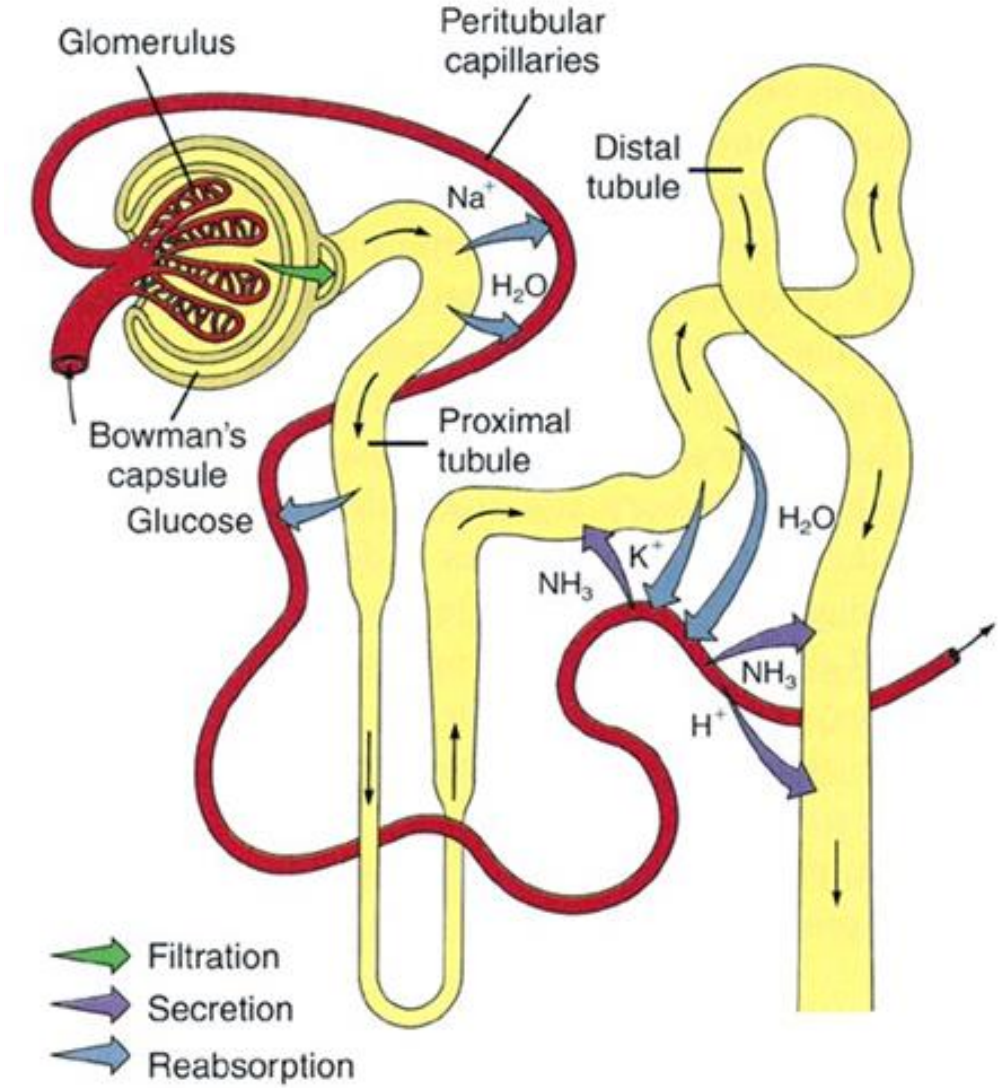
Urine formation

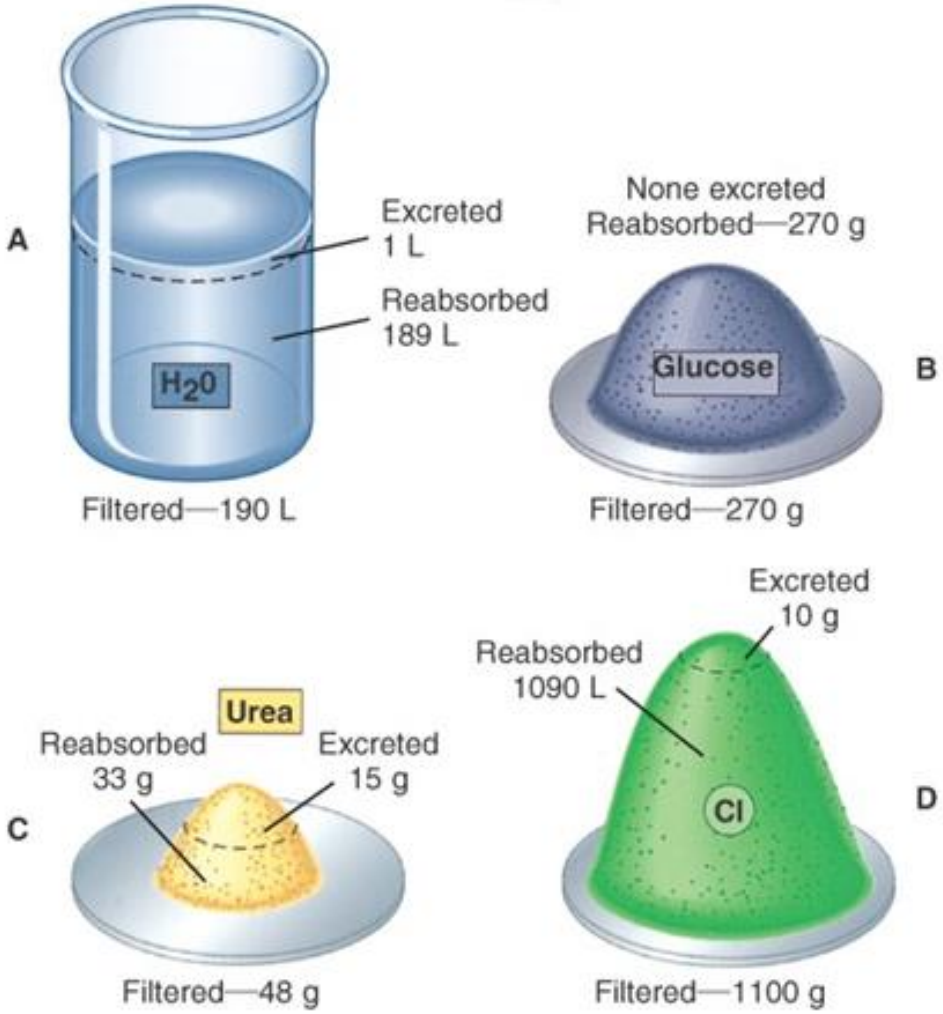


Urine formation

- Three processes performed
  - Glomerular filtration
    - Of water and protein free solutes
  - Tubular reabsorption
    - Of molecules into peritubular blood
  - Tubular secretion
    - Of molecules from peritubular blood and into tubule

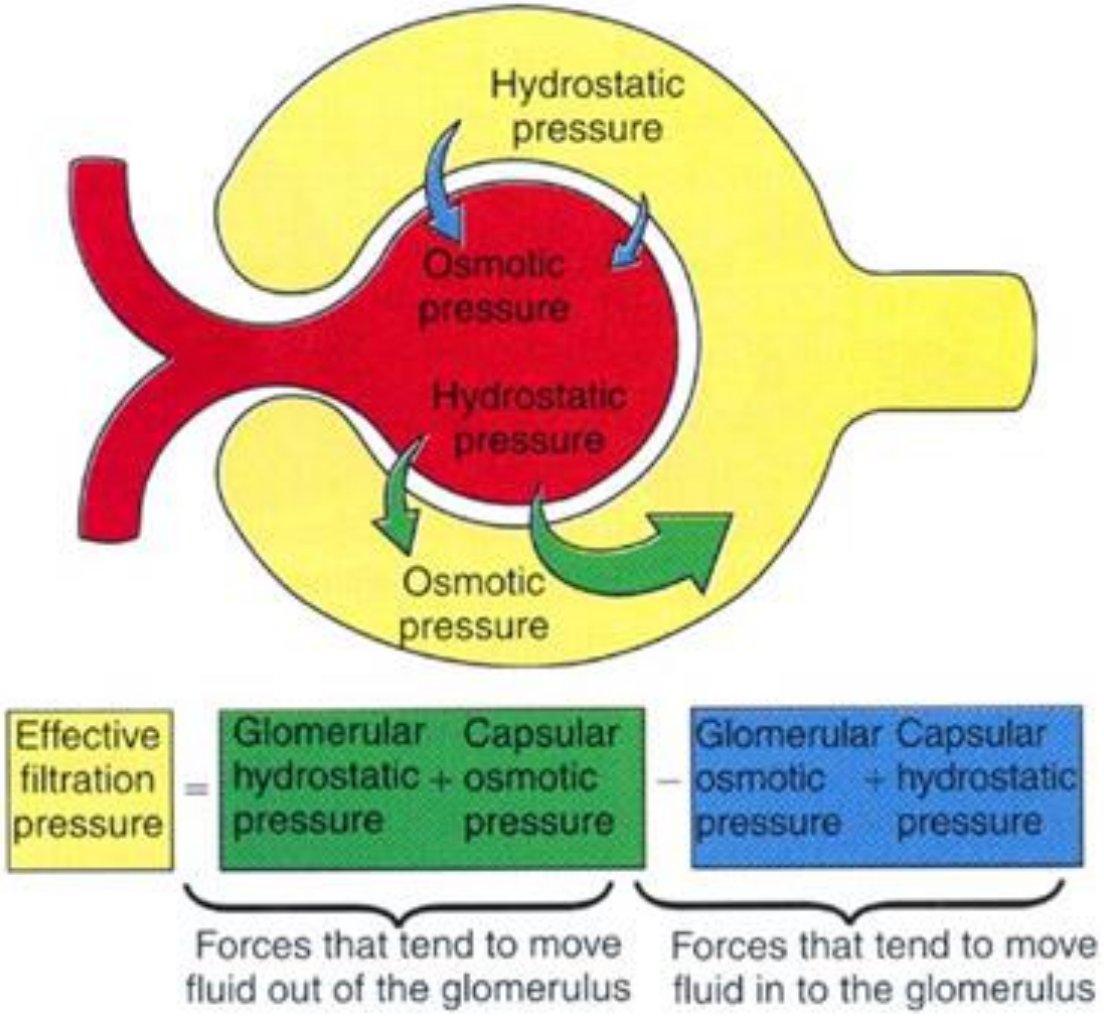


Urine formation



- Most plasma filtrated through hydrostatic pressure
- Reabsorbs needed non wastes and nutrients (orthostatic)
- Secretes last minute wastes

Filtration



- Occurs in the renal corpuscles
- Filters all but blood cells and plasma proteins
- Results in approx. 180 L of glomerular filtrate per day
- Occurs due to pressure gradients

Filtration

- Occurs more rapidly in corpuscle then in other capillaries
  - Mainly due to structural differences
    - More fenestrations (and larger)
    - Glomerular hydrostatic pressure is higher
      - Efferent arteriole is smaller then afferent

Filtration

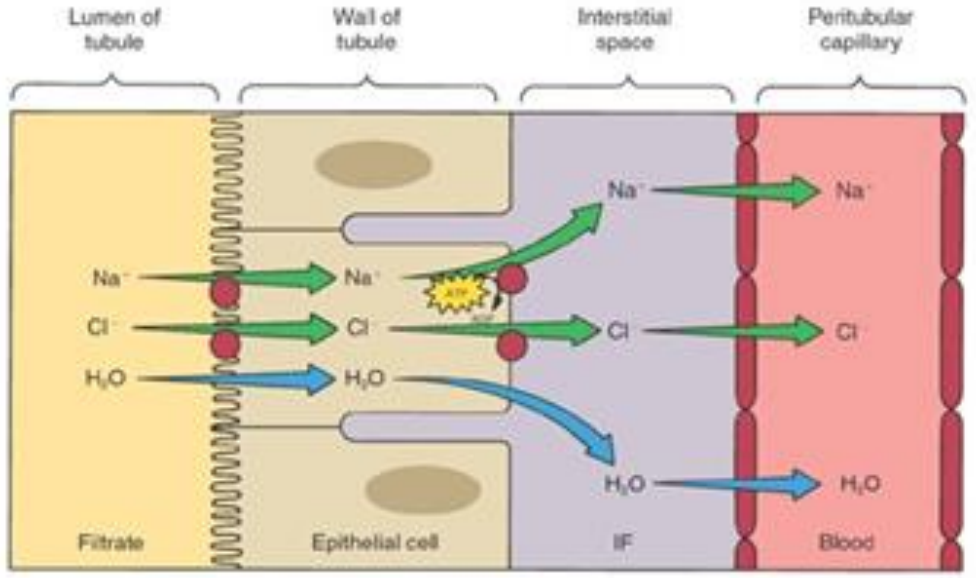
- Glomerular Filtration Rate (GFR)
  - Directly proportional to EFP
  - Can be altered by dilation/constriction of afferent and efferent arterioles or systemic BP

Reabsorption

- Result of passive and active transport
  - Proximal tubules reabsorb water, electrolytes and nutrients
  - Remainder reabsorb relatively little in comparison
- > 2/3 of the 180 L of filtrate reabsorbed before it hits proximal tubule

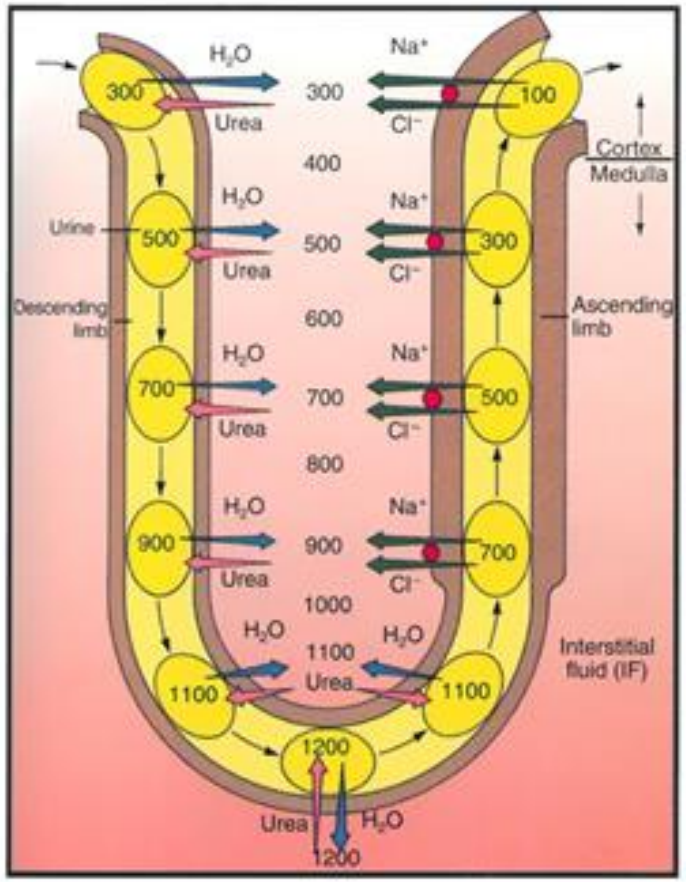
Proximal Reabsorption

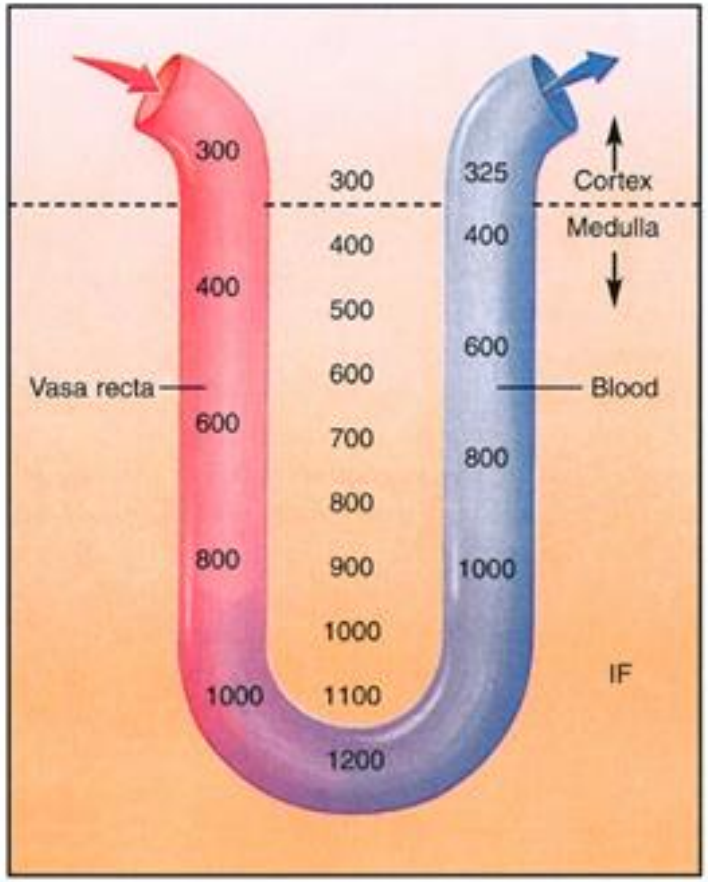
- Na actively transported into blood
- Glucose and amino acids “hitch a ride” (Na co-transport mechanism)
- Cl passively moves into plasma due to gradient (Na move changed the gradient)
- Na and Cl move creates osmotic imbalance so water moves into blood
- ½ of Urea (catabolism product from proteins) moves out of tubule



Loop Reabsorption

- Occurs in the Jux nephrons based on countercurrent flow (flows in opposite directions) of the loop and vasa recta

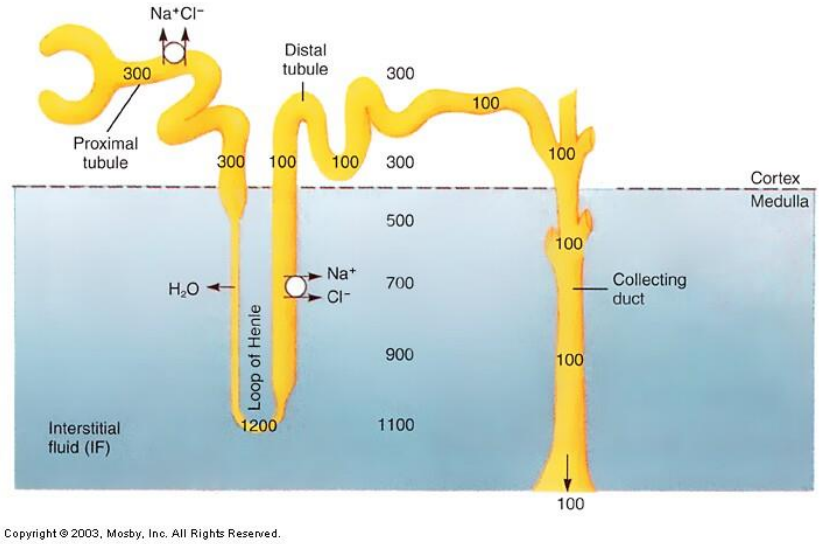




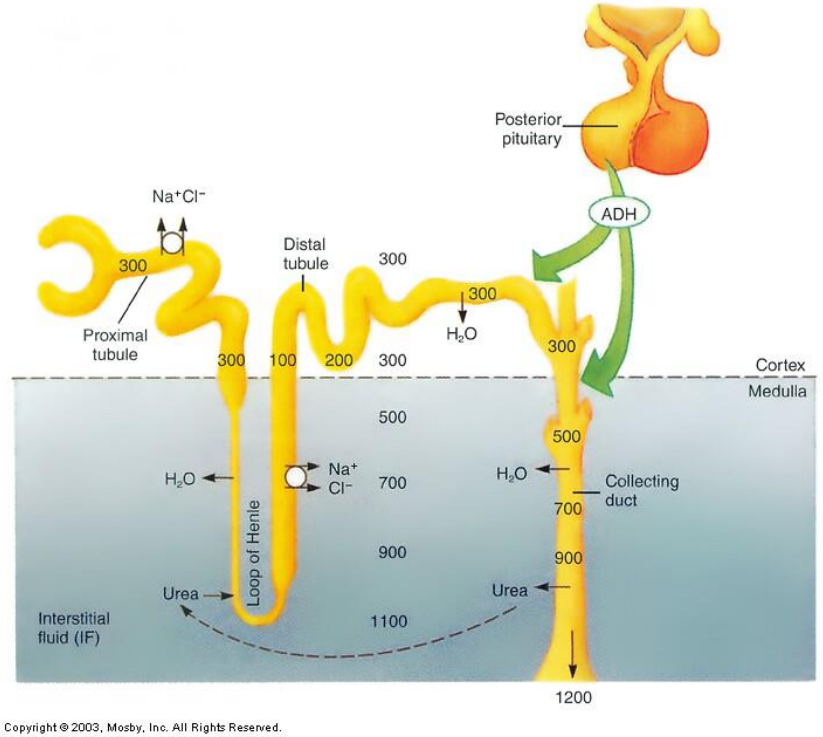
Distal Tubules and Collecting Ducts

- Distal tubules similar to proximal though limit water reabsorption
- Collecting ducts also prohibit water reabsorption
- Produces/maintains hypotonic fluid
- ADH affects walls of collecting ducts to allow for reabsorption of water

Distal Tubules and Collecting Ducts



Hypotonic Urine



Hypertonic Urine

Tubular Secretion

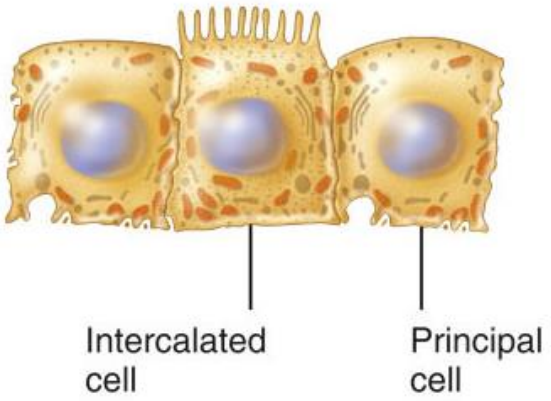
- Secretion of products from the tubular cells (from the blood)
- Distal and collecting tubules secrete K, H and Ammonia
  - K and H are actively transported in exchange for Na
    - K secretion is based on aldosterone levels
    - H secretion is based on blood H levels
  - Ammonia is secreted from the cells where they are produced
  - May also secrete certain drugs (toxins)

Hormones and Homeostasis

- Five hormones affect the extent of Na^+, Cl^-, Ca^{2+}, and water reabsorption as well as K^+ secretion by the renal tubules.
- These hormones, all of which are key to maintaining homeostasis of not only renal blood flow and BP, but systemic blood flow and BP are:
  - Angiotensin II
  - Antidiuretic Hormone (ADH)
  - Aldosterone
  - Atrial Natriuretic Peptide (ANP)
  - Parathyroid Hormone (PTH)

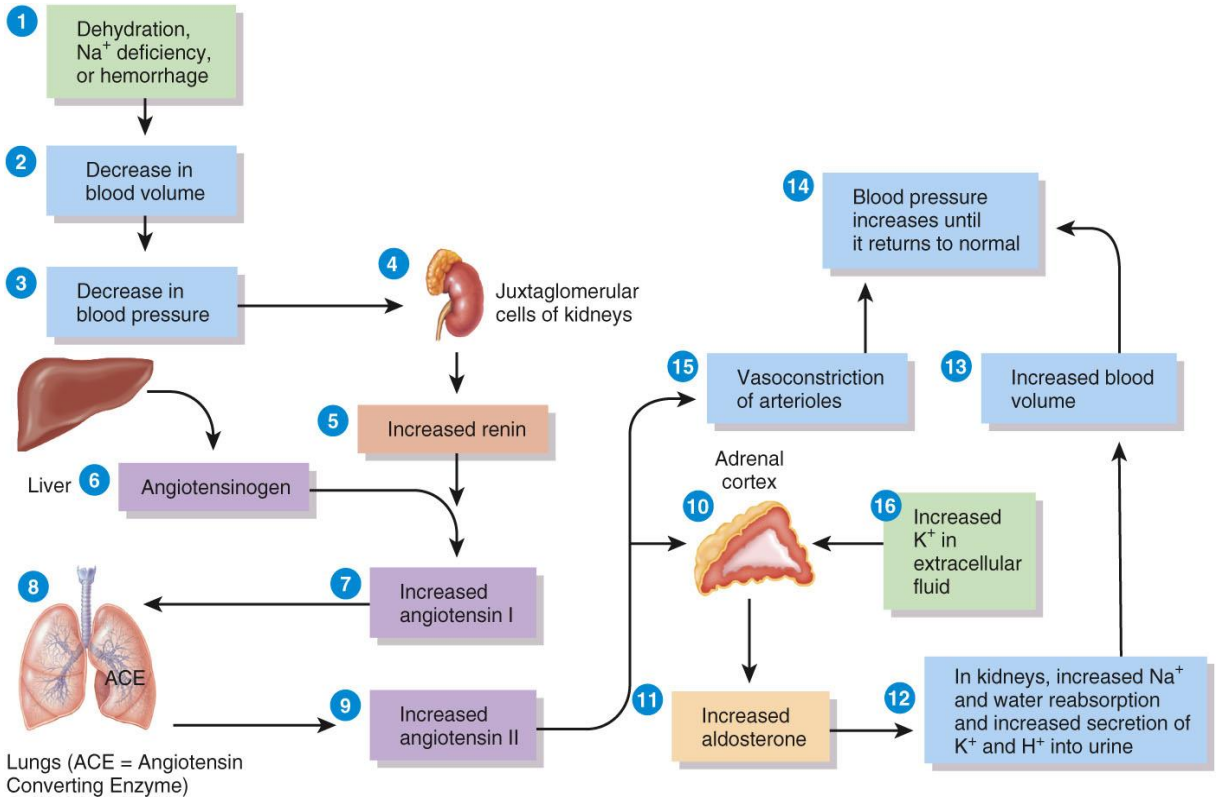
Hormones and Homeostasis

- ADH is released by the posterior pituitary in response to low blood flow in this part of the brain.
  - ADH affects facultative water reabsorption by increasing the water permeability of principal cells in the last part of the distal convoluted tubule and throughout the collecting duct.
  - In the absence of ADH, the apical membranes of principal cells are almost impermeable to water.



Hormones and Homeostasis

- Secretion of the hormones angiotensin II and aldosterone are tied to one another:

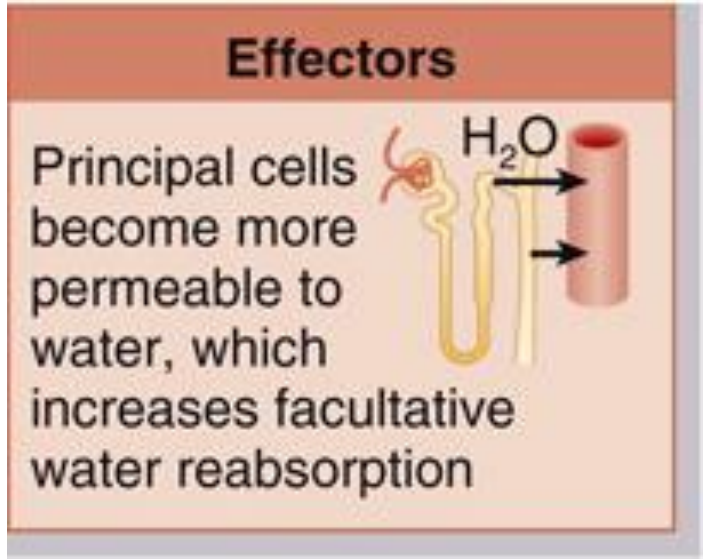


Hormones and Homeostasis

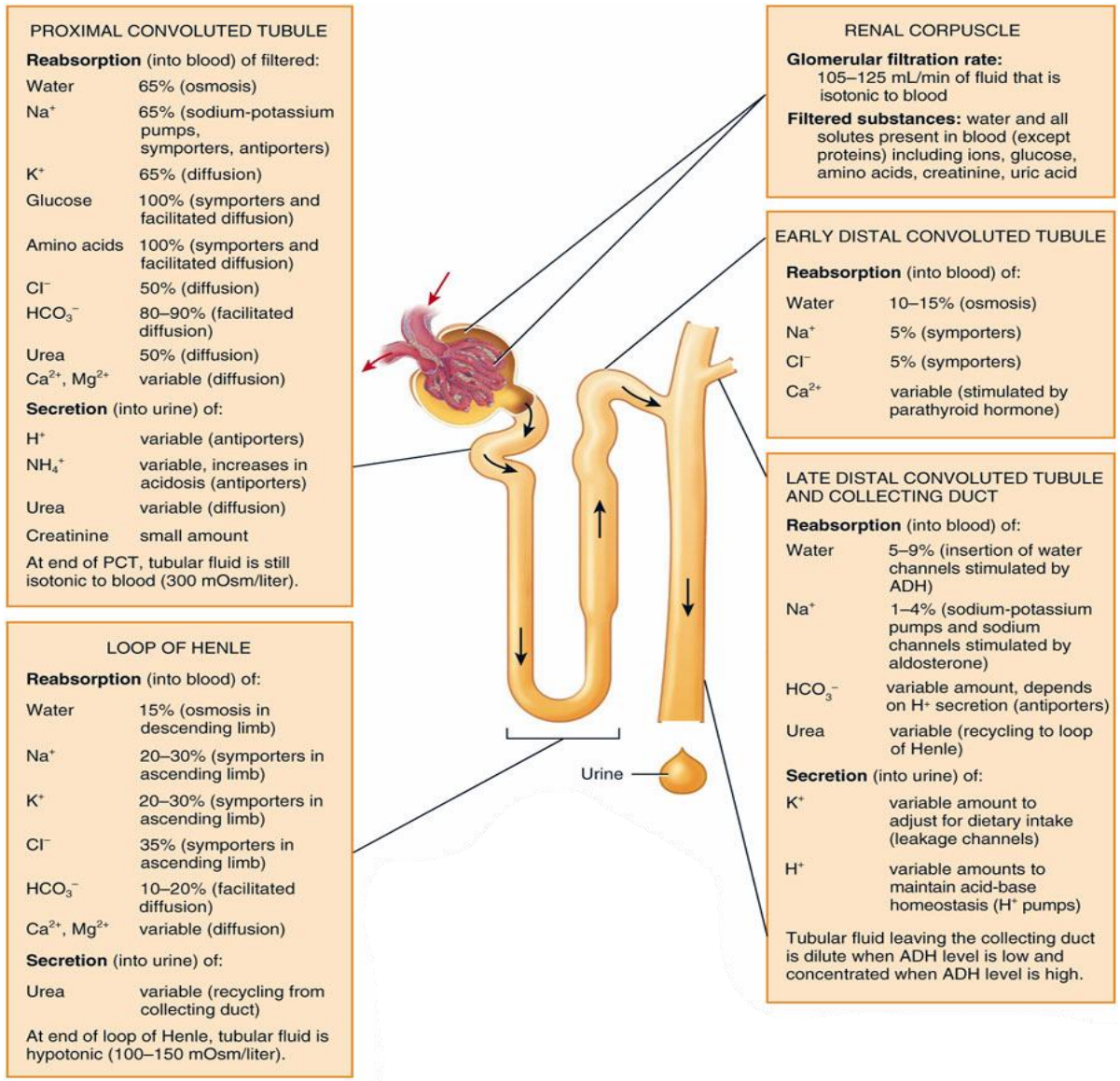
- Renin clips off a 10-amino-acid peptide called angiotensin I from angiotensinogen, which is synthesized by hepatocytes.
- By clipping off two more amino acids, angiotensin converting enzyme (ACE) converts angiotensin I to angiotensin II, which is the active form of the hormone.
- Angiotensin II has 3 main effects:
  - Vasoconstriction decreases GFR.
  - It increases blood volume by increasing reabsorption of water and electrolytes in the PCT.
  - It stimulates the adrenal cortex to release aldosterone.

Hormones and Homeostasis

- Aldosterone stimulates the principal cells in the collecting ducts to reabsorb more Na^+ and Cl^- and secrete more K^+. The osmotic consequence of reabsorbing more Na^+ and Cl^- is that more water is reabsorbed, which increases blood volume and blood pressure.



Summary of Renal Function



Erythropoietin

- Glycoprotein hormone released from kidneys
- Inactive form erythropoietinogen continually released from liver for erythropoiesis (RBC production)
- Decrease in O_2 levels = ↑ erythropoietin secretion
- Stimulates marrow to ↑ erythropoiesis
- RBC #'s ↑, O_2 delivery ↑, system returns to normal

Prostaglandins

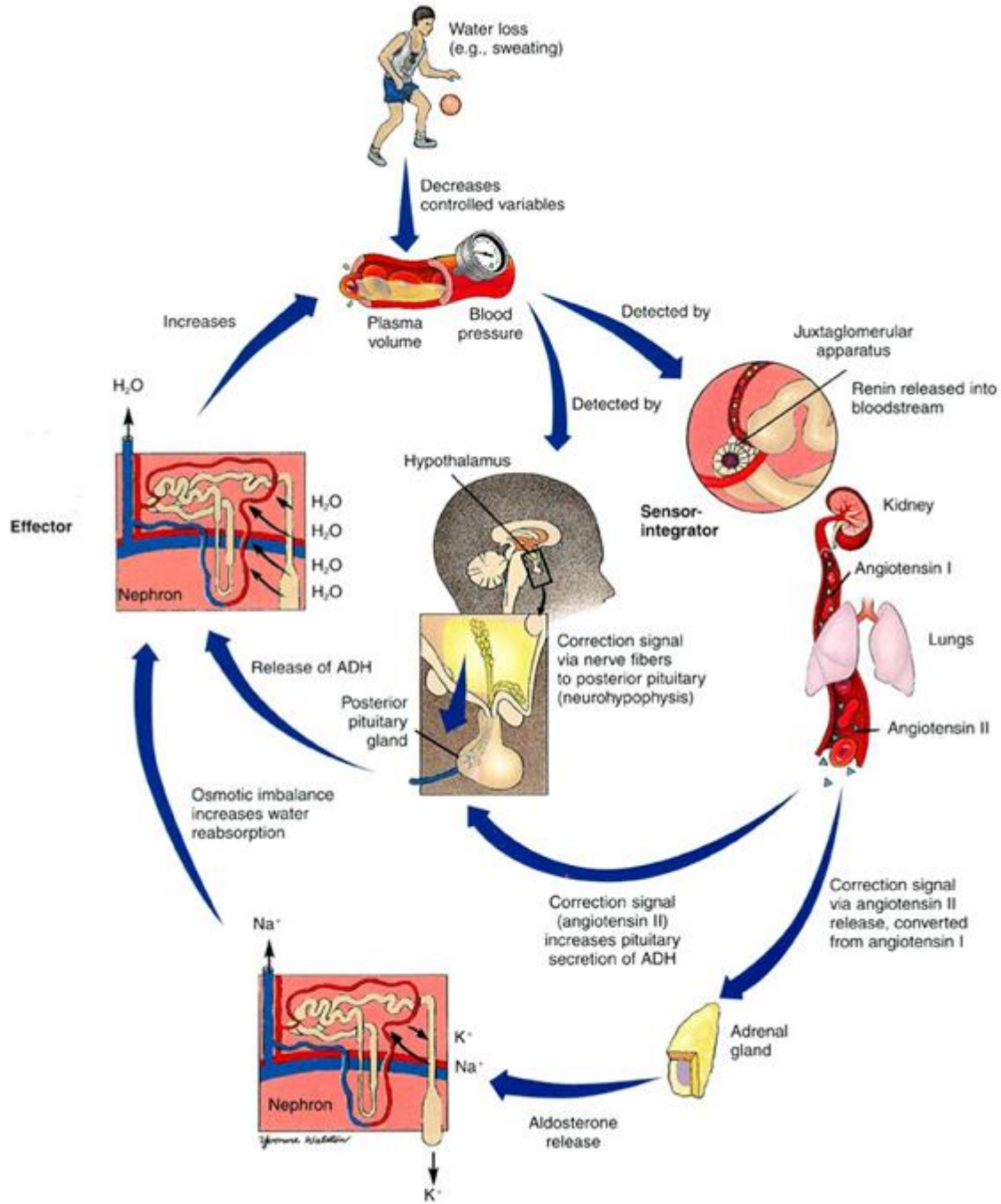
- Tissue hormones
- Lipids
- 16 major types
- Formed and released on stimulus
- Regulate effects of hormones, i.e. BP, digestive juices, inflammatory response

Regulation of Urine Volume

- Volume
  - Renin-angiotensin-aldosterone chain
- Concentration
  - Atrial natriuretic hormone (aldosterone antagonist promoting Na excretion)
  - Solute concentrations (think of hyperglycemia)
- Not usually affected by GFR

Regulation of Urine Volume

- Autoregulation (tubuloglomerular feedback)
  - Protects kidney from rapid systemic changes in BP
  - Regulates resistance in afferent arterioles which help regulate GFR
  - Also helps regulate RAAS chain and BP
  - Myogenic mechanism
    - If BP increases (during muscular exertion) the walls of the afferent arterioles are constricted to decrease blood flow
    - Returns GFR to resting state
    - If BP decreases afferent arterioles are relaxed increasing blood flow


Water loss
(e.g., sweating)
Decreases
controlled variables
Plasma
volume
Blood
pressure
Increases
Detected by
Detected by
Juxtaglomerular
apparatus
Renin released into
bloodstream
Sensor-
integrator
Kidney
Angiotensin I
Lungs
Angiotensin II
Hypothalamus
Correction signal
via nerve fibers
to posterior pituitary
(neurohypophysis)
Posterior
pituitary
gland
Release of ADH
Effector
H_2O
H_2O
H_2O
H_2O
H_2O
Nephron
Osmotic imbalance
increases water
reabsorption
Correction signal
(angiotensin II)
increases pituitary
secretion of ADH
Correction signal
via angiotensin II
release, converted
from angiotensin I
Adrenal
gland
Aldosterone
release
Na^+
K^+
Na^+
Nephron
K^+

Urine Composition

- Approximately 95% water
- May contain:
  - Nitrogenous wastes
    - Urea, uric acid, ammonia and creatinine
  - Electrolytes
    - Na, K, Cl, HCO_3, Phosphate and Sulfate
  - Toxins
  - Pigments
    - Urochromes (yellow pigment from breakdown of old RBC)
    - Pigments from foods or drugs
  - Hormones
  - Abnormal Constituents
    - Blood, glucose, albumin, calculi

Normal Urine Characteristics

- Transparent yellow, amber, straw colored
- Normal levels of electrolytes
- Slight odor
- Acidic (pH 4.6 – 8.0)

Abnormal

- Dark color pigment
- Cloudiness
- Solute particulate
  - Glucose
- Electrolytes in excess
- Strong odor (acetone)
- Alkalosis

Abnormal urine production

- Hyponatremia
- Hypernatremia
- Dehydration
- Overhydration
- Hypokalemia
- Hyperkalemia

Micturition

- AKA Voiding urine
  - Bladder holds 800 ml
  - When volume reaches 400 ml micturition reflex
  - External bladder sphincter relaxation
  - Reflex contraction of muscles of bladder
  - Urine flows into urethra
  - Sphincter contraction occurs following emptying of bladder
  - Requires intact lobes and nerves of autonomic nervous system specific to urinary function

Body Fluids

- Normally
  - Homeostasis - Intake = output
  - Intake
    - Beverages, ingested foods, metabolism
  - Output
    - Kidneys
    - Skin (evaporation)
    - Skin (perspiration)
    - Lungs
    - GI tract
  - [ ] of plasma changes osmotic pressure and stimulates thirst center