Excretory System-Training Handout

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Excretion - Excretion is the removal of the metabolic wastes of an organism. Wastes that are removed include carbon dioxide, water, salt, urea and uric acid. All excreted wastes travel at some time in the blood.

Organs of the Excretory System

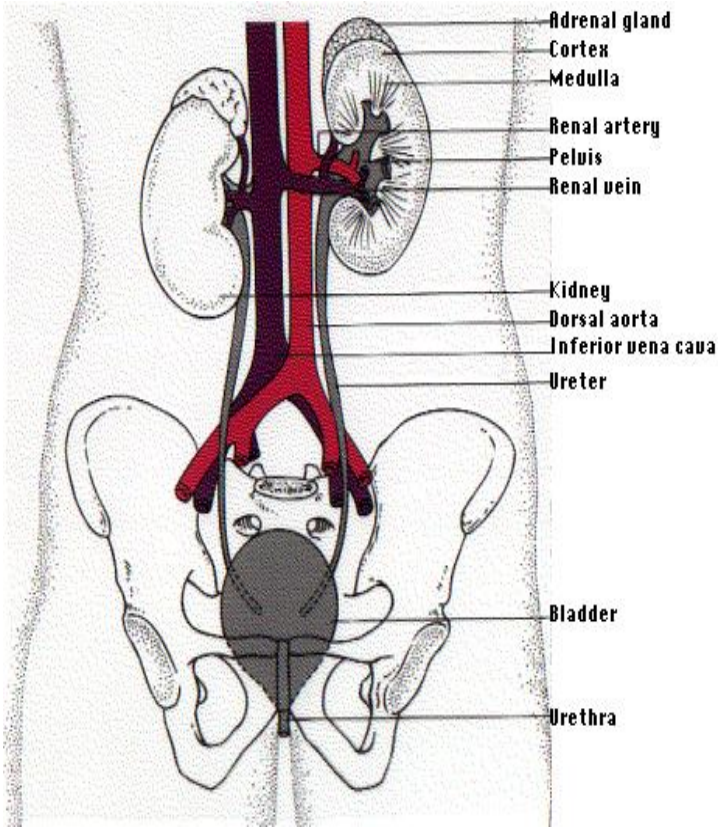
- **Lungs** - removal of excess carbon dioxide
- **Liver** - produces urea and uric acid as a by-product of the breakdown of proteins
- **Skin** - removal of excess water, salt, urea and uric acid
- **Urinary System** - kidneys filter the blood to form urine, which is excess water, salt, urea and uric acid

Importance:

- Humans produce waste products that must be removed from their body.
- Most animals have a system that deals with nitrogen-rich wastes from the breakdown of proteins and nucleic acids.
- Ammonia (NH_3) is toxic.
- It helps maintain homeostasis ï balancing osmotic action and pH**.**

Urinary System Functions:

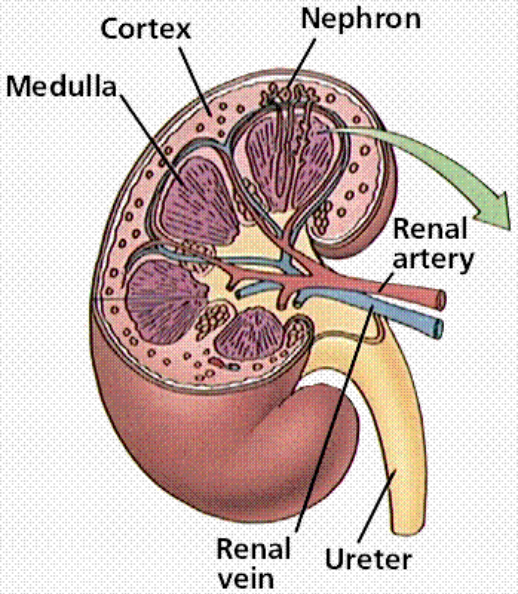
- Excrete toxins and nitrogenous waste
- Regulate levels of many chemicals in blood
- Maintain water balance
- Helps regulate blood pressure

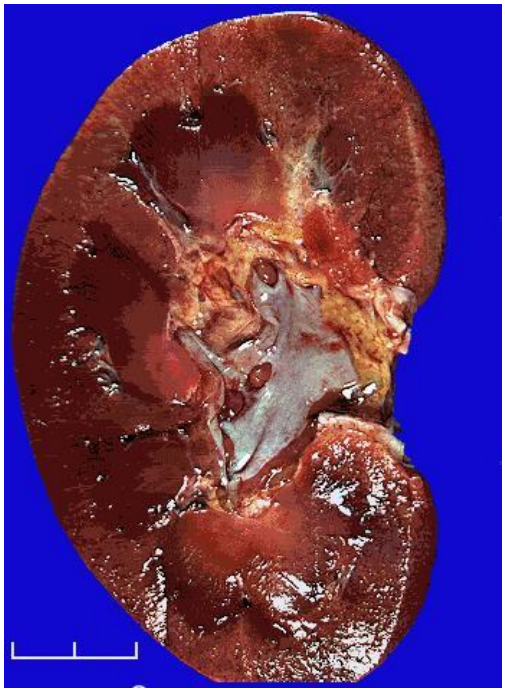


Organs of the Urinary System

Kidney – filters blood and forms urine- receives 20-25 % of arterial blood

Homeostatic device ï regulates composition of the blood
Filtration ï removes waste

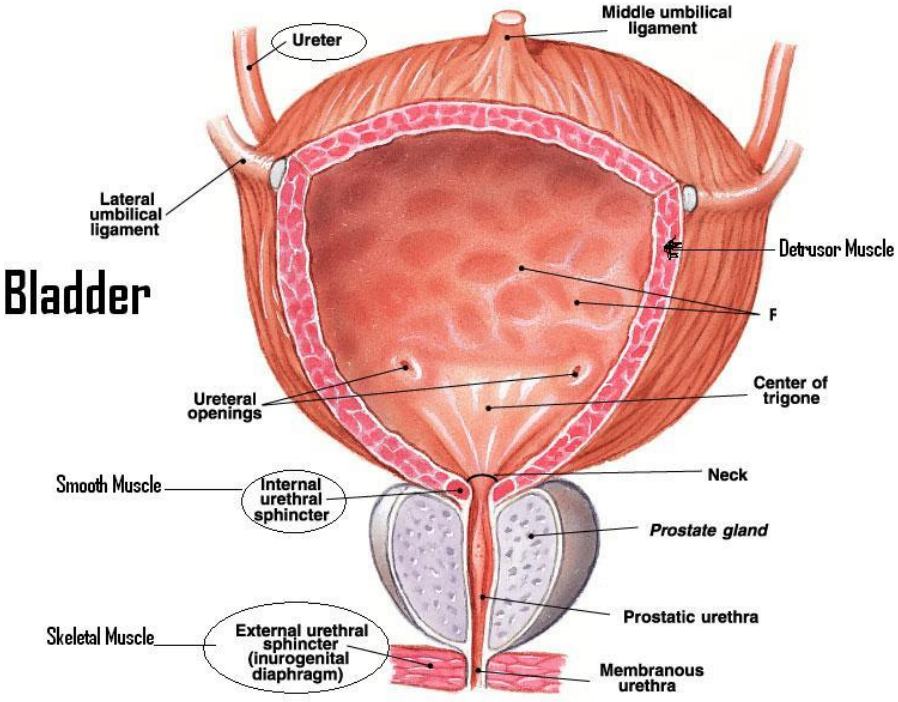




Ureter – carries urine to the urinary bladder
Muscles contract and relax to move urine out of kidneys every 10 to 15 seconds to prevent infection

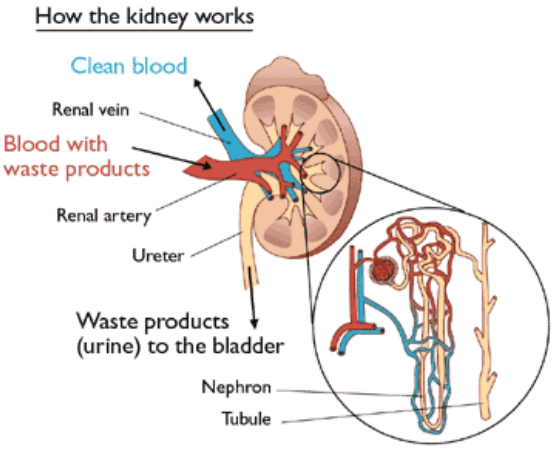
Urinary Bladder – holds urine ï it can hold up to 16 oz of urine for 2-5 hours

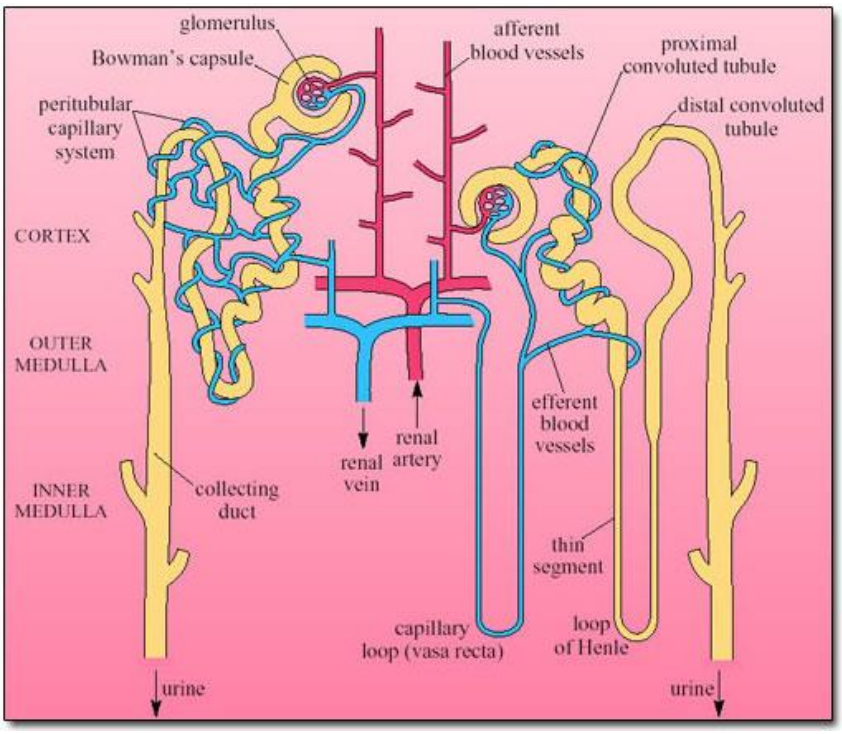
Urethra – releases urine from the body by relaxing the sphincter muscle (circular muscle around the bladder opening to keep it from leaking) at bottom of bladder and contracting the bladder muscles



Functions of the kidney

- **filtration** ï fluid pressure forces water and dissolved substances out of blood
- **reabsorption** ï returns useful items as blood cells, plasma protein, glucose, amino acids, some salts and some water to the blood Some urea and other salts are also reabsorbed.
- **secretion** ï *involves active transport* - removes residues from toxins drugs, more urea and uric acid into urine, excess potassium ions, and regulates pH of blood



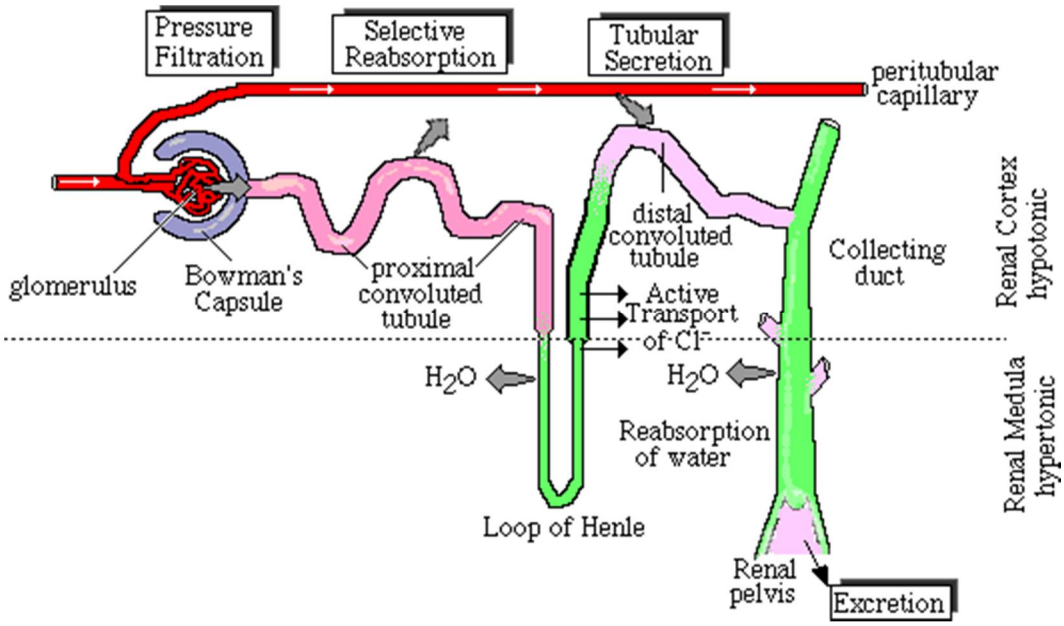


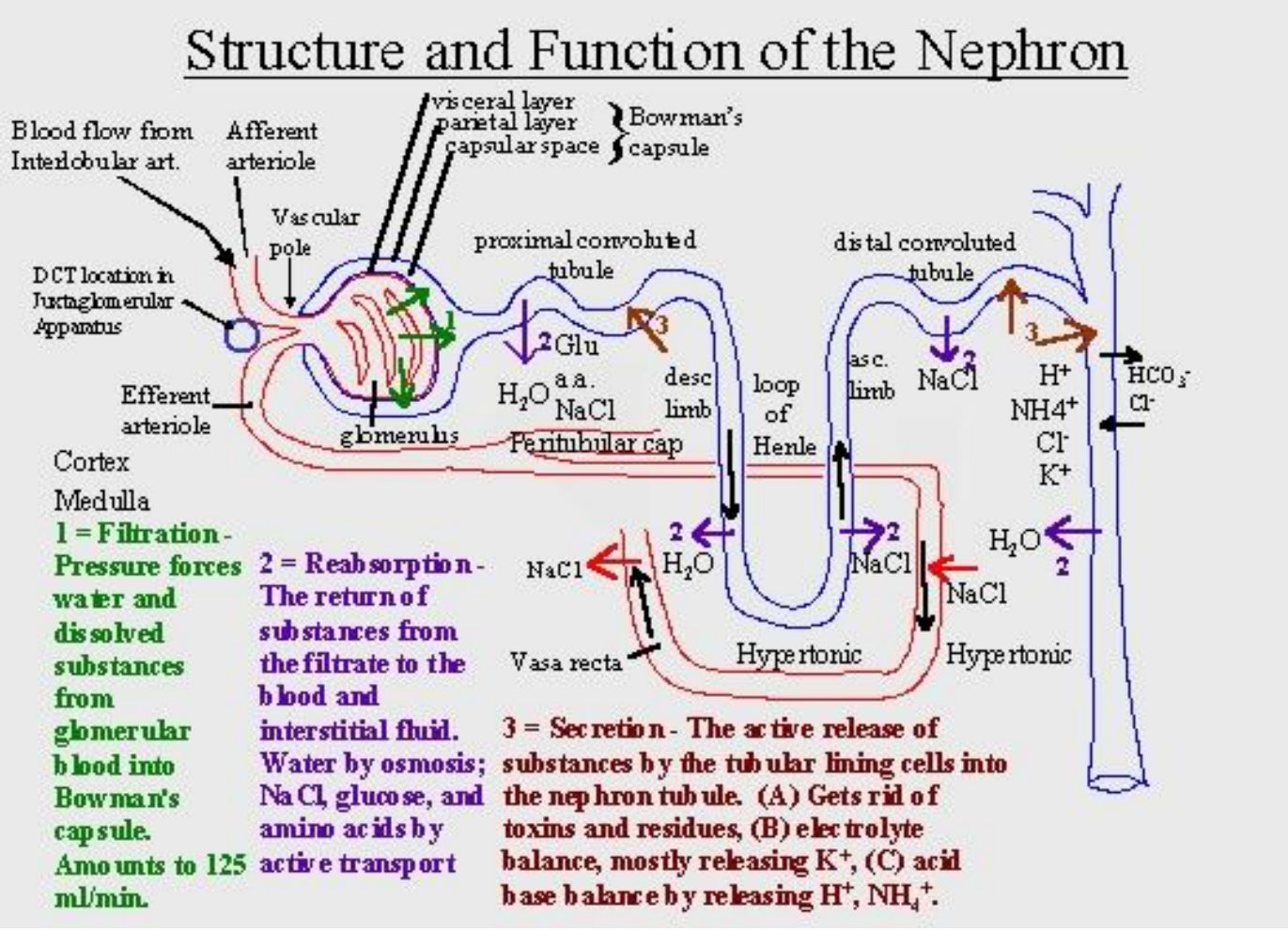
Nephron – basic unit of kidney

Overview of Nephron Structure and Function

- General Nephron Structure
  - glomerulus ï site of filtration from arterial blood
  - proximal convolute tubuleï first tube off glomerulus .
  - Loop of Henle ï U-turn connecting tubules
  - distal convoluted tubule ï to the Collecting Tubule
  - collecting tubule ï urine from many nephrons
  - peritubular capillaries ï ñaroundò the ñtubesò
- General Nephron Function
  - glomerular filtration
  - tubular reabsorption
  - tubular secretion
- Fluid Processing in the Kidneys
  - 180 liters of blood fluid processes each day
  - 1.5 liters of urine produced each day

Nephron Function:





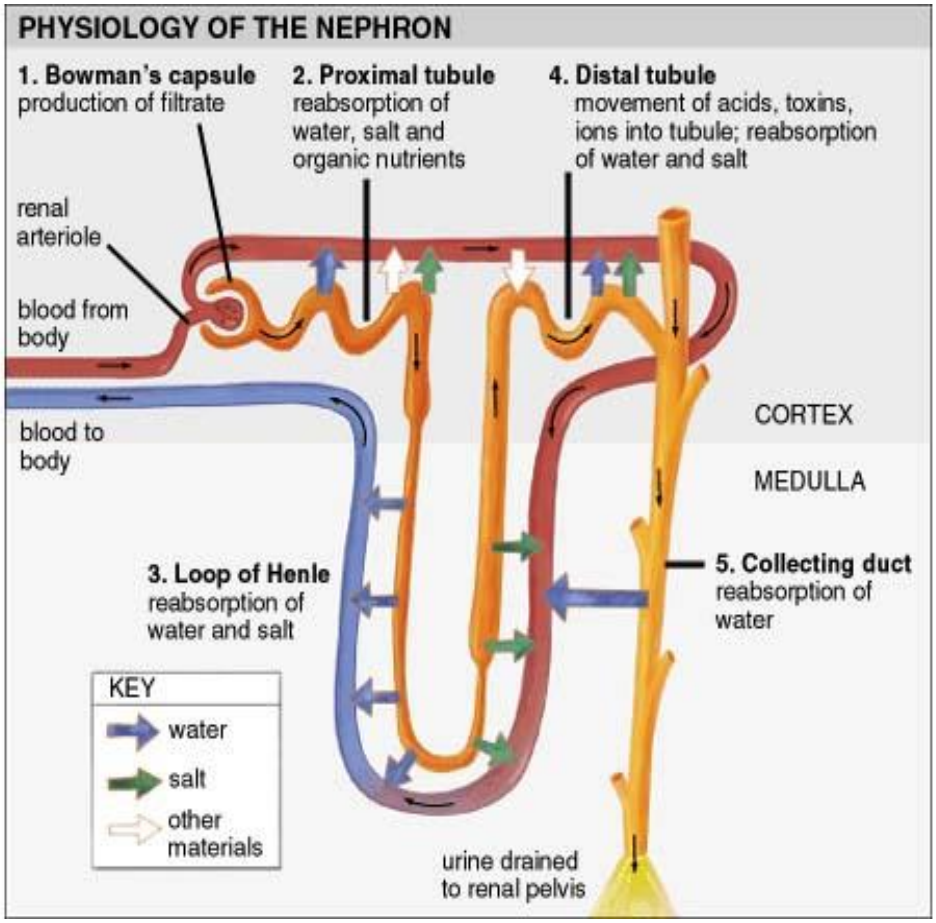
STAGES OF URINE FORMATION IN THE NEPHRON

- **Glomerular filtration** ï into Bowmanôs Capsule
  - substances move from blood in glomerulus to the Bowmanôs capsule

- **Tubular Reabsorption of solutes and water**
  - **Solute Reabsorption** ï from proximal tubule to capillary
  - **substances move from renal tubules into blood of peritubular capillaries**
    - **glucose, water, urea, proteins, creatine**
    - **amino, lactic, citric, and uric acids**
    - **phosphate, sulfate, calcium, potassium, and sodium ions**

  - **Water Reabsorption** ï from proximal tubule and Loop of Henle to capillary

- **Tubular Secretion** ï from capillary to distal
  - substances move from blood of peritubular capillaries into renal tubules
  - drugs and ions



Glomerular Filtration

A. Filtration Membrane

1. hydrostatic pressure ï forces 1/5 of blood fluid through capillary walls into glomerular capsule
2. filtration membrane ï has three parts
   a. fenestrated capillare endothelium (prevents passage of blood cells)
   b. basal membrane (allows most solutes but larger proteins)
   c. visceral membrane of glomerular capsule
3. <u>solutes that can pass into glomerular capsule</u>
   < 3 nm easily pass (water, sugar, amino acids, nitogenous waste molecules)
   - 9 nm larger proteins cannot pass through

B. Net Filtration Pressure

NFP = force OUT of blood ï force to remain IN blood

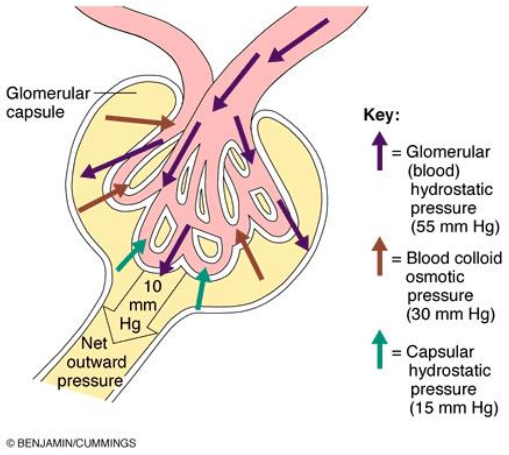
NFP = glomerular hydrostatic pressure ï (glomerular osmotic pressure + capsular hydrostatic pressure)

NFP = 55 mm Hg ï (30 mm Hg + 15 mm Hg)

NFP = 55 mm Hg ï (45 mm Hg)

NFP = net filtration pressure = 10 mm Hg

[This is the NET forces pushing fluid/solutes OUT of blood]



C. Glomerular Filtration Rate (GFR)

1. glomerular filtration rate = milliliters of blood fluid filtered by glomerulus each minute
   Factors effecting the GFR:
   a. total filtration surface area
   b. membrane permeability to fluid/solutes
   c. Net Filtration Pressure
2. Normal GFR = 125 ml/min (7.5 L/hr, 180 L/day)
3. NFP ï primary factor controlling GFR
   a. bleeding ï NFP drops, lowers the pressure
   b. dehydration ï NFP drops, lowers the pressure

D. Intrinsic Controls: Regulation of Glomerular Filtration

1. renal autoregulation ï rate of FILTRATE production must be coordinated with reabsorption rate
2. myogenic mechanism ï circular muscle around the glomerular arterioles reacts to pressure changes
    a. increased blood pressure -> vasoconstriction
    b. decreased blood pressure -> vasodilation
3. tubuloglomerular feedback mechanism ï macula densa cells (of juxtaglomerular apparatus) sense the solute concentration of the FILTRATE

    a. low concentration -> vasodilation
    b. high concentration -> vasoconstriction
4. renin-angiotensin mechanism

   renin (released by juxtoglomerular cells) -> anigiotensinogen -> angiotensin I -> angiotensin II -> global vasoconstrictor (rise in blood pressure) release of aldosterone (resorption of more Na^+)

   Factors causing release of Renin:
    a. reduced stretch of juxtaglomerular cells
    b. stimulation by macula densa cells (as above)
    c. stimulation of juxtaglomerular cells by sympathetics

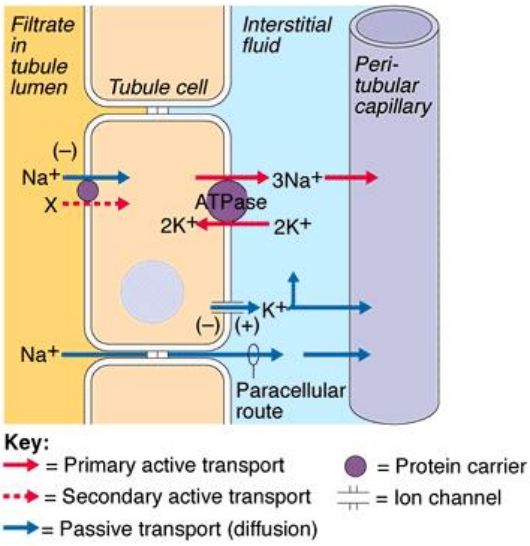
E. Extrinsic Controls: Sympathetic Innervation

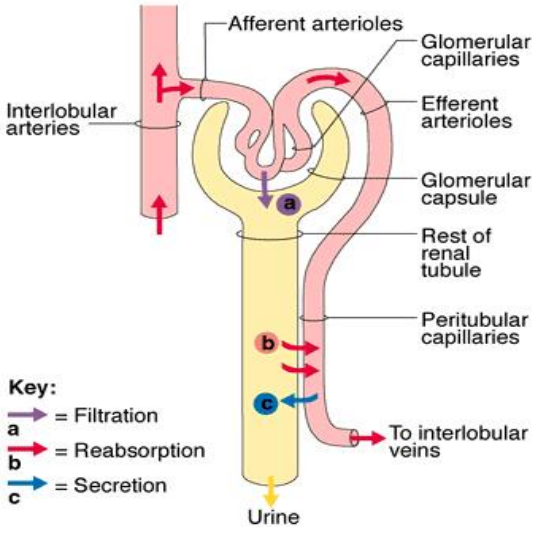
1. sympathetics ï cause increased release of renin
2. epinephrine ï causes increased vasoconstriction

Tubular Reabsorption: Reabsorbing the Glomerular Filtrate

A. Overview of Reabsorption

1. filtrate - all fluid and its solutes pushed into the capsule
2. urine - filtrate minus reabsorbed substances
3. route of reabsorption (transepithelial process)
   luminal surface of tubule cells >>
   basolateral membrane of tubule cells >>
   interstitial fluid between tubule cells and capillaries >>
   endothelium of the peritubular capillary
4. most sugars and amino acids are reabsorbed
5. water and ion reabsorption depends on hormonal control





B. Active Tubular Reabsorption

1. glucose, amino acids, lactate, vitamins, ions
    a. move across luminal surface by diffusion
    b. actively transported across basolateral membrane
        i. contransported with Na^+
    c. diffuse into capillary by diffusion
2. transport maximum (T_m) - when ñ carrier proteinsò for specific solute becomes saturated and cannot carry the substance across the membrane
    a. diabetes mellitus ï lower Tm (glucose lost)

C. Passive Tubular Resorption

1. Na^+ driven into interstitial space actively (above)
2. HCO_3^- and Cl^- follow Na^+ into the space
3. obligatory water resoprtion ï water follows ions into the interstitial space between tubule & capillary
4. solvent drag ï solutes will begin to move into tubule from filtrate, following water (especially some urea and lipid-soluble molecules

D. Nonreabsorbed Substances

1. urea, creatinine, uric acid ï most is not reabsorbed because of the following reasons
    a. no carrier molecules for active transport
    b. not lipid-soluble
    c. too large (as with most proteins)

E. Absorption in Different Regions of Renal Tubule

1. proximal tubule ï closest to the glomerular capsule
    a. almost all glucose & amino acids
    b. 75-80% of water and Na+
    c. most active transport of ions
2. Loop of Henle ï connects proximal & distal tubules
    Regulates Total water retained or lost:
    a. descending limb ï water can return
    b. ascending limb ï water can be reabsorbed
3. distal tuble & collecting duct ï final passageway
    a. antidiuretic hormone (ADH) ï causes increased permeability to Na^+ and water, allow resorption
    b. aldosterone ï stimulated be renin-angiotensin, enhances Na^+ reabsorption (water follows)
        i. lower blood pressure
        ii. low Na^+ concentration (hyponatremia)
    c. atrial natriuretic factor (ANF) ï reduces Na^+ permeability, less water (in response to high B.P.)

Tubular Secretion

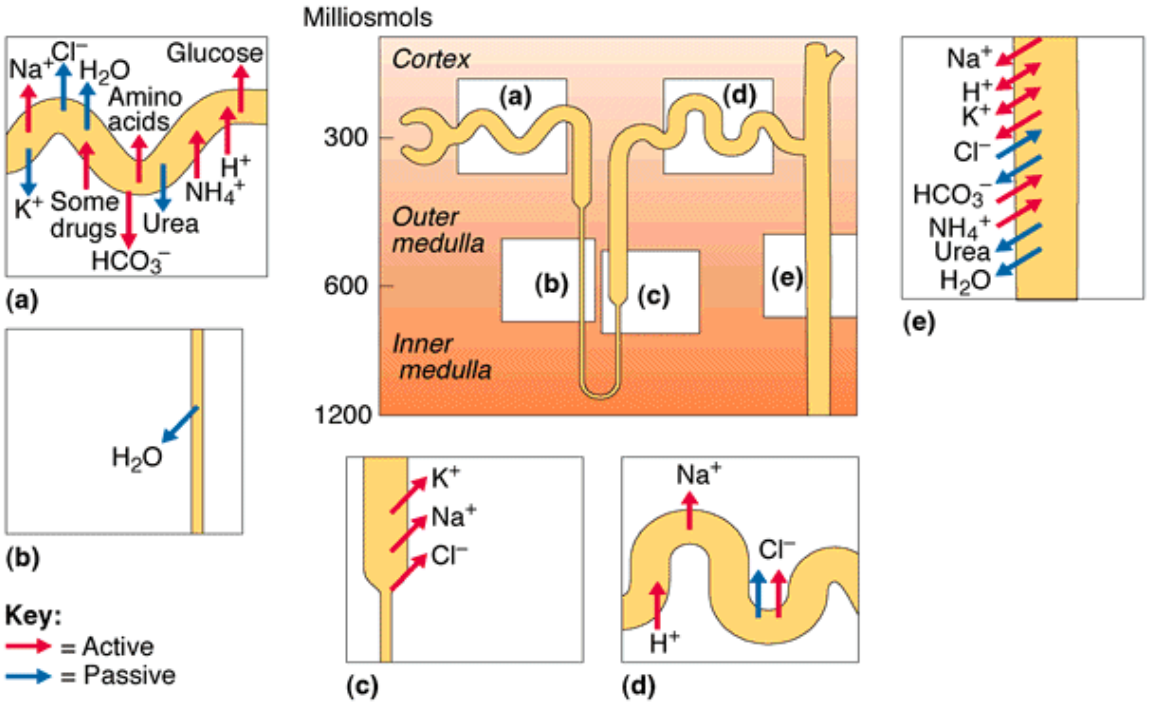
A. Movement from Capillaries to Tubular Cells

1. K^+, creatinine, ammonia, organic acids, drugs
2. Primary functions of tubular secretion:
    a. moving drugs into the urine
    b. moving more urea & uric acid into urine
    c. removing excess K^+ from blood
    d. regulating pH (H^+ ion removal)

Regulation of Urine Concentration & Volume

A. Osmolarity ï Number of Solute particles in 1 Liter water
   1. independent of size of solute (Na+, glucose)
   2. 1 osmol = 6.02 X 10^23 particle in 1 Liter
   3. <u>milliosmol (mosm)</u> = 0.001 osmol
   4. normal body fluids = 300 mosm

B. Countercurrent Multiplier Mechanism for Maintenance of Blood/Urine Osmolarity
   1. Water moves out along Descending Limb of the Loop of Henle, creating 1200 mosm urine at the base
   2. Na+Cl- moves out along the Ascending Limb of the Loop of Henle, creating 100 mosm urine at distal end. This salt helps pull more water out of the Descending Limb in positive feedback mechanism.
   3. In times of dehydration, Collecting Tubules leak urea to interstitial space, further increasing water retention by increasing osmolarity.



   4. Vasa recta (capillaries around Loop of Henle) have no Net Effect on water/salt balance

C. Formation of Dilute Urine
    1. When water removal is needed, no ADH is released, so that the Distal and Collecting Tubules will not actively transport Na^+ out; no water moves out
    2. Urine may be as low as 50 mosm

D. Formation of Concentrated Urine (Water Conservation)
    1. antidiuretic hormone (ADH) ï stimulates reabsorption of water in the Distal and Collecting Tubules

E. Diuretics (Stimulate Water Loss)
    1. alcohol ï inhibits action of ADH
    2. caffeine ï causes renal vasodilation; increases GFR
    3. Na^+ resorption blockers ï block Na^+ movement

Renal Clearance

A. Renal Clearance (RC) ï the rate at which the kidney can remove a substance from the blood

RC = U/P X V

U/P = concentration of substance in urine (mg/ml) / concentration of substance in plasma (mg/ml)

V = rate of the formation of urine (ml/minute) (normal = 1 ml/minute)

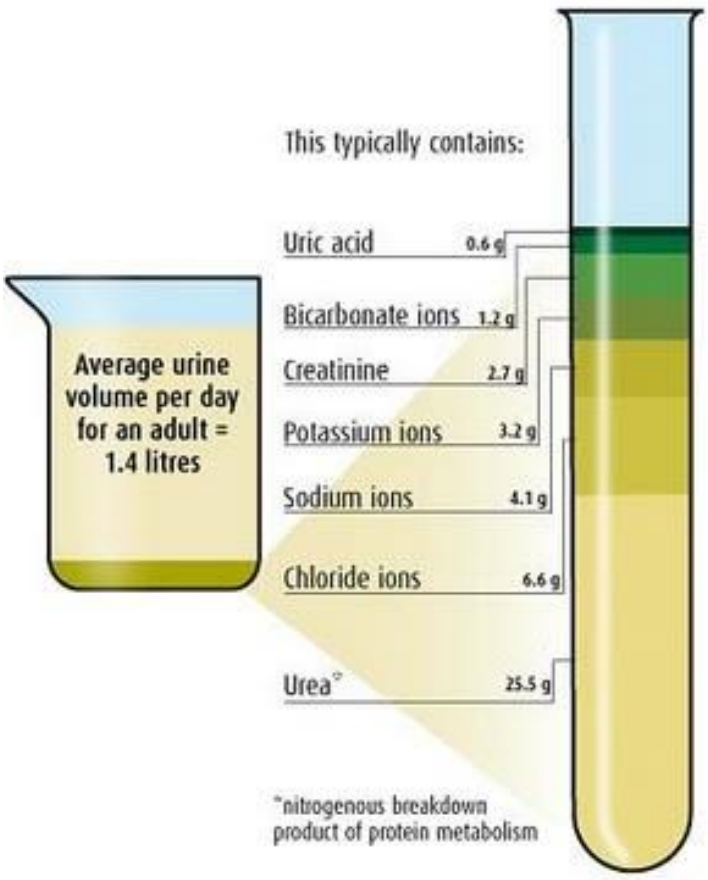
B. Glomerular Filtration Rate = 125 ml/minute; (determined by challenge with ñInsulinò)
    1. RC < 125 ï reabsorption is occurring
    2. RC > 125 ï tubule cells secrete into the urine

Characteristics and Composition of Urine

A. Physical Characteristics
    1. color ï clear to yellowish; influenced by diet, drugs, and health state
    2. odor ï slightly aromatic; influenced by diet, drugs, and health state
    3. pH (H^+ conc.) ï usually about 6; changes in diet can affect the pH
    4. specific gravity ï compared density to distilled water; urine slightly heavier (with solutes)

B. Chemical Composition
    1. 95% water
    2. 5% solutes ï urea (breakdown of amino acids); uric acid; creatinine

Composition of Urine



Normal GFR = 125 mL/min or 7.5 l/hr or 180 l/day

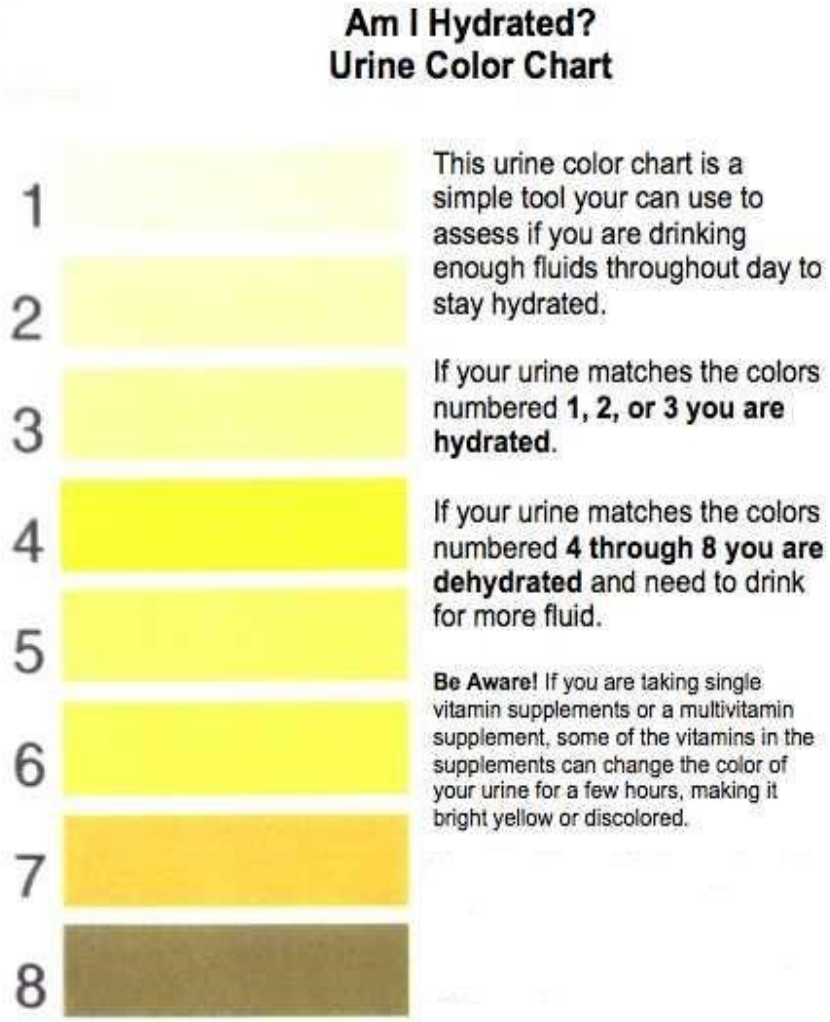
***GFR*– amount of filtrate formed per minute in all nephrons of both kidneys**

- The amount of fluid filtered from the glomeruli into Bowman's space per unit of time.
- Renal capillaries are much more permeable than others.
- The flow rate is 180 L/day (125 ml/min) compared to 4 L/day in the other capillaries.
- The entire plasma volume is filtered about 60 times a day! Most is reabsorbed!

$$\textbf{GFR} = \frac{\textbf{UV}}{\textbf{P}} = \frac{\textbf{Urine concentration x Rate of Urine Flow}}{\textbf{Blood Plasma Concentration}} = \frac{\textbf{g/ml x ml/min}}{\textbf{g}} = \textbf{ml/min}$$

Note: Cranberry juice acidifies the urine which can help prevent bacterial growth and some types of kidney stones. It also reduces the adherence of bacteria onto the walls of the urinary tract reducing the risk of urinary tract infections.

HYDRATION



DISORDERS AND DISEASES OF THE EXCRETORY SYSTEM

- **Obstructive Disorders –** flow of urine is blocked causing it to back up and injure one or both kidneys
- **Kidney Stones** - hard, crystalline mineral material formed within the kidney or urinary tract. Kidney stones are a common cause of blood in the urine (hematuria) and often severe pain in the abdomen, flank, or groin.
- **UTI's (Urinary Tract Infections) –** infections of the urinary tract – can be in kidneys, ureters, bladder or urethra
- **Glomerular Disorders –** disorders that affect kidney function by attacking the glomeruli
- **Glomerulonephritis** ï a group of diseases that injure the part of the kidney that filters blood (called glomeruli).
- **Glomerulosclerosis** - a disorder that scars the tiny blood vessels that filter urine from the blood in the kidneyôs glomeruli
- **Renal failure –** partial or complete failure of kidneys to function
- **Incontinence** – loss of bladder control
- **Prostatitis** – swelling and inflammation of the prostate gland
- **BPH (Benign Prostyatic Hyperplasia)–** enlarged prostate gland The prostate enlargement in benign prostatic hyperplasia is not malignant (not cancer). BPH can impede the flow of urine. Symptoms include frequent urge to urinate, getting up at night to urinate, difficulty urinating and dribbling of urine.