Urinary System
(Anatomy & Physiology)

IACLD CME, Monday, February 20, 2012

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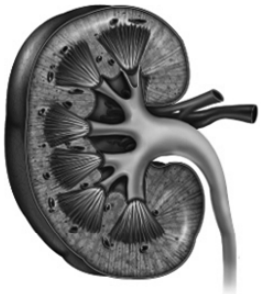
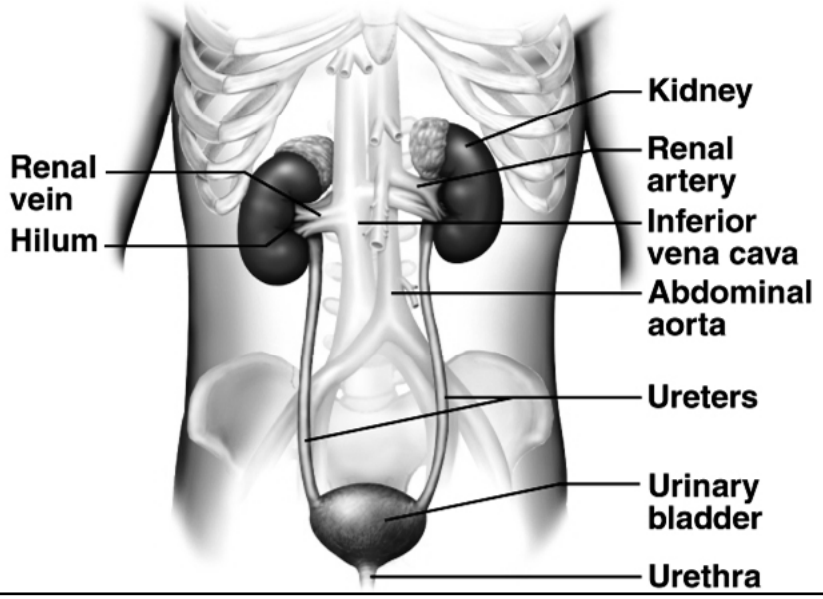
The Urinary System

- Functions of the urinary system
- Anatomy of the kidney
- Urine formation
  - glomerular filtration
  - tubular reabsorption
  - water conservation
- Urine and renal function tests
- Urine storage and elimination



Urinary System



Kidney Functions

- Blood Plasma Filtration: eliminates waste, returns useful chemicals to blood
- Blood Volume & Pressure Regulation
- Regulation of Body Fluids Osmolarity
- Secretes renin, activates angiotensin, aldosterone
  - controls BP, electrolyte balance
- Secretes erythropoietin, controls RBC count
- Regulates P_{CO_2} and Acid Base Balance
- Detoxifies free radicals and drugs
- 1, 25 dihydroxycholecalciferol
- Gluconeogenesis

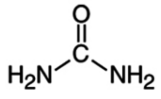
Excretion

Separation of wastes from body fluids & eliminating them:

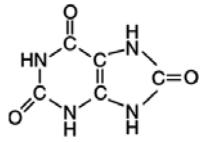
- **Respiratory System**:, CO_2 ,water
- **Integumentary System**: water, salts, lactic acid, urea
- **Digestive system**: water, salts, CO_2, lipids, bile pigments, cholesterol
- **Urinary System**: many metabolic wastes, toxins, drugs, hormones, salts, H+ and water

Nitrogenous Wastes

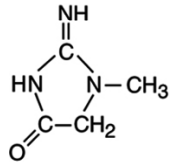
- Urea
  - proteins→amino acids →NH_2 removed →forms ammonia, liver converts to urea
- Uric acid
  - nucleic acid catabolism
- Creatinine
  - creatine phosphate catabolism
- Renal Failure
  - Azotemia: nitrogenous wastes in blood
  - Uremia: toxic effects as wastes accumulate



Urea

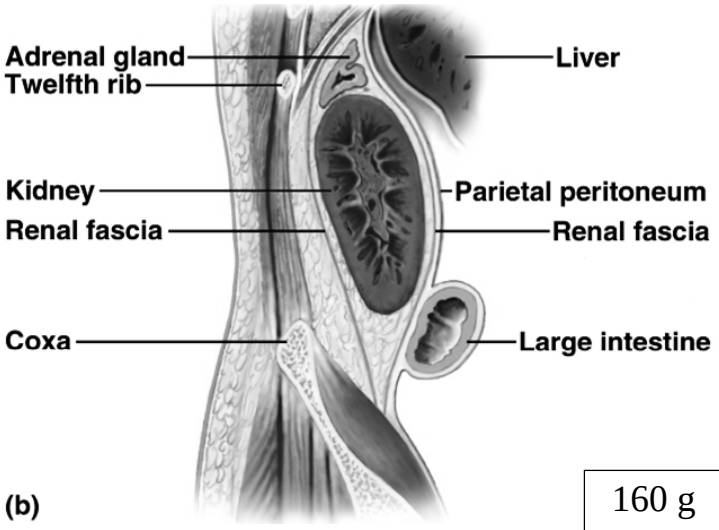


Uric acid



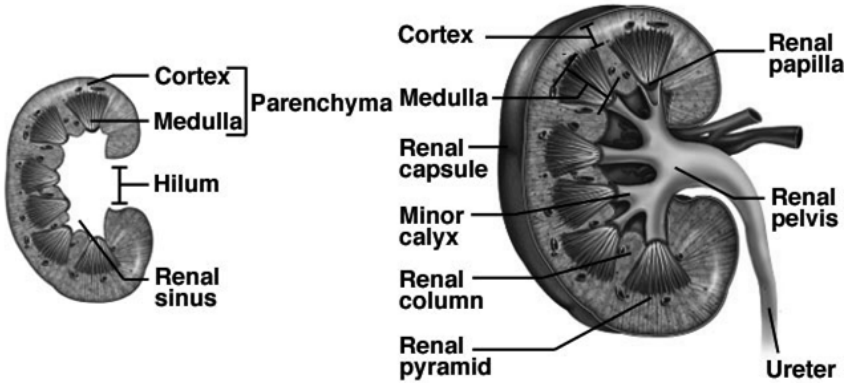
Creatinine

Anatomy of Kidney



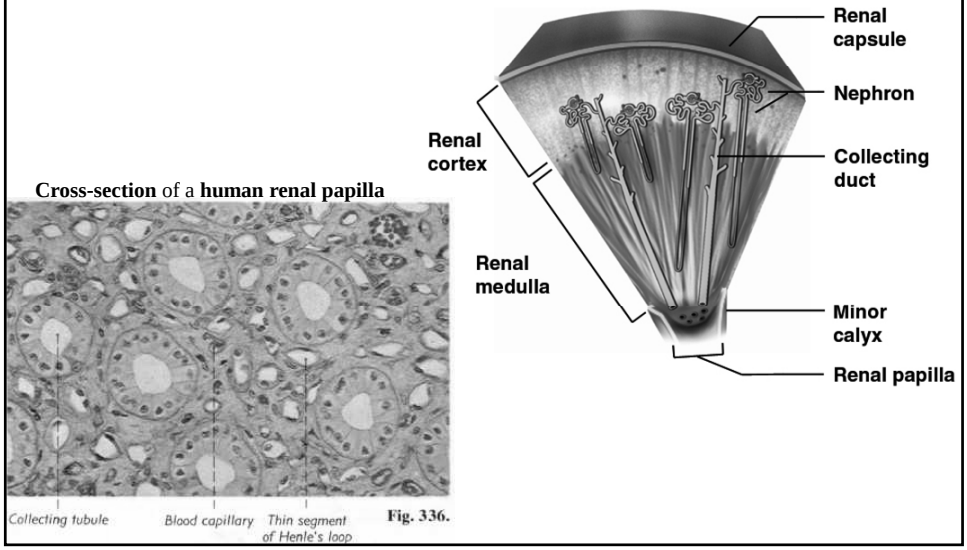
160 g
12 x 6 x 3 cm

Anatomy of Kidney



- Renal cortex: outer 1 cm
- Renal medulla: renal columns, pyramids - papilla
- Lobe of kidney: pyramid + it's overlying cortex

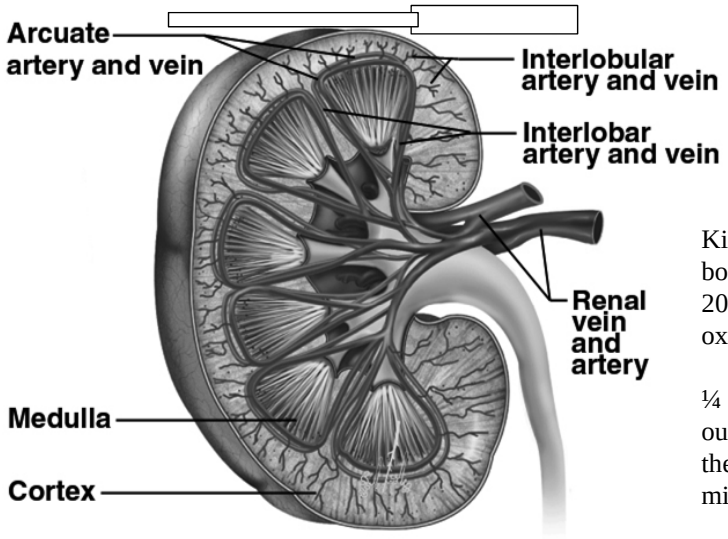
Lobe of Kidney



Cross-section of a **human renal papilla**

Fig. 336.

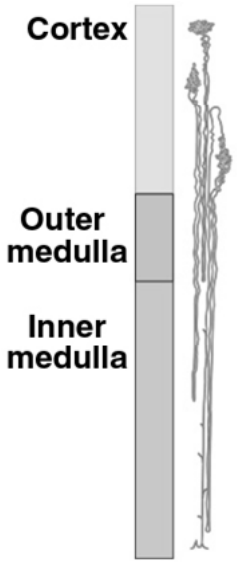
Blood Supply Diagram



Kidneys are 1% of body weight and use 20-25% of the oxygen.

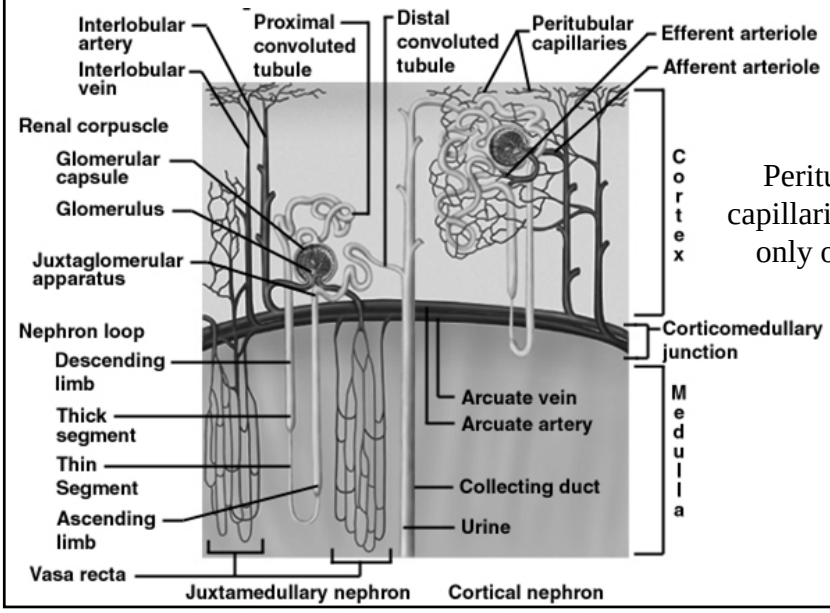
¼ of the cardiac output is delivered to the kidneys each minute

Nephrons



- True proportions of nephron loops to convoluted tubules shown
- Cortical nephrons (85%)
  - short nephron loops
  - efferent arterioles branch off peritubular capillaries
- Juxtamedullary nephrons (15%)
  - very long nephron loops, maintain salt gradient, helps conserve water
  - efferent arterioles branch off vasa recta, blood supply for medulla

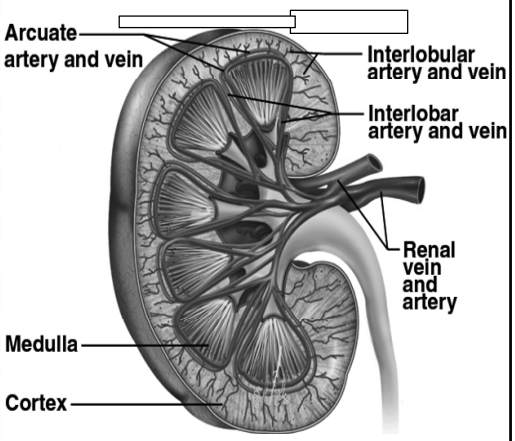
Nephrons



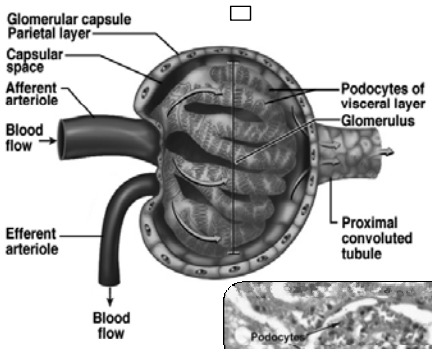
Peritubular capillaries shown only on right

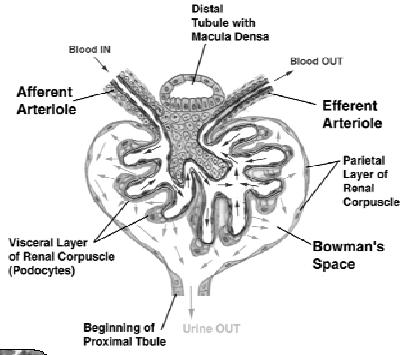
Path of Blood Through Kidney

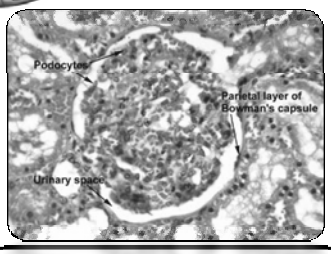
Renal artery
Interlobar artery
Arcuate artery
Interlobular artery
Afferent arteriole
Glomerular capillary
Efferent arteriole
Vasa recta and peritubular capillary
Interlobular vein
Arcuate vein
Interlobar vein
Renal vein

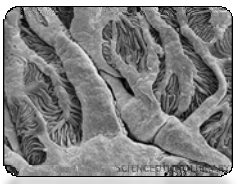


Renal Corpuscle



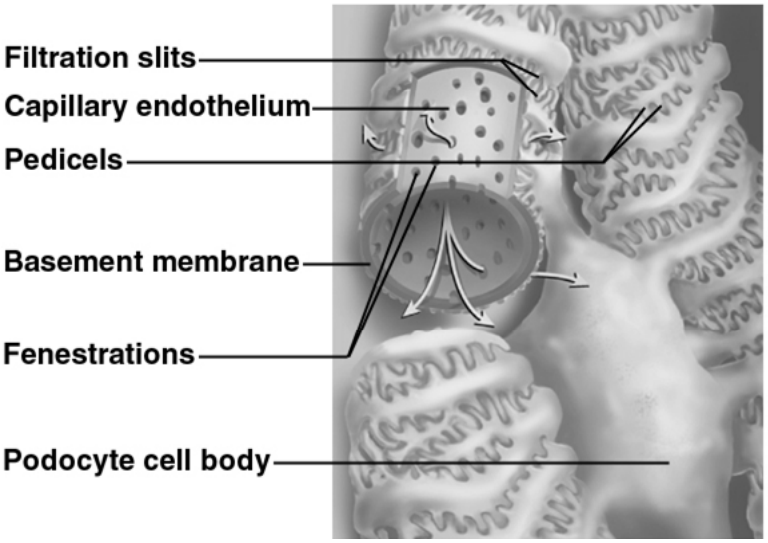






Glomerular filtrate collects in capsular space, flows into renal tubule

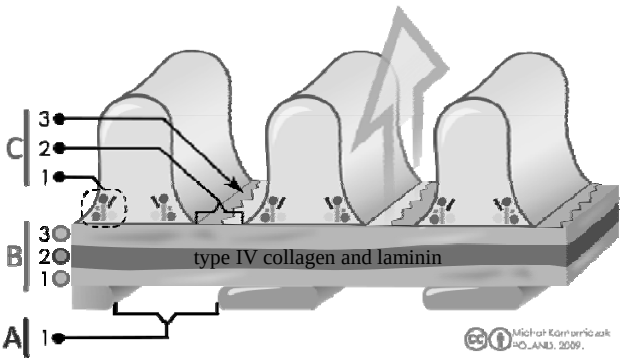
Filtration Membrane Diagram

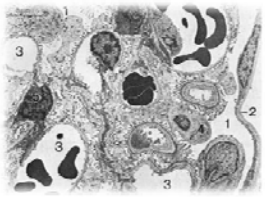


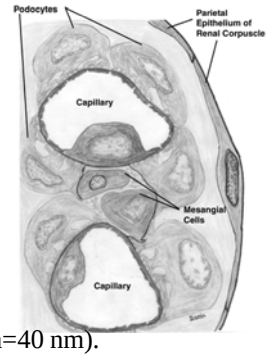
Filtration Membrane

- Fenestrated endothelium
  - 70-90nm pores exclude blood cells
- Basement membrane
  - proteoglycan gel, negative charge excludes molecules > 8nm
  - blood plasma 7% protein, glomerular filtrate 0.03%
- Filtration slits
  - podocyte arms have pedicels with negatively charged filtration slits, allow particles < 3nm to pass

Filtration Barrier



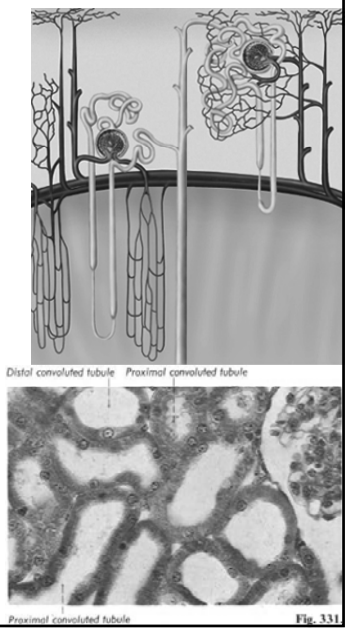




A. The endothelial cells of the glomerulus; 1. pores (fenestra=40 nm).
B. Glomerular basement membrane: 1.lamina rara interna 2.lamina densa 3.lamina rara externa.
C. Podocytes: 1. enzymatic and structural proteins (nephrin & CD2AP)
2. filtration slit (<1.8, 1.8-4.2, >4.2 nm)
3. diaphragma

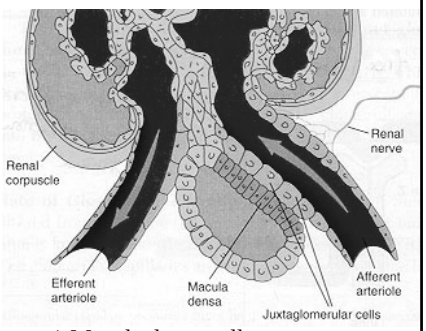
Renal (Uriniferous) Tubule

- Proximal convoluted tubule (PCT)
  - longest, most coiled, simple cuboidal with brush border
- Nephron loop - U shaped; descending + ascending limbs
  - **thick segment** (simple cuboidal) initial part of descending limb and part or all of ascending limb, active transport of salts
  - **thin segment** (simple squamous) very water permeable
- Distal convoluted tubule (DCT)
  - cuboidal, minimal microvilli

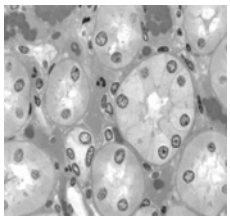


Renal (Uriniferous) Tubule 2

- Juxtaglomerular apparatus:
  DCT, afferent/efferent arterioles



- Collecting duct: several DCT's join

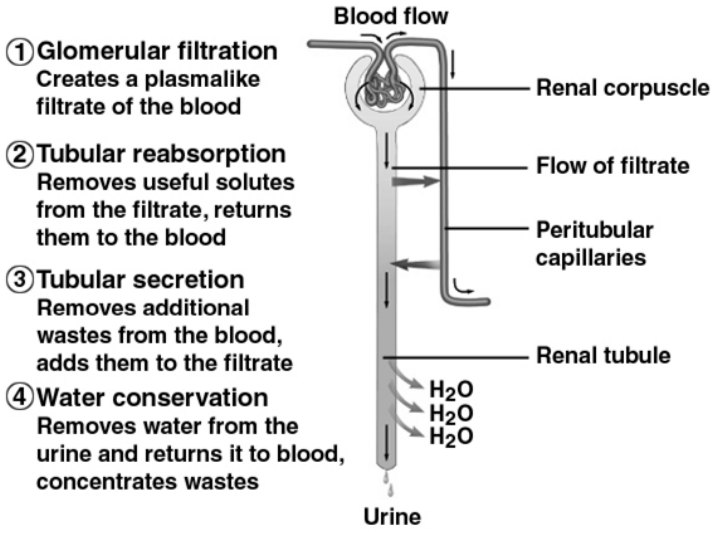


1. Macula densa cells
2. Juxtaglumerular cells
3. Extraglumerular mesangial cells

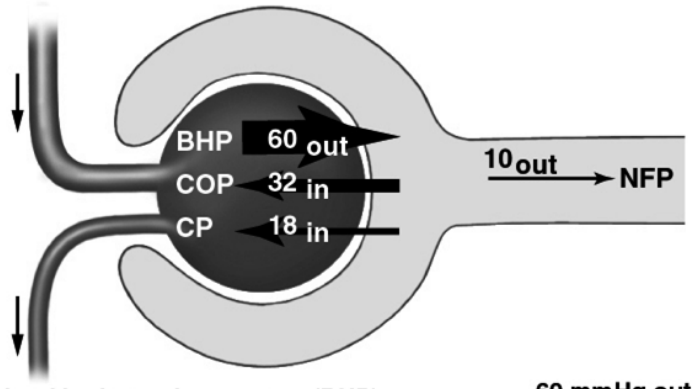
Flow of glomerular filtrate:

– glomerular capsule → PCT → nephron loop → DCT → collecting duct → papillary duct → minor calyx → major calyx → renal pelvis → ureter → urinary bladder → urethra

Urine Formation Preview



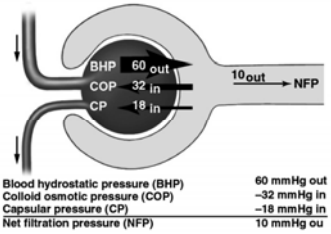
Filtration Pressure



Blood hydrostatic pressure (BHP)	60 mmHg out
Colloid osmotic pressure (COP)	–32 mmHg in
Capsular pressure (CP)	–18 mmHg in
Net filtration pressure (NFP)	10 mmHg ou

Glomerular Filtration Rate (GFR)

- Filtrate formed per minute
- GFR ≈ NFP

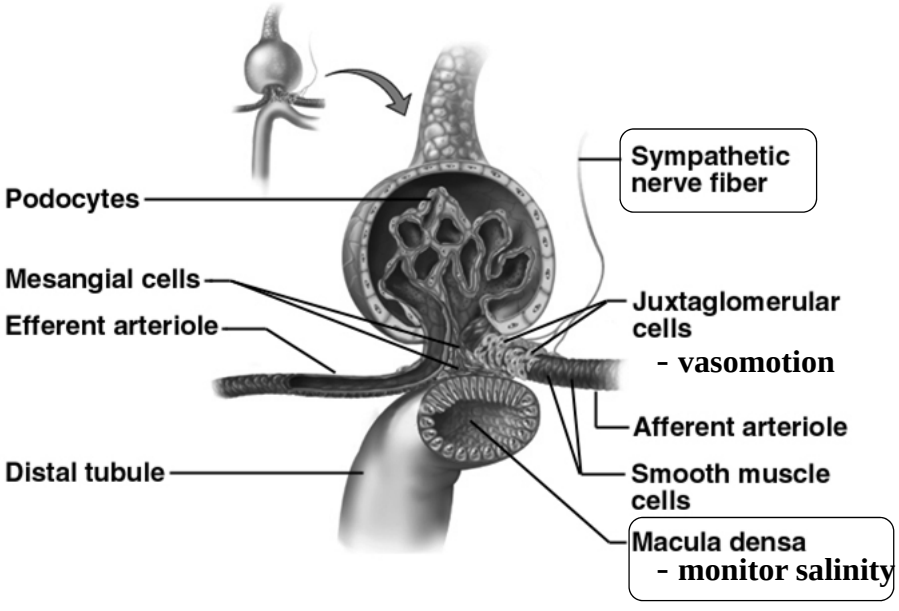


- GFR = NFP × K_f ≈ 125 ml/min or 180 L/day
- Filtration coefficient (K_f) depends on
  - Permeability
  - surface area of filtration barrier
- 99% of filtrate reabsorbed: 1 to 2 L urine excreted

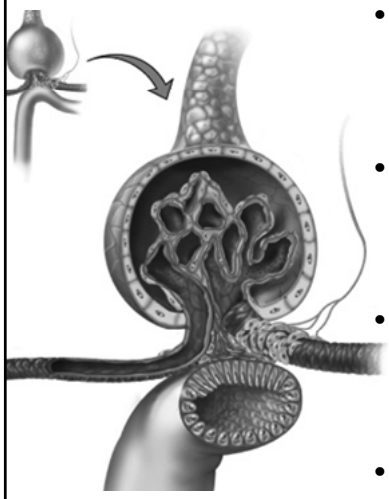
Effects of GFR Abnormalities

- ↑GFR= ↑urine output → dehydration, electrolyte depletion
- ↓GFR → wastes reabsorbed (azotemia possible)
- GFR controlled by adjusting glomerular blood pressure
  - autoregulation
  - sympathetic control
  - hormonal mechanism: renin and angiotensin

Juxtaglomerular Apparatus

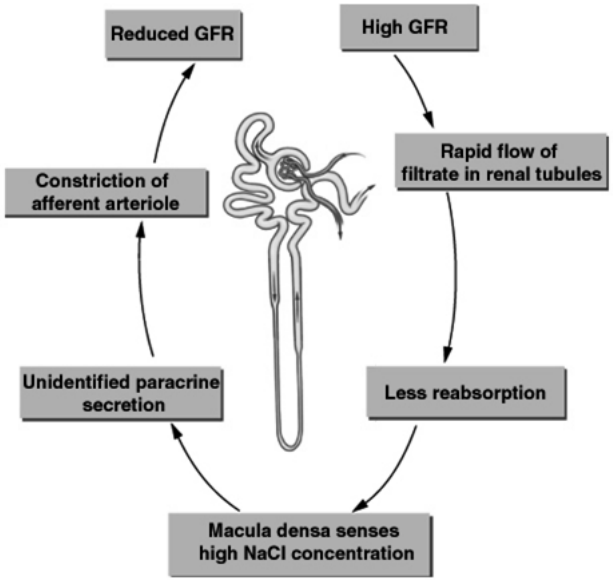


Renal Autoregulation of GFR



- ↑ BP → constrict afferent arteriole, dilate efferent
- ↓ BP → dilate afferent arteriole, constrict efferent
- Stable for BP range of 80 to 170 mmHg (systolic)
- Cannot compensate for extreme BP

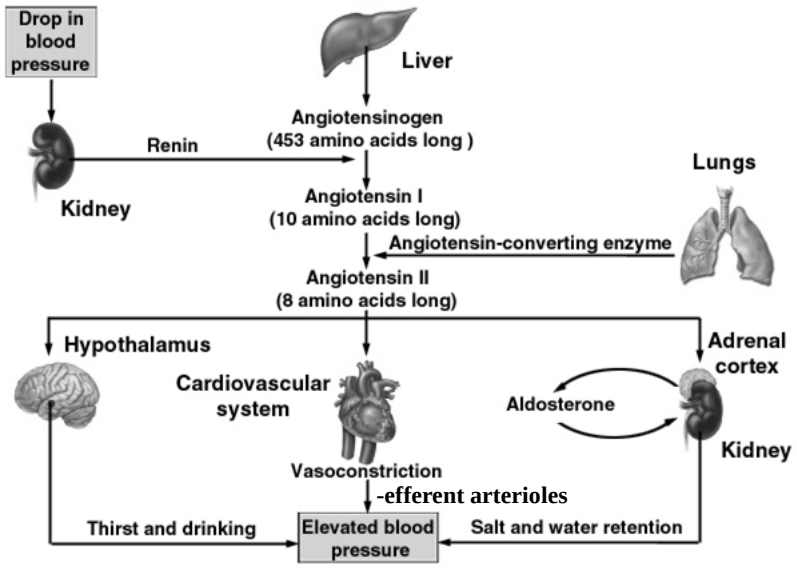
Negative Feedback Control of GFR



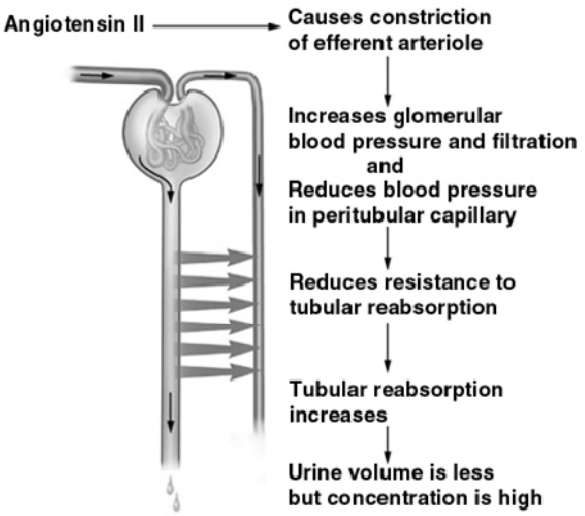
Sympathetic Control of GFR

- Strenuous exercise or acute conditions (circulatory shock) stimulate afferent arterioles to constrict
- ↓ GFR and urine production, redirecting blood flow to heart, brain and skeletal muscles

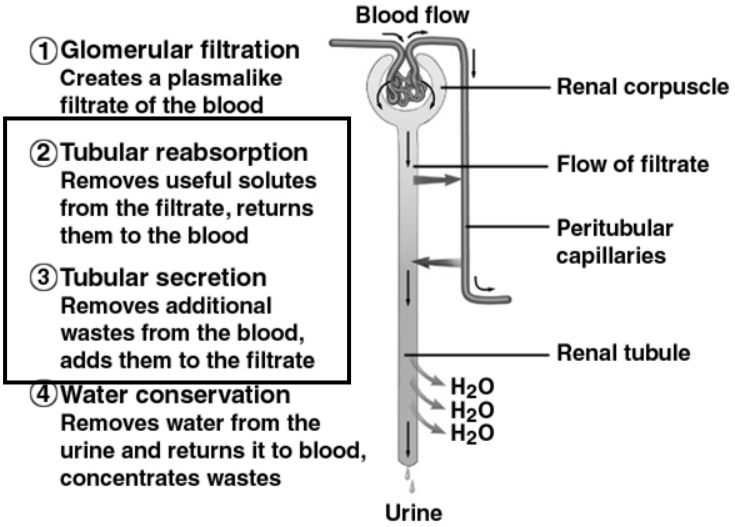
Hormonal Control of GFR



Effects of Angiotensin II

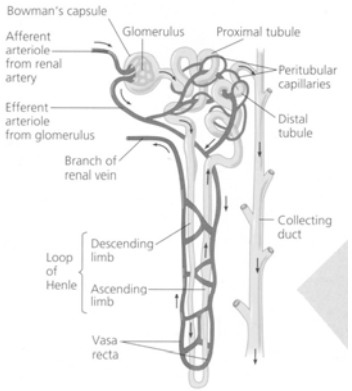


Tubular Reabsorption and Secretion



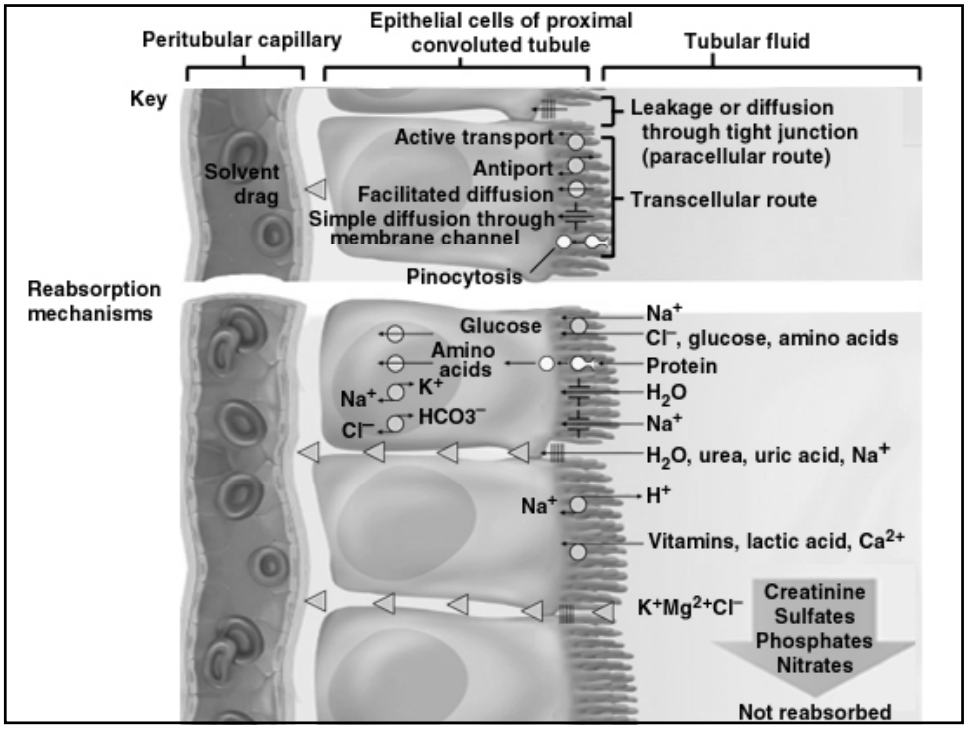
Peritubular Capillaries

- Blood has unusually high COP here, and BHP is only 8 mm Hg (or lower when constricted by angiotensin II); this favors reabsorption
- Water absorbed by osmosis and carries other solutes with it (solvent drag)



Proximal Convoluted Tubules (PCT)

- Reabsorbs 65% of GF to peritubular capillaries
- Great length, prominent microvilli and abundant mitochondria for active transport
- Reabsorbs greater variety of chemicals than other parts of nephron
  - transcellular route - through epithelial cells of PCT
  - paracellular route - between epithelial cells of PCT
- Transport maximum: when transport proteins of plasma membrane are saturated; glucose > 220 mg/dL remains in urine (glycosuria)



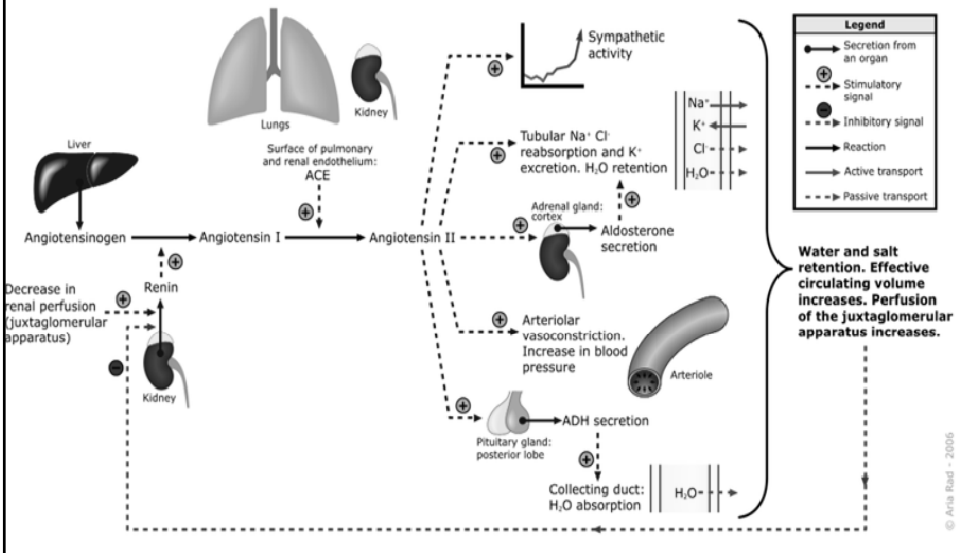
Tubular Secretion of PCT and Nephron Loop

- Waste removal
  - urea, uric acid, bile salts, ammonia, catecholamines, many drugs
- Acid-base balance
  - secretion of hydrogen and bicarbonate ions regulates pH of body fluids
- Primary function of nephron loop
  - water conservation, also involved in electrolyte reabsorption

DCT and Collecting Duct

- Effect of aldosterone
  - ↓ BP causes angiotensin II formation
  - angiotensin II stimulates adrenal cortex
  - adrenal cortex secretes aldosterone
  - aldosterone promotes Na^+ reabsorption
  - Na^+ reabsorption promotes water reabsorption
  - water reabsorption ↓ urine volume
  - BP drops less rapidly

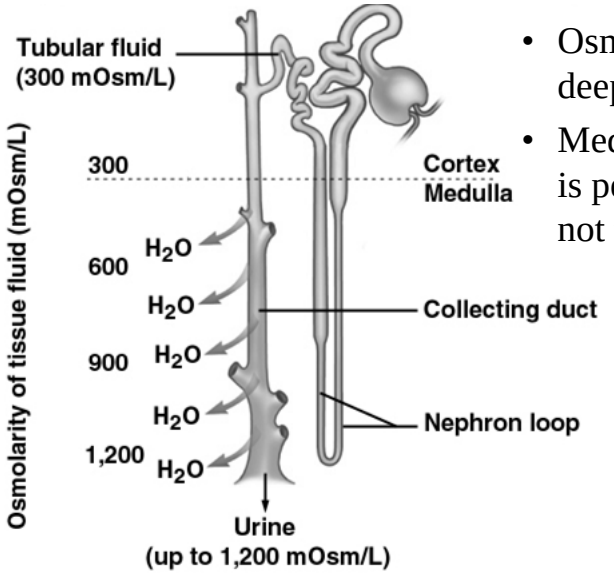
Renin-Angiotensin-Aldosterone System



DCT and Collecting Duct 2

- Effect of Atrial Natriuretic Factor (ANF)
  - ↑ BP stimulates right atrium
  - atrium secretes ANF
  - ANF promotes Na^+ and water excretion
  - BP drops
- Effect of ADH
  - dehydration stimulates hypothalamus
  - hypothalamus stimulates posterior pituitary
  - posterior pituitary releases ADH
  - ADH ↑ water reabsorption
  - urine volume ↓

Collecting Duct Concentrates Urine



- Osmolarity 4x as high deep in medulla
- Medullary portion of CD is permeable to water but not to NaCl

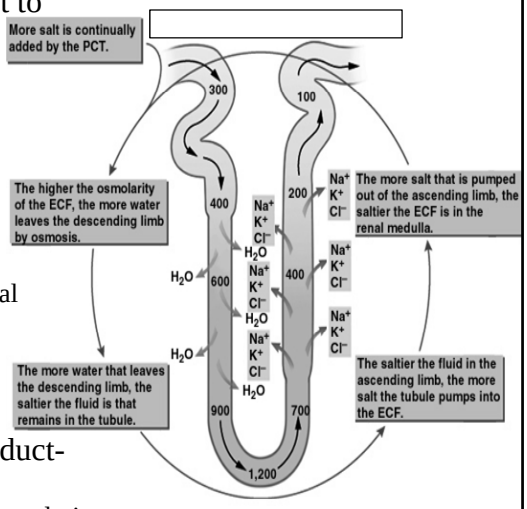
Control of Water Loss

- Producing hypertonic urine
  - GFR drops
  - tubular reabsorption ↑
  - less NaCl remains in CD
  - ADH ↑ CD's water permeability
  - more water is reabsorbed
  - urine is more concentrated

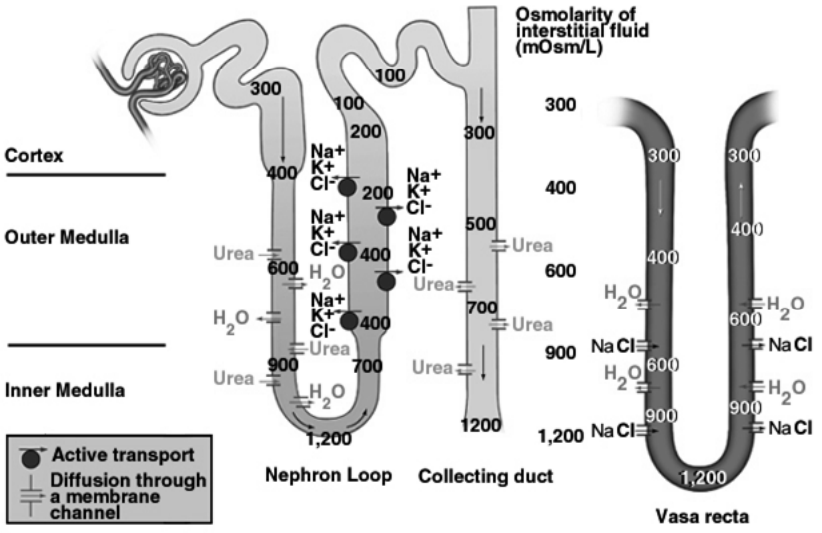
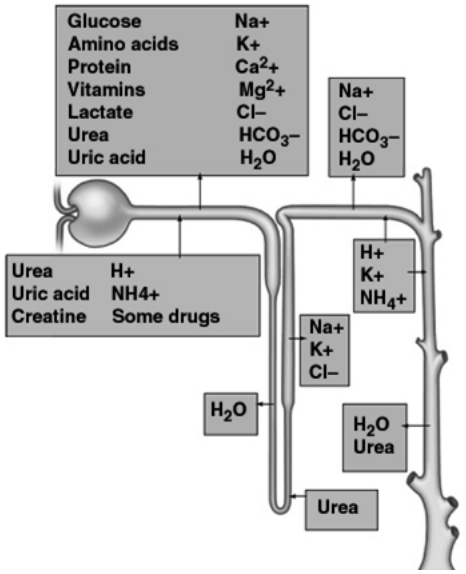
Normal urine output = 0.5ml/kg body weight/hr
30 to 40 ml per hour for an adult

Countercurrent Multiplier of Nephron Loop Diagram

- Recaptures NaCl and returns it to renal medulla
- Descending limb
  - reabsorbs water but not salt
  - concentrates tubular fluid
- Ascending limb
  - reabsorbs Na^+, K^+, and Cl^-
  - maintains high osmolarity of renal medulla
  - impermeable to water
  - tubular fluid becomes hypotonic
- Recycling of urea: collecting duct-medulla
  - urea accounts for 40% of high osmolarity of medulla



Maintenance of Osmolarity in Renal Medulla



Summary of Tubular Reabsorption and Secretion