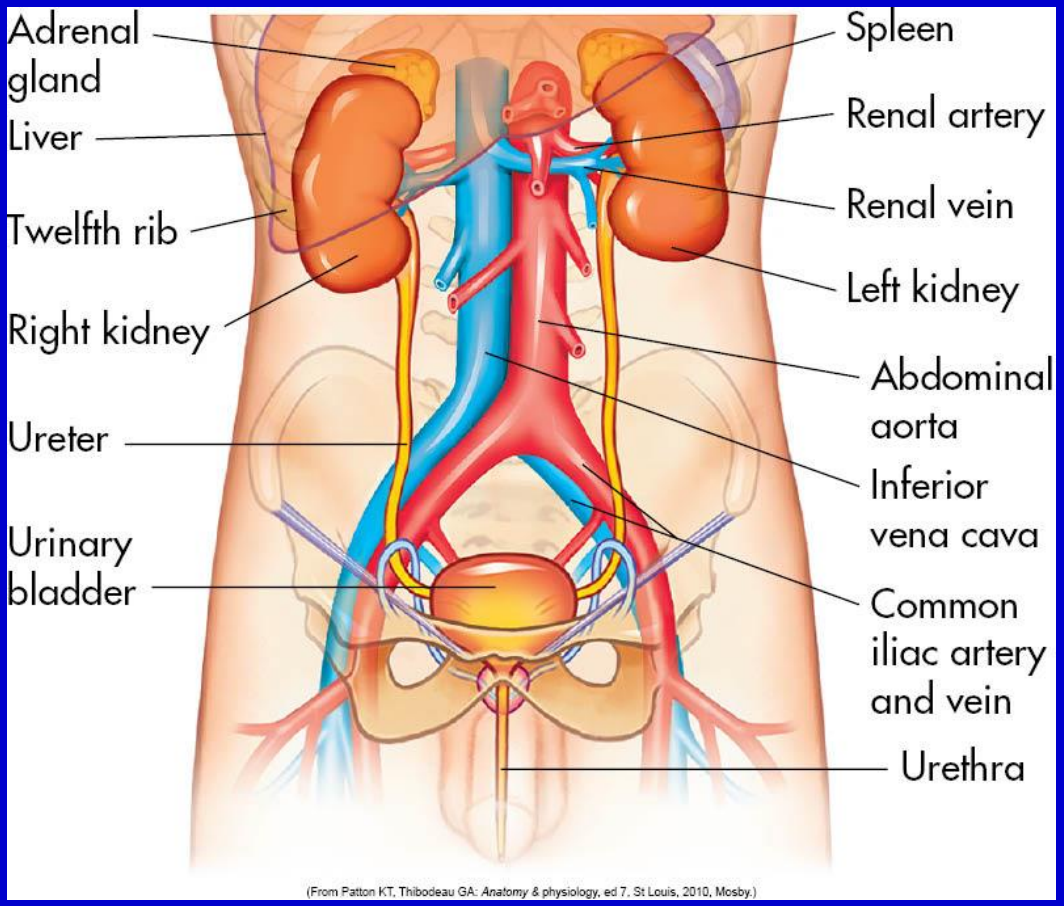
Structure and Function of the Renal and Urologic Systems

Structures of the Kidney

- Kidneys
  - Retroperitoneal- posterior to the peritoneum of abdominal cavity. Anatomical landmark: costovertebral angle
  - Renal capsule- dense irregular connective tissue that serves as barrier against trauma and maintains shape of kidney
  - Renal fascia- dense irregular connective tissue; anchors with other surrounding structures
  - Hilum- thru which the ureter and blood vessel emerge

Structures of the Kidney

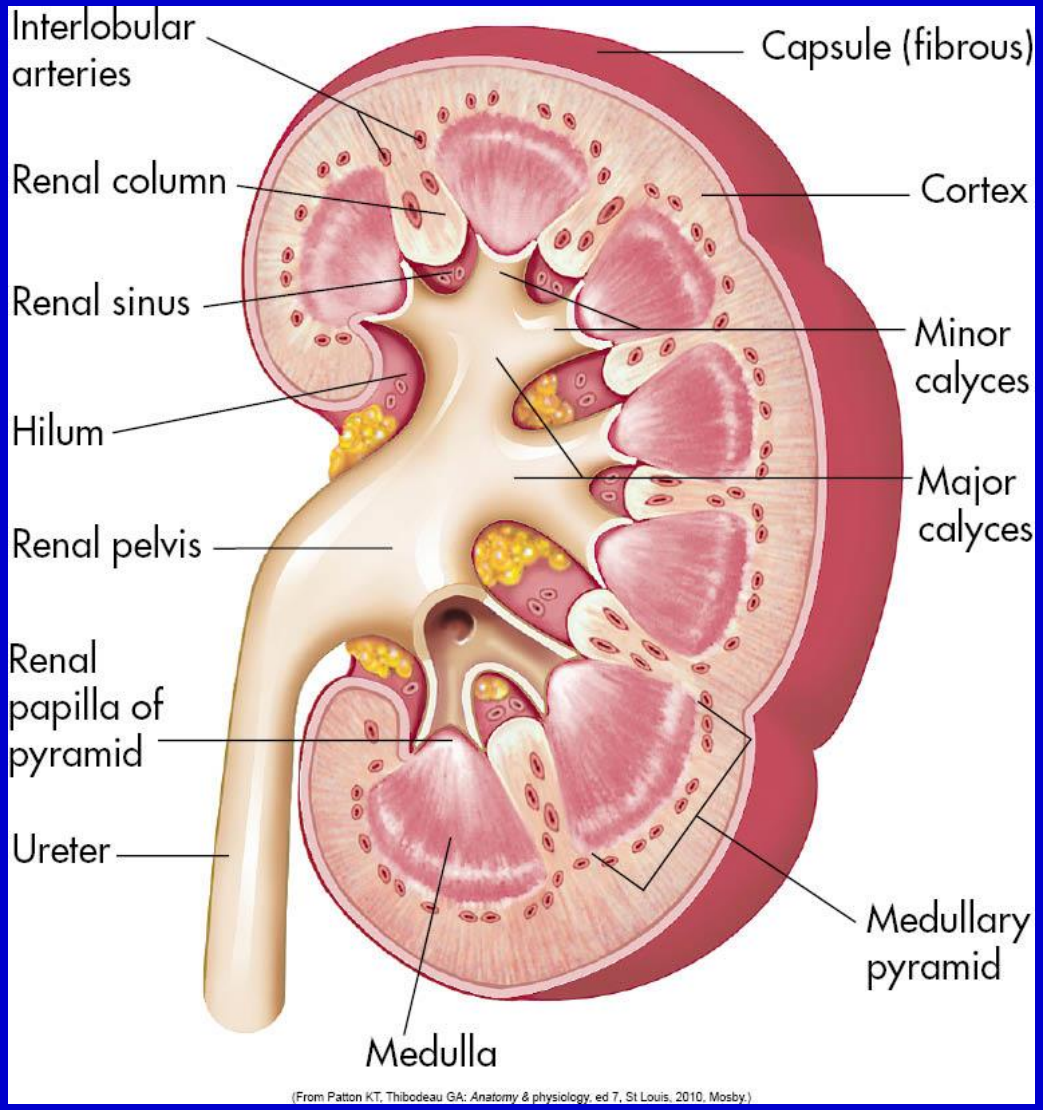


(From Patton KT, Thibodeau GA: *Anatomy & physiology*, ed 7. St Louis, 2010, Mosby.)

Structures of the Kidney

- Renal cortex- superficial layer
- Renal medulla- deep inner region
- Renal pyramids- cone-shaped composition of the medulla
- Renal columns- portions of renal cortex that extend to the whole kidney
- Minor calyx- cuplike structure that drains wastes from papillary ducts
- Major calyx- drains wastes from minor calyx
- Renal pelvis- large cavity that drains urine from the major calices

Structures of the Kidney



Nephron

- 1.2 million nephrons per kidney
- Functional unit of the kidney
  - Superficial cortical and midcortical nephrons (80 to 85%)
    - Have short loop of Henle
  - Juxtamedullary nephrons (15-20%)
    - Have long loop of Henle
    - Long loop of Henle enable kidneys to excrete very dilute or very concentrated urine

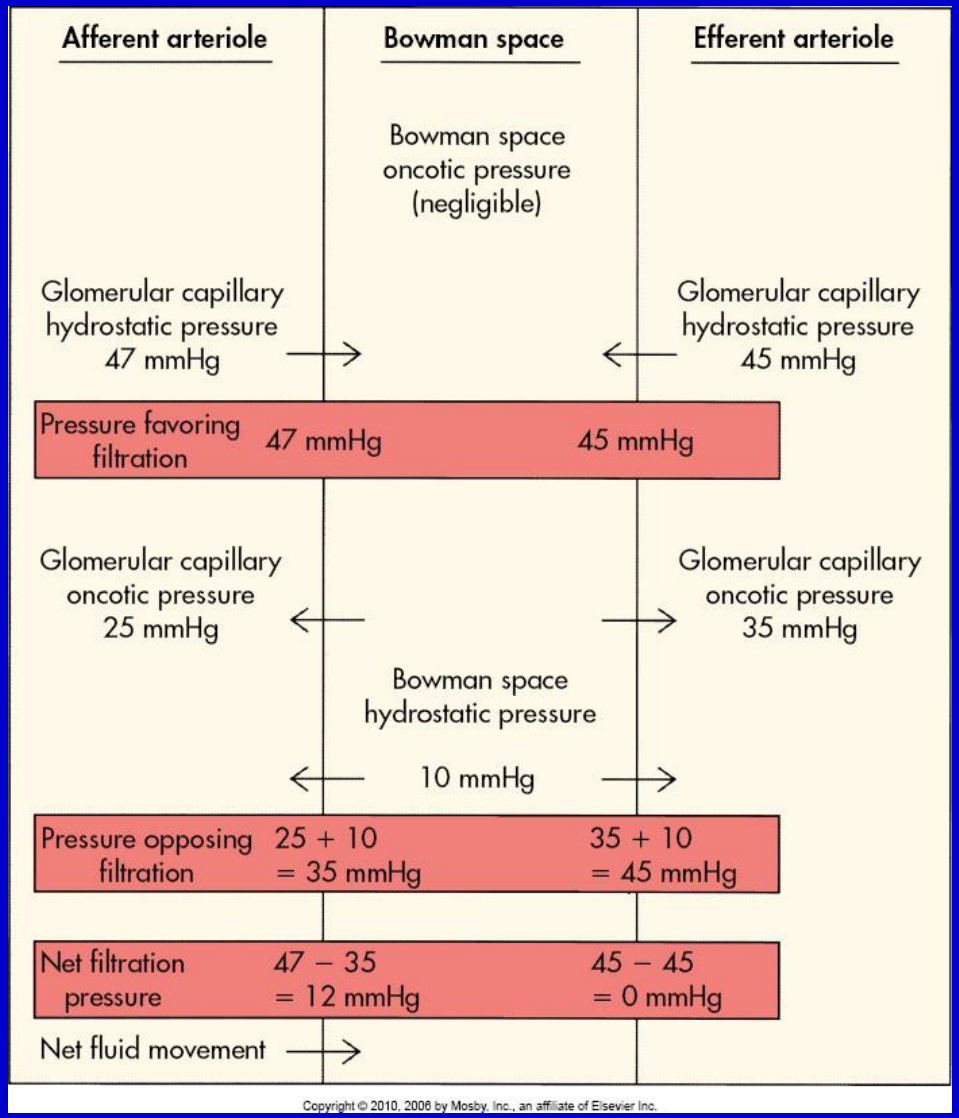
Nephron

- Functional units of the kidneys
- Two parts:
  - Renal corpuscle
    - Glomerulus- capillary network between afferent and efferent arterioles
    - Bowman capsule- double-walled epithelial cup that surround the glomerulus
  - Renal tubules
    - Proximal convoluted tubule
    - Loop of Henle
    - Distal convoluted tubule

Glomerulus

- Glomerular filtration- first step in urine production
- Most solutes in blood plasma → glomerular capillaries → glomerular capsule (Bowman) → rental tubule
- Net filtration pressure
  - Formula: NFP= GBHP – CHP – BCOP
  - GBHP- glomerular blood hydrostatic pressure
  - CHP- capsular hydrostatic pressure
  - BCOP- blood colloid osmotic pressure

Glomerular Filtration



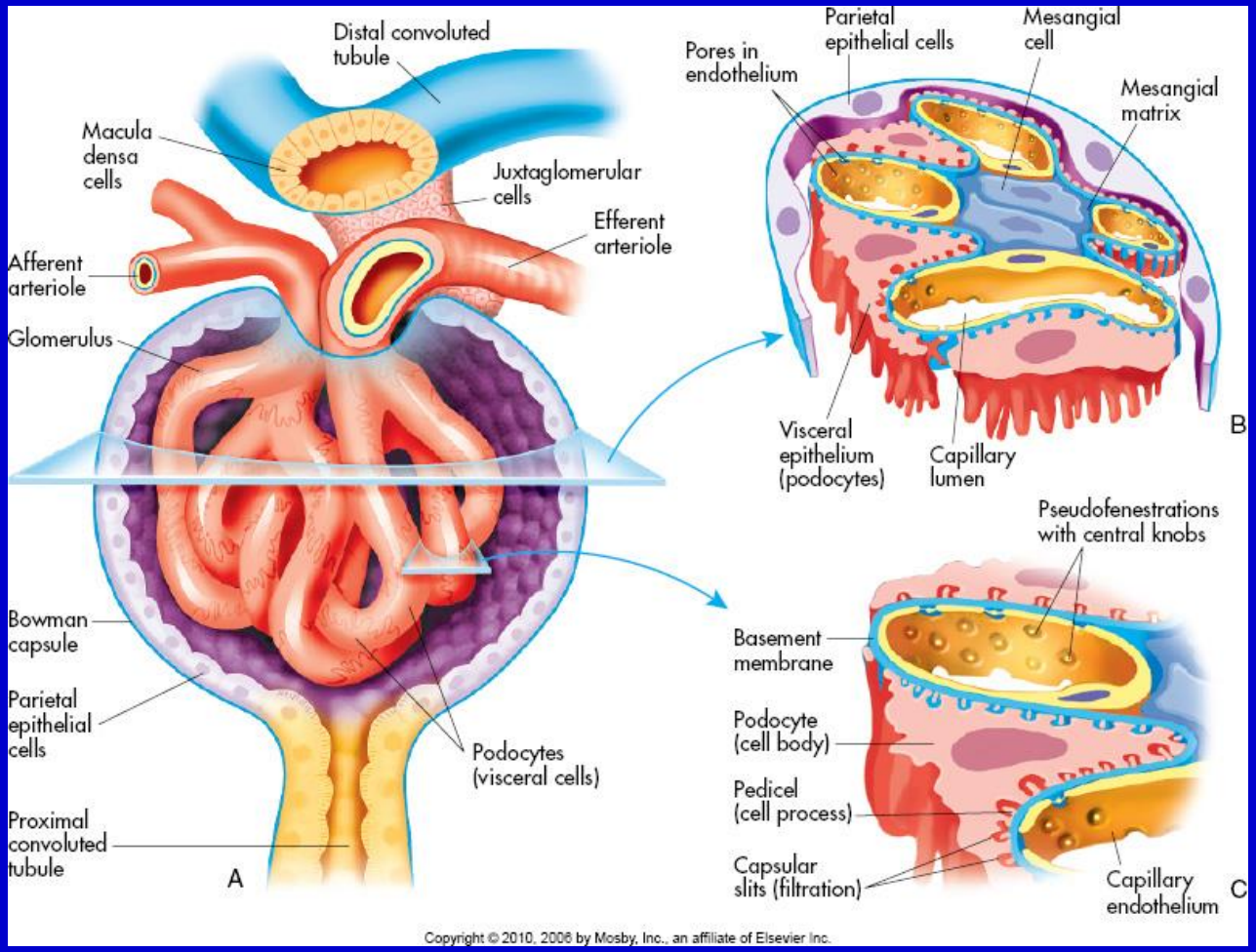
Glomerulus

- Glomerular filtration membrane
  - **Glomerular endothelium-** has larges fenestrations (pores).
    - Permits all solutes in blood plasma to exit glomerular capillaries except blood cells and platelets
  - **Basement membrane-** consists of collagen and proteoglycans. Prevents filtration of plasma proteins
  - **Capillary epithelium**
    - Also referred to as podocytes or visceral epithelium
    - Filtration slits
    - Permits passage of molecules smaller than 0.007 micrometer

Nephron

- Juxtaglomerular apparatus
  - Juxtaglomerular cells- modified smooth muscles cells part of the afferent arterioled
  - Macula densa- columnar tubule cells that are crowding together; near the nephron and part of the ascending loop of Henle
  - Main function is to regulate BP and filtration rate of the glomerulus
  - Secrete renin when BP in the arteriole falls.

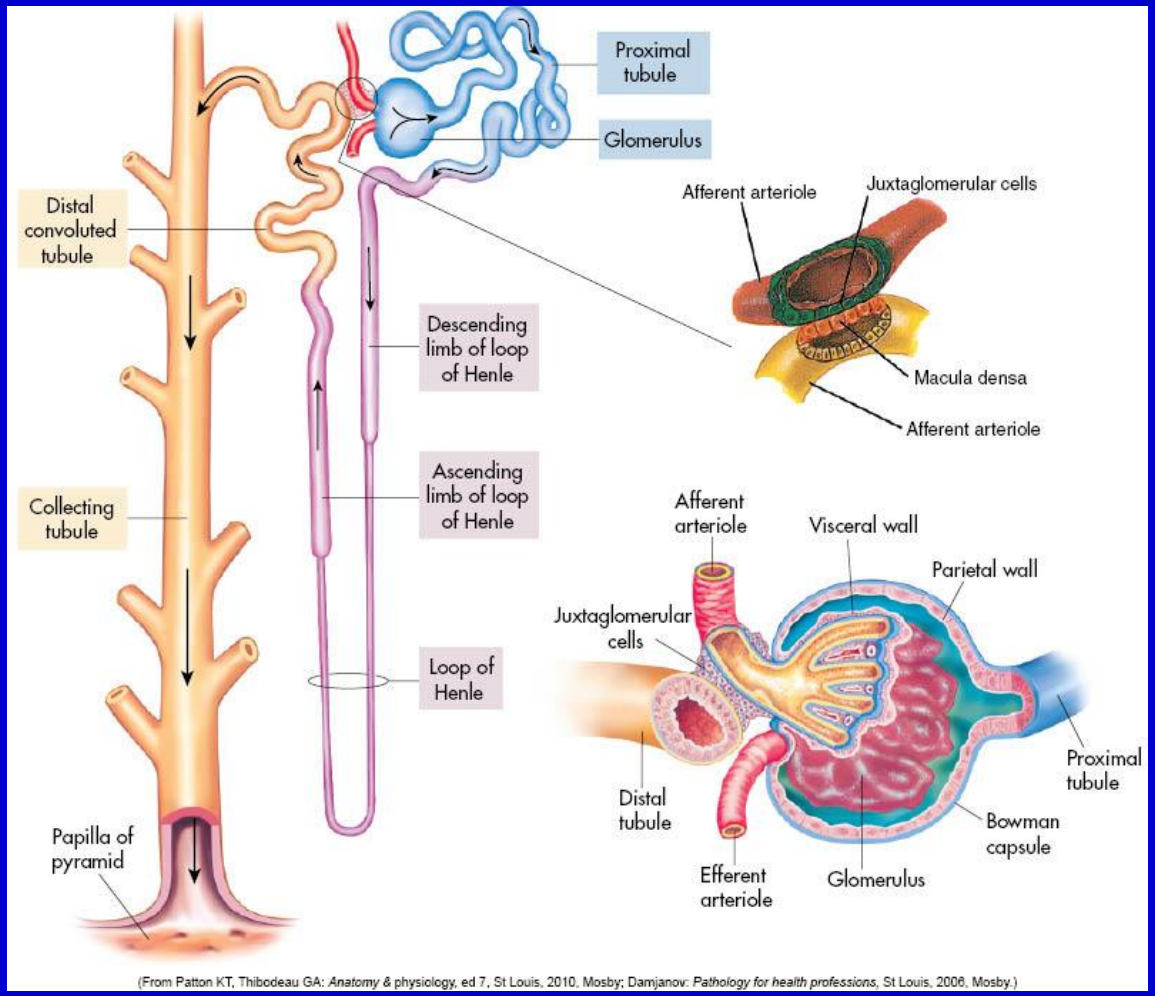
Juxtaglomerular Apparatus



Nephron

- Renal tubules
  - Proximal tubule- simple cuboidal epithelial cells with microvilli
  - Loop of Henle- simple squamous epithelial cells
  - Distal tubule- simple cuboidal epithelial cells
  - Collecting duct- simple cuboidal epithelium
    - Principal cells- have receptors of ADH
    - Intercalated cells- have a role in regulation of blood pH

Structures of the Kidney



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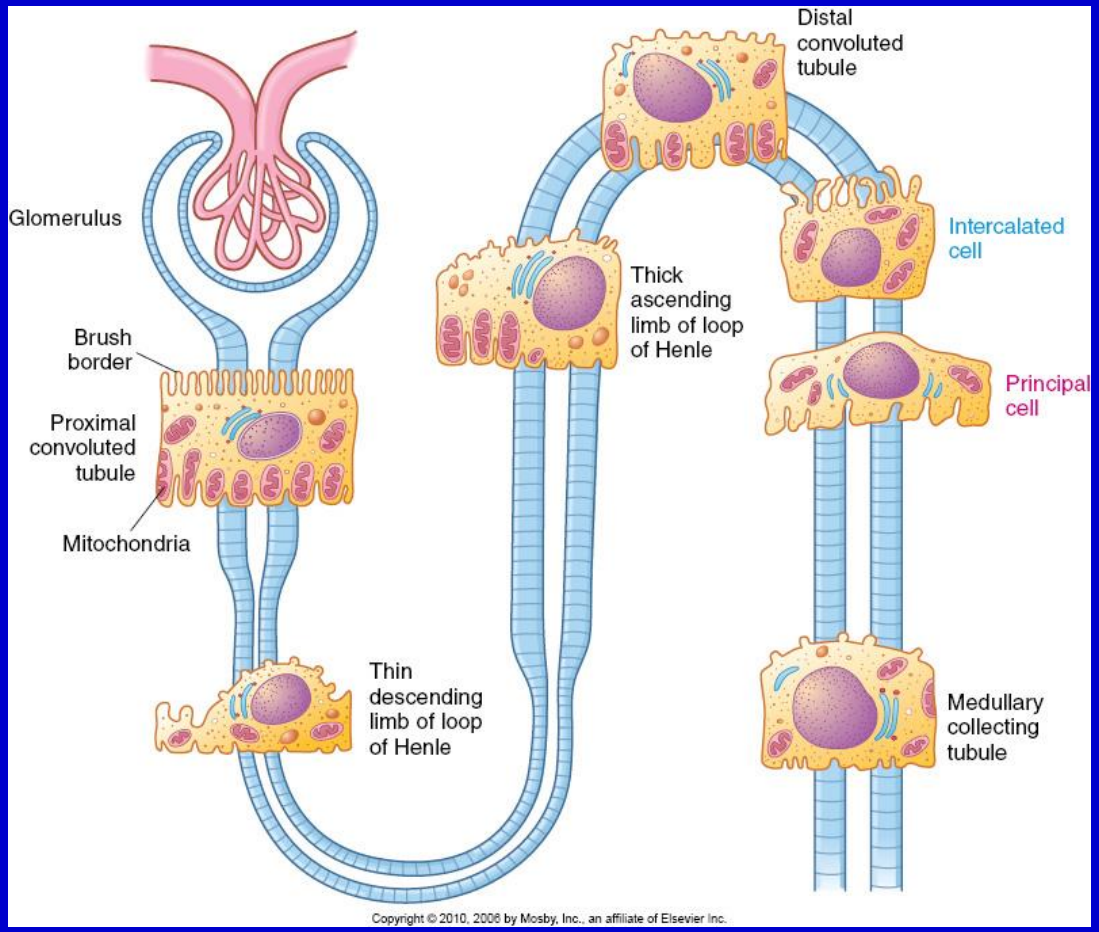
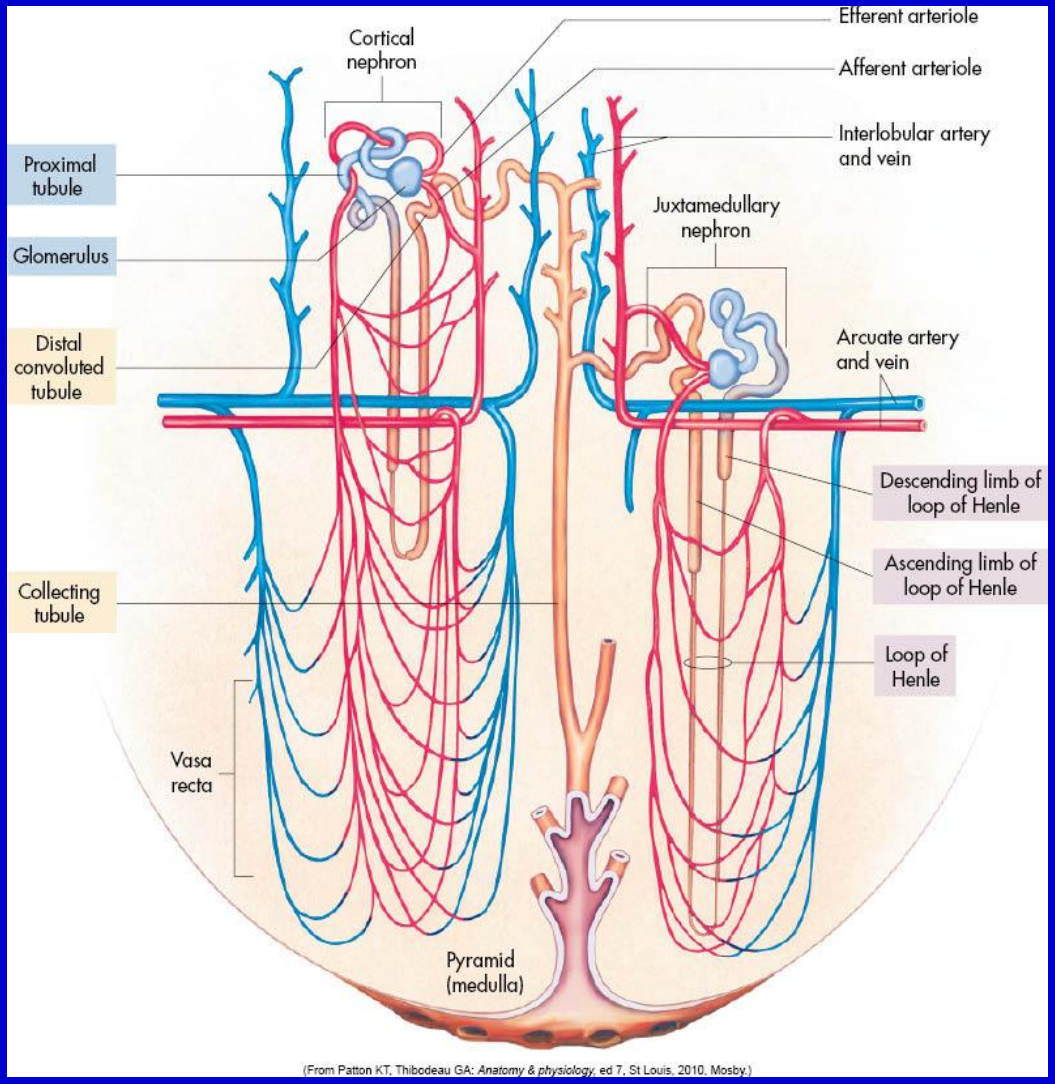
Structures of the Kidney



Blood Vessels

- Renal arteries- delivers 20-25% of resting CO to kidneys
- Interlobar arteries- pass thru renal columns and between pyramids
- Arcuate arteries- arch b/w medulla and cortex
- Interlobular arteries
- Afferent arterioles- one afferent arteriole for each nephron
- Glomerular capillaries
- Efferent arterioles-
- Peritubular capillaries and vasa recta- surround tubular parts of the nephron; vasa recta are long loop-shaped capillaries

Structures of the Kidney



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Renal Blood Flow (RBF)

- Receive 1000 to 1200 ml of blood per minute
  - 600-700 ml as plasma (renal plasma flow [RPF])
- Glomerular filtration rate (GFR)
  - Amount of filtrate formed in all the renal corpuscles of both kidneys each minute
  - Mean GFR: 125ml/min (males); 105 ml/min (females)
  - If GFR is high- needed substances may pass so quickly; if GFR is low- nearly all filtrate is reabsorbed
  - Directly related to the perfusion pressure in the glomerular capillaries (RBF)

Regulation of RBF/GFR

- Two ways:
  - (1) adjusting blood flow into and out of glomerulus
  - (2) altering the glomerular capillary surface area available for filtration
- Renal Autoregulation
  - Myogenic mechanism (stretch)
  - Tubuloglomerular feedback (NaCl content)
- Neural regulation
  - Sympathetic nervous system
    - Vasoconstriction (diminishes GFR)

Regulation of RBF/GFR

- Renal Autoregulation
  - Myogenic mechanism (stretch)
    - BP increase stretches the walls of the afferent arteriole → afferent arteriole contracts → narrows the arteriole's lumen → dec. in blood flow → dec GFR
  - Tubuloglomerular feedback (NaCl content)
    - Macula densa senses increased passage of Na, Cl, H20 as a result of increased BP → decreased production of NO by JGA → vasoconstriction of afferent arterioles → decrease GFR

Regulation of RBF/GFR

- Neural regulation
  - Sympathetic nervous system
  - Norephinephrine causes vasoconstriction → dec GFR
  - At rest, low sympathetic ANS stimulation → arterioles are dilated
  - With moderate sympathetic ANS stimulation → constriction of arterioles → dec GFR slightly
  - With greater ANS stimulation → vasoconstriction predominate → GFR drops → (1) reduces UO; (2) permits greater blood flow to other body tissues

Regulation of RBF/GFR

- Hormonal regulation
  - Angiotension II reduces GFR
    - Potent vasoconstrictor that narrows both afferent and efferent arterioles and reduces renal blood flow
  - Atrial natriuretic peptide increases GFR
    - Increase blood vol → inc stretching of atria → stimulates secretion of ANP → relaxes mesangial cells → increase capillary surface area available for filtration

Renal Functions

- Regulation of blood volume and serum osmolarity (water/sodium balance)
  - ADH
  - Renin-angiotensin-aldosterone system

Renal Functions

- Excrete metabolic wastes
  - Creatinine, urea (end product of protein metabolism), certain drugs
- Regulate acid-base balance
  - Balance of H^+ and HCO_3
- Secrete hormones
  - Renin-angiotensin-aldosterone system
  - Erythropoietin
  - Conversion of vitamin D to usable form

Renal Processes

- Filtration
  - Movement of protein free plasma across the glomerular membrane (hydrostatic pressure)
- Tubular reabsorption
  - Movement of fluid/solutes from tubular lumen to the peritubular capillaries
- Tubular secretion
  - Transfer of substances from the peritubular capillaries to the tubular lumen
- Excretion
  - Elimination of fluids/substances in the final urine

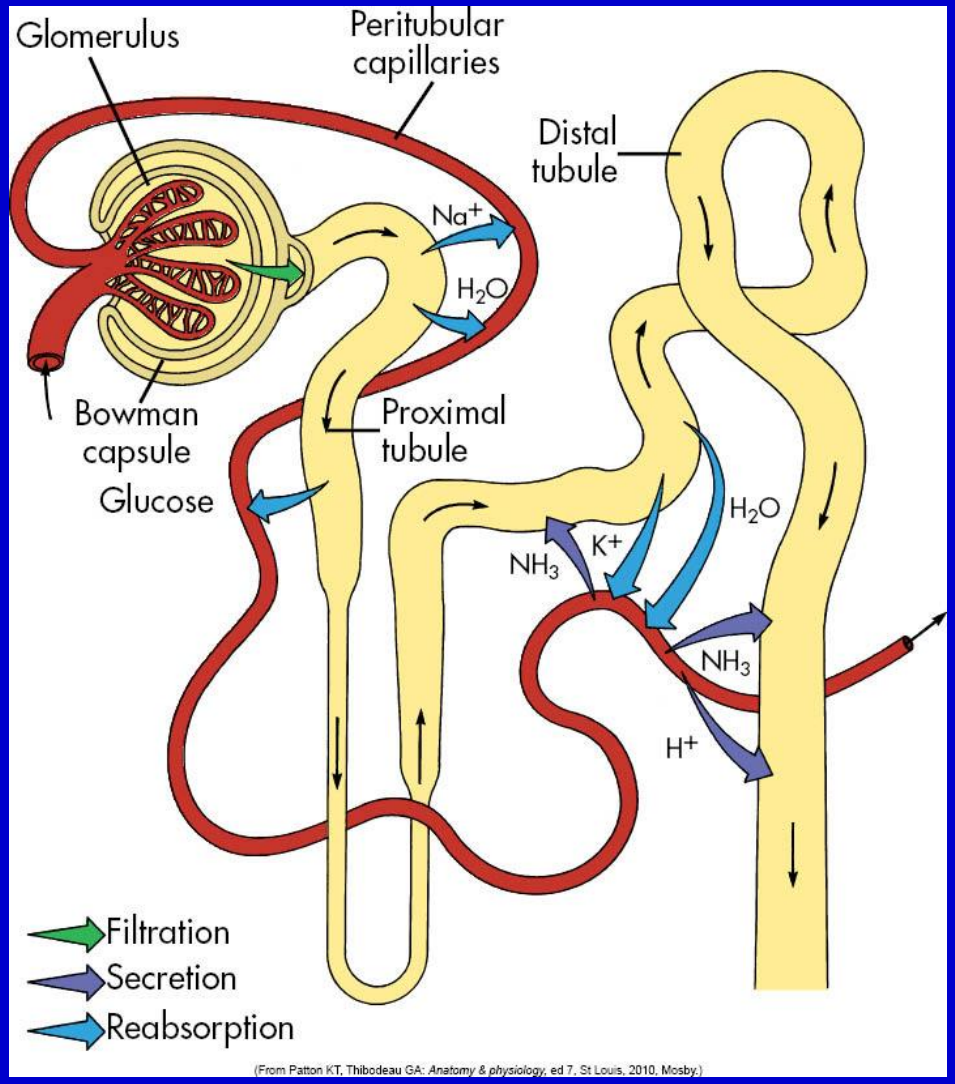
Tubular Transport

- Active transport of fluids and substances
  - Reabsorption: normally 99% of the glomerular filtrate is reabsorbed!
  - Solutes are reabsorbed by both active and passive processes
  - Small proteins and peptides reabsorbed by pinocytosis
  - Tubular secretion of H+, K+, NH4+, creatinine, and certain drugs
  - Tubular secretion: (1) helps control blood pH; (2) helps eliminates wastes
- Urea: major constituent of urine, along with water
  - 50% of urea is reabsorbed, 50% excreted in the urine
  - Provides osmotic gradient

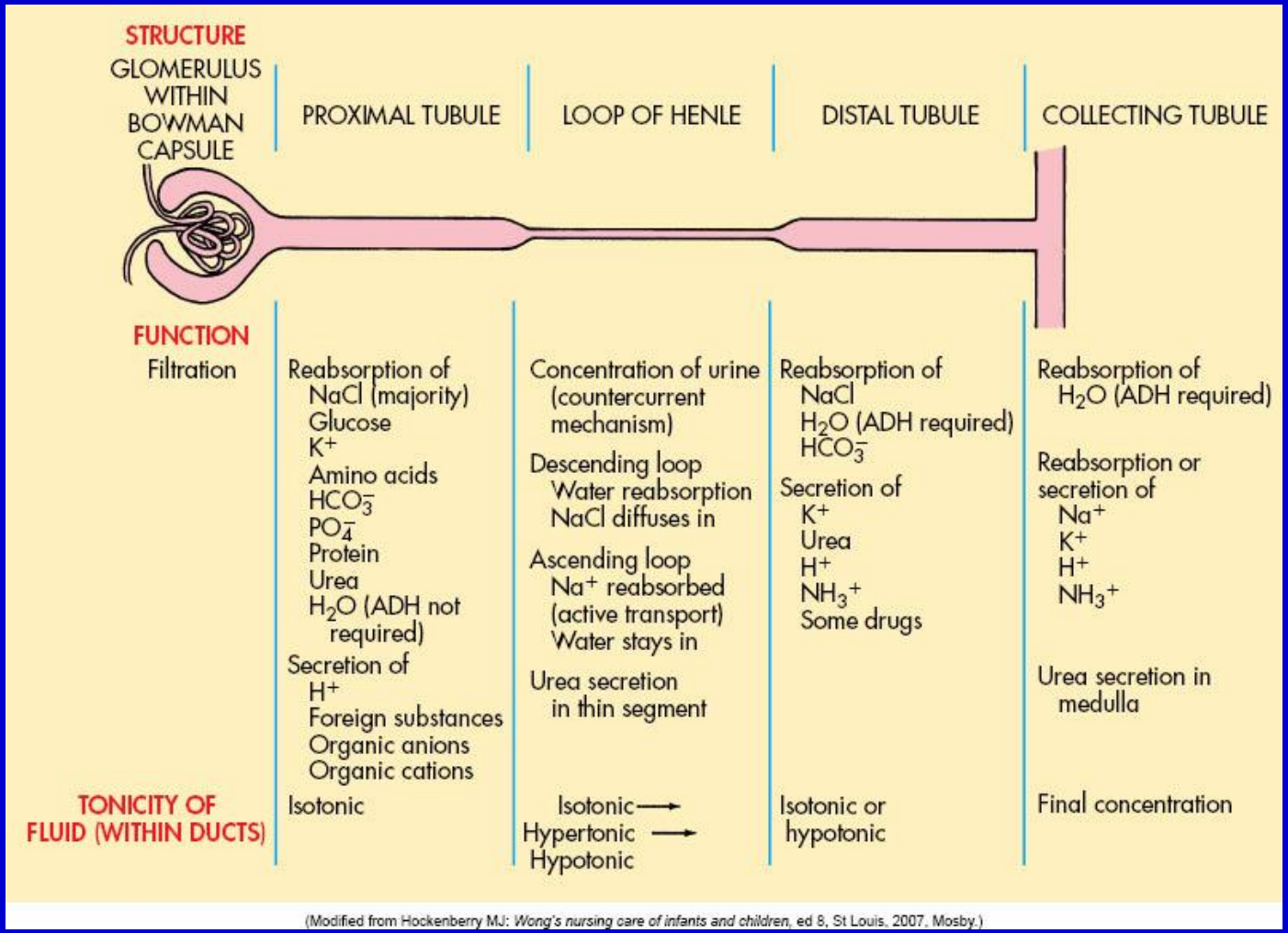
Transport Mechanisms

- Primary active transport
  - Requires ATP production; e.g., Na/K pump
- Secondary active transport
  - Driven by the ion's electrochemical gradient
- Transport maximum
  - Upper limit on how many molecules of a substance can be transported at any given period
- Obligatory water reabsorption
  - Occurs in the proximal convoluted tubule; in response to movement of solute
- Facultative water reabsorption
  - In collecting ducts; in response to ADH

Nephron Function



Nephron Function



(Modified from Hockenberry MJ: *Wong's nursing care of infants and children*, ed 8, St Louis, 2007, Mosby.)

Renal “Clearance”

- The ability of the kidneys to filter a substance and excrete it in the urine is a reflection of the GFR, tubular secretion, and tubular reabsorption (thus also RBF and functioning of nephrons)

Hormonal regulation of tubular reabsorption and secretion

- Renin-angiotensin-aldosterone system
- Antidiuretic hormone
- Atrial natriuretic peptide
- Parathyroid hormone

Hormonal regulation of tubular reabsorption and secretion

- Renin-angiotensin-aldosterone system
  - Dec BP and BV → dec stretch in the afferent arterioled → JGA produces renin → renin stimulates production of angiotensin I from angiotensinogen → angiotensin I converted to angiotensin II in the lungs by ACE → angiotensin II (1) dec GFR by vasoconstriction; (2) reabsorp Na, Cl, H20 in PCT; (3) stimulates production of aldosterone from adrenal cortex which inc. reabsorption of Na and Cl and secrete more K

Hormonal regulation of tubular reabsorption and secretion

- Antidiuretic hormone
  - Secreted by posterior pituitary gland
  - Regulates facultative water reabsorption by inc permeability of principal cells in the DCT
  - Inc osmolality of plasma → osmoreceptors in hypothalamus stimulate secretion of ADH → inc insertion of aquaporin- 2 in principal cells → inc permeability to water → facultative water reabsorption dec osmolality

Hormonal regulation of tubular reabsorption and secretion

- Atrial natriuretic peptide
  - Large inc in BV → inc stretching of atria → release of ANP → (1) inhibit reabsorption of Na and water in PCT; (2) inhibit secretion of aldosterone and ADH

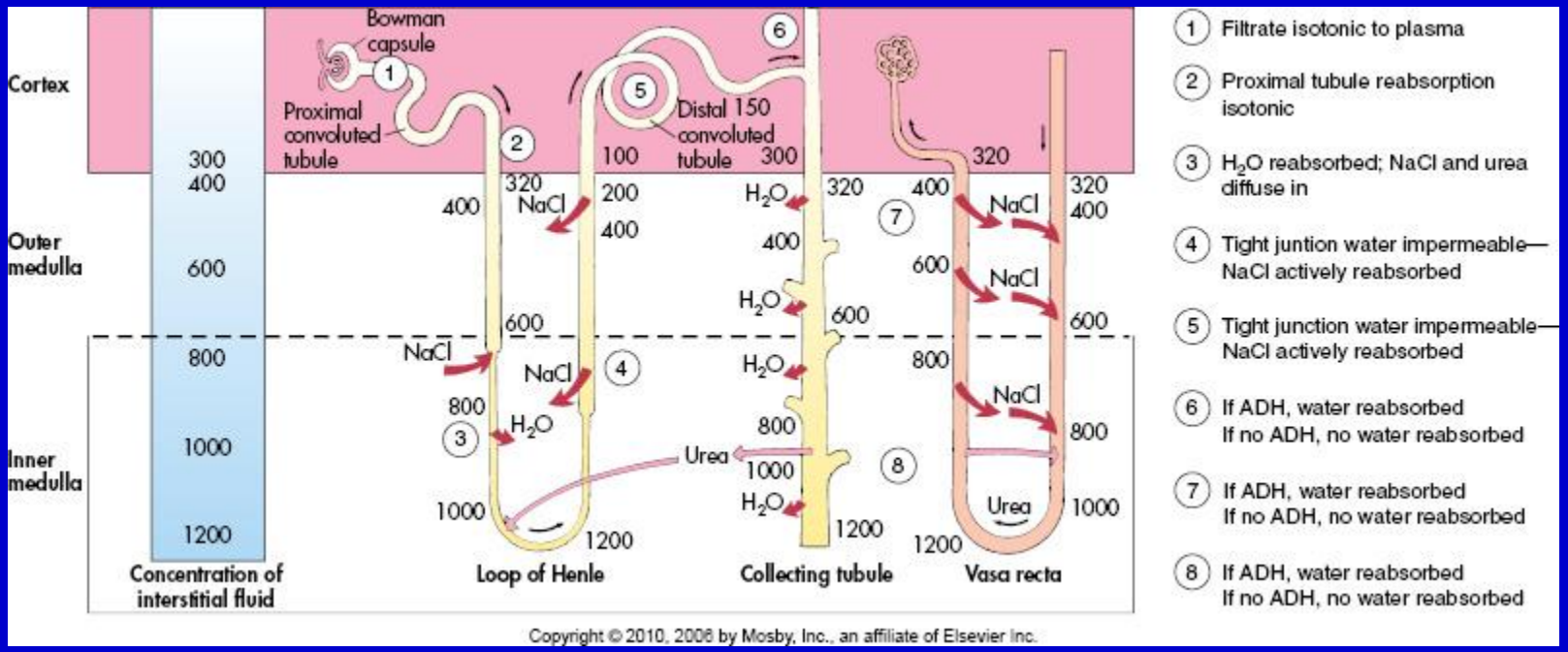
Hormonal regulation of tubular reabsorption and secretion

- Parathyroid hormone
  - Dec Ca2+ in blood → stimulates PTH glands to release PTH → (1) stimulates DCT to reabsorb more Ca2+ into the blood; (2) inhibits HPO4^2- reabsorption in the PCT

Concentration and Dilution of Urine

- Countercurrent exchange system
  - Contributes to production of concentrated urine
  - Fluid flows in opposite direction through parallel tubes
  - Fluid moves up and down the parallel limbs of the loop of Henle
  - The longer the loop, the greater the concentration gradient

Countercurrent Exchange System



Concentration and Dilution of Urine

- Urea
- Catecholamines
- Antidiuretic hormone (ADH)
- Urodilantin
- Natriuretic peptide
- Diuretics

Renal Hormones

- Vitamin D
- Erythropoietin

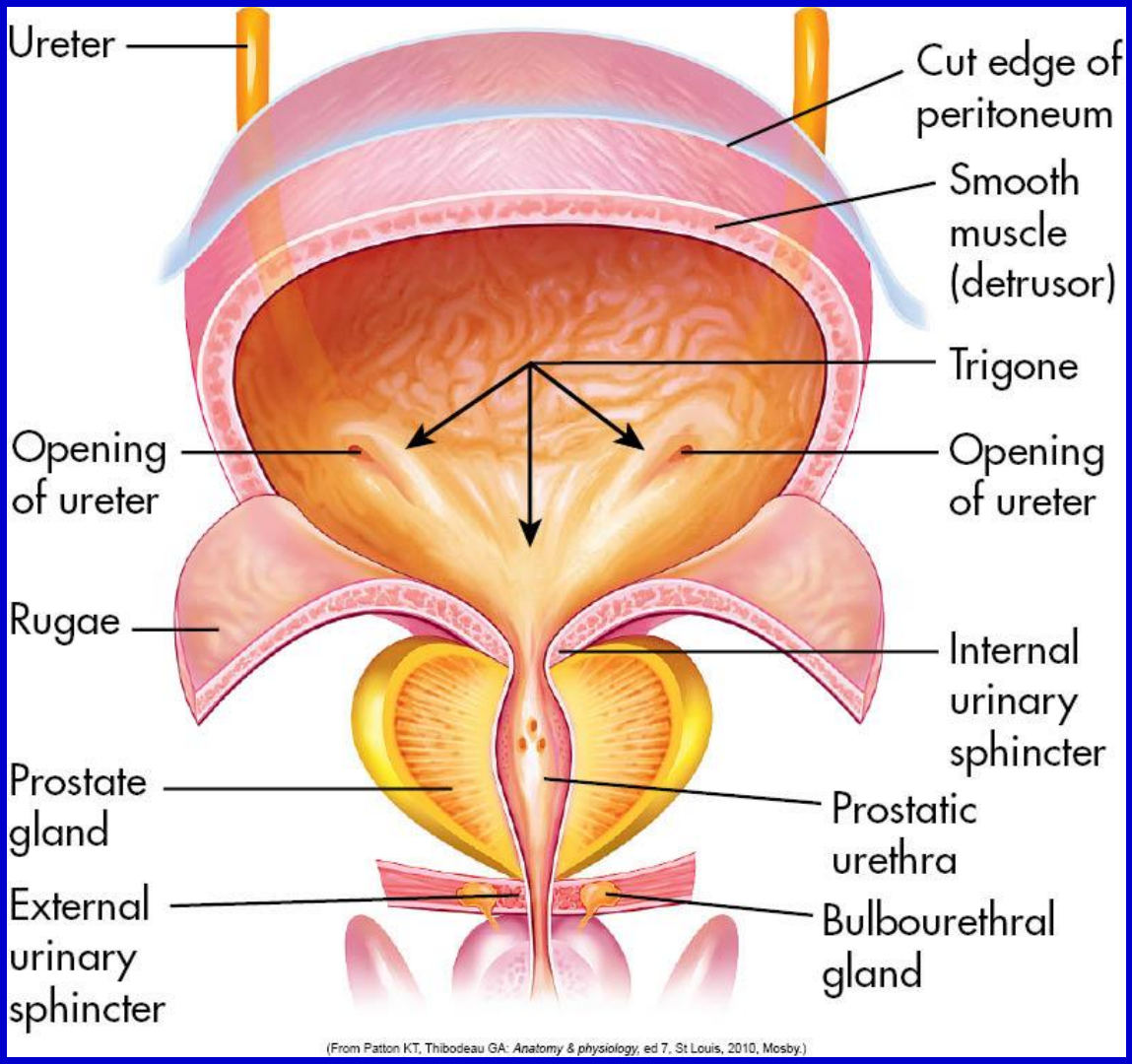
Structures of the Kidney

- Ureters
  - 30 cm long
  - Long, intertwining muscle bundles
  - Pass obliquely though posterior aspect of bladder
  - Peristaltic activity
  - Micturition compresses the lower end of the ureter to avoid urine reflux

Structures of the Urologic System

- Bladder
  - Detrusor muscle- smooth muscle fibers
  - Transitional epithelium- allows for expansion of the urinary bladder
  - Trigone- floor of the urinary bladder
  - Micturition reflex
    - Involuntary and voluntary muscle contractions; stretching of the bladder sends impulses to S2-S3 (micturition center) to trigger micturition reflex
    - Nerve impulses causes contraction of detrusor and relaxation of internal urethral sphincter
- Urethra
  - Internal and external sphincters
  - 3 to 4 cm in females
  - 18 to 20 cm in males

Bladder and Urethra



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Tests of Renal Function

- Clearance and glomerular filtration rate
  - Inulin
  - Creatinine
- Clearance and renal blood flow
- Blood tests
  - Plasma creatinine concentration
  - Plasma cystatin C concentration
  - Blood urea nitrogen (BUN)

Tests of Renal Function

- Urinalysis
  - Urine color
  - Urine pH
  - Specific gravity
  - Urine sediment
    - RBCs
    - Casts
    - Crystals
    - WBCs

Tests of Renal Function

- Urinalysis
  - Reagent strips (dipsticks)
    - Glucose
    - Bilirubin
    - Urobilinogen
    - Leukocyte esterase
    - Nitrates
    - Ketones
    - Proteins
    - RBCs, hemoglobin, and myoglobin

Aging and Renal Function

- Decrease in kidney size
- Decrease in renal blood flow and GFR
- Number of nephrons decrease due to renal vascular and perfusion changes
- Glomerular capillaries atrophy
- Tubular transport response decreases
- Increased bladder symptoms
  - Urgency, frequency, and nocturia