

INTRODUCTION

Urinary System Basics

A. Concept

1. Kidneys
2. Ureters
3. Urinary bladder
4. Urethra

B. Importance

Homeostasis

1. General meaning _ maintenance of life requirements within narrow tolerance limits, given continual variable influences.
2. Specific urinary application _ overall homeostasis of body fluids
 - a. Direct _ blood & ECF
 - b. Indirect _ ICF, from contact with ECF

C. Functions

1. Fluid balance *[details later]*
 - a. Volume maintenance
 - b. Solute amounts
 - c. Acid-base maintenance
 - d. Transport between ECF & ICF _ osmotic context
2. Excretion

- a. Fluid balance _ in order to maintain homeostasis, elimination of excesses required
- b. Toxicity _ elimination of toxins

Excretion

A. Meaning

1. Separation from body fluids & ejection out of body of metabolic waste products
2. Must have been involved in metabolic reactions to be an excretion

B. Systems Represented

1. Urinary _ full-time, primary function
2. Integumentary _ part-time, but very significant function
3. Respiratory _ part-time, significant function
4. Digestive _ part-time, secondary function

C. Substances Excreted

1. General
 - a. Due to varying homeostatic needs, some substances which are considered valuable metabolites may at times be excreted
 - b. Other, usually toxic, substances are always excreted in greater quantities
2. Water _ from ingestion & cellular respiration
 - a. Urine
 - 1200-1400 ml/day

- Less in hot weather & strenuous exercise
 - b. Skin, via sweat glands & diffusion
 - 450-750 ml/day
 - Up to 10x more in hot weather & exercise
 - c. Expired as water vapor
 - 350-450 ml/day
 - May double during exercise
 - d. Feces _ 100-150 ml/day under all conditions
3. CO₂ _ from cellular respiration
- a. Overwhelming majority expired
 - b. Some via urine, feces & sweat _ CaCO₃
4. Nitrogenous organic compounds
- a. From amino acid metabolism in the liver
 - General
 - Most via urine
 - Some via bile & sweat
 - Urea _ 90% of total
 - Urate (uric acid)
 - Ammonia (NH₃) _ quite toxic
 - Excess amino acids _ only 1-2 g/day
 - b. From muscle metabolism _ creatinine
 - From unique high energy creatine-PO₄
 - Some excreted via urine
 - c. From benzoic acid detoxification

- Hippuric acid _ benzoic acid + glycine
- Via urine

5. Non-nitrogenous organic compounds

a. General

- Most via urine
- Slight via sweat & oil glands, & feces
- Quite variable in types & amounts

b. Glucose _ barely perceptible amounts

c. Ketone bodies

- From fatty acid metabolism
- Minute amounts

d. Oxalates _ small amounts

e. Citrate _ small amounts

f. Vitamins _ excess water soluble

g. Hormones

h. Enzymes _ only a few

6. Inorganic salts (electrolytes)

a. General

- Most via urine _ exceptions noted
- Some in sweat & feces

b. In decreasing amount:

Chloride
Sodium
Potassium
Sulfate
Phosphate
Calcium _ more via feces

Magnesium _ more via feces

7. Heat
 - a. Not a chemical substance, but there is elimination of the excess not utilized to maintain body temperature
 - b. From cellular respiration
 - c. Most via skin
 - Sweat carries away more heat than dry skin
 - Extra vessels deliver more heated blood
 - d. Some via urine, feces & expired air

D. Basic Processes [all details later]

1. Filtration
 - a. Removes majority of substances from blood
 - b. Substances now in space which eventually leads outside of the body
2. Reabsorption
 - a. Removal of most components from what was filtered & return to body fluids
 - b. Selectivity is its importance
3. Secretion
 - a. Addition of extra amounts of some substances to what was filtered
 - b. From body fluids via different route

Gross Kidney Structure [details from lab]

A. Regions

1. Cortex _ outer
2. Medulla
 - a. Inner
 - b. Divisions
 - Pyramids _ 8-15
 - Columns

B. Urine Collecting Structures

1. Calyces
 - a. Minor
 - One per pyramid _ funnel-shaped
 - Receives urine from papillary ducts [*later*]
 - b. Major _ confluence of several minor
2. Pelvis _ receives major calyces
3. Ureter
 - a. Tube from narrowing of pelvis
 - b. Exits kidney through hilus
 - c. Represents duct for entire kidney
 - d. Takes urine to bladder
4. Blood vessels
 - a. Renal artery & vein

- b. Interlobar arteries & veins
 - Branches from renals
 - Run through columns
- c. Arcuate arteries & veins
 - Perpendicular branches from interlobars
 - Run along cortical-medullary border
- d. Interlobular arteries & veins
 - Perpendicular branches from arcuates
 - Run through cortex outwardly
- e. Intralobular arteries & veins
 - Branches from interlobulars
 - Run through cortex laterally

Microscopic Kidney Structure

A. Nephron

1. General

- a. Basic structural & functional unit
- b. 1.5 million per kidney
- c. Essentially a tubular glandular unit
- d. 2 types
 - Cortical
 - Majority
 - Shorter _ 35 mm
 - Mostly within cortex
 - Juxtamedullary

- Longer _ 50 mm
 - Over half its length runs through pyramid, almost to apex (papilla)
2. Bowman's (renal) capsule
 - a. Double-walled rounded cup-like
 - b. 200 μm across
 - c. Squamous parietal wall
 - d. Visceral wall of unique podocytes _ cling to & follow contours of enclosed glomerulus [*not part of nephron per se -- later*]
 - e. Beginning portion
 3. Proximal convoluted tubule
 - a. About 15 mm (L) x 60 μm (D)
 - b. Simple cuboidal cells with microvilli
 - c. Completely within cortex
 4. Thick descending (straight proximal) tubule
 - a. About 2 mm (L) x 30 μm (D)
 - b. Low cuboidal cells with microvilli
 - c. Enters medulla in juxtamedullary nephrons
 5. Loop of Henle (thin portions)
 - a. General
 - About 5-15 mm (L) x 15 μm (D)
 - Longer in juxtamedullary nephrons
 - Squamous cells
 - b. Descending portion _ longer

- c. Ascending portion _ shorter
- 6. Thick ascending (straight distal) tubule
 - a. About 7 mm (L) x 60 μ m (D)
 - b. Cuboidal cells with short microvilli
 - c. Runs back into cortex
- 7. Distal convoluted tubule
 - a. About 10 mm (L) x 60 μ m (D)
 - b. Cuboidal cells with sparse (beginning) to no microvilli (end)
 - c. Last portion of nephron

B. Excretory Ducts

- 1. General
 - a. Take liquid from nephron
 - b. Chemical adjustments to produce final urine
 - c. Pass urine to minor calyces
 - d. Total length of one pathway of this highly branched & interconnected complex _ 20 mm
- 2. Collecting tubule
 - a. Begins at end of distal convoluted tubule
 - b. Same diameter as DCT
 - c. Simple cuboidal cells
- 3. Collecting ducts
 - a. Smallest formed by confluence of several collecting tubules
 - b. Several levels of branching _ to larger ducts

- c. Up to 100 μm diameter
 - d. Cells from simple cuboidal to simple columnar
4. Papillary duct (of Bellini)
- a. Largest ducts _ confluence of several of largest collecting ducts
 - b. 200 μm diameter
 - c. 10-25 per papilla of a pyramid
 - d. Final ducts - empty into minor calyx

C. Capillaries & Arterioles

1. General
- a. Supply nephron with blood for filtering
 - b. Receptacle for reabsorbed substances
 - c. Source for secreted substances
2. Glomerulus
- a. Balled-up capillary bed
 - b. Nestled within Bowman's capsule _ tightly adherent to visceral wall
 - c. Special lining squamous cells _ fenestrated & extremely permeable
3. Afferent arteriole
- a. Branches from intralobular artery
 - b. Joins glomerulus
4. Efferent arteriole
- a. Joins opposite end of glomerulus

- b. Carries blood from glomerulus
 - c. Exception to venule draining capillaries
 - d. Smaller than afferent
5. Peritubular capillaries
- a. Capillary bed surrounding cortical nephron portions
 - b. Variations in 2 nephron types
 - Cortical _ around straight proximal & distal, & most of thin loop of Henle
 - Juxtamedullary _ only around convoluted portions
 - c. Receive blood from efferent arterioles
 - d. Join venules which lead to intralobular vein
6. Vasa recta
- a. Only in association with juxtamedullary nephrons
 - b. Origin from efferent arterioles, just like peritubular
 - c. Descend into medulla, paralleling straight tubule portions & thin loop of Henle
 - d. Hairpin turn, just like loop of Henle
 - e. Lateral interconnections among vasa recta form plexuses in medulla
 - e. Join same venules as peritubular capillaries

D. Renal (Malpighian) Corpuscle

- 1. Concept _ term applied to glomerulus & the attached Bowman' capsule which surrounds it
- 2. Significance _ represents vital link between nephron & its initial blood supply

URINE FORMATION

Filtration

A. Introduction

1. Location _ renal corpuscles
2. Concept
 - a. Filtration (diffusion under pressure) of substances from blood circulating through glomerulus into capsular space of nephron.
 - b. Involves passage through glomerular endothelium, a basement membrane & the capsule's visceral wall of podocytes.
3. Significance
 - a. Rapid removal of diffusible substances from blood
 - b. No selectivity as to importance _ basically just size
 - c. Later, more leisurely selective processes in other parts of nephron

B. Ultrafiltrate

1. Concept _ filtrate contains same concentration of substances as blood
2. Significance _ this direct quantitative reflection permits kidneys to accurately determine the homeostatic fates of the various substances
3. Exclusions _ non-permeable materials
 - a. Formed elements

- b. Plasma proteins
- c. Lipids _ e.g. cyclomicrons

C. Physical Mechanisms

1. Glomerular endothelium
 - a. Many large fenestrations
 - b. Only formed elements not permeable
2. Basement membrane
 - a. Ionized _ highly negative
 - b. Repels plasma proteins _ negatively ionized
3. Visceral wall of capsule
 - a. Podocytes
 - Branching major & minor processes _ wrap around glomerulus
 - Terminal _ feet (pedicels)
 - Feet from different podocytes interdigitate
 - b. Diffusion through gaps between feet

D. Pressures Responsible

1. Blood
 - a. Glomerular hydrostatic (blood) pressure at afferent arteriolar end about 60 mmHg
 - b. Much higher than body's other capillaries
 - c. This force necessary to drive filtration
2. Colloid osmotic

- a. From blood's non-diffusible plasma proteins _ about 25 mmHg
 - b. Opposes blood pressure & filtration
3. Capsular hydrostatic
- a. From filtrate constantly within capsule, between visceral & parietal walls _ about 10 mmHg
 - b. Opposes filtration
4. Net filtration pressure
- a. Blood - (colloid osmotic + capsular)
 - b. $60 \text{ mmHg} - (25 \text{ mmHg} + 10 \text{ mmHg}) = 25 \text{ mmHg}$

E. Rate

1. Basic
 - a. 125 ml/min from all nephrons in both kidneys
 - b. 180 L per day
 - c. Represents 20% of the plasma
2. Variations
 - a. Sex _ lower in women
 - b. Variable under different conditions in same person

F. Unique Variables

1. General _ necessary to form sufficient filtrate quickly
2. To maintain high net filtration pressure
 - a. Glomerulus between 2 arterioles
 - Only place in body
 - Efferent (2nd) arteriole's resistance helps maintain

higher pressure than venule would

- b. Difference in afferent/efferent diameters
 - Efferent smaller
 - Increased resistance to flow raises pressure
 - c. Renal blood pressure _ higher than other organs
3. Permeability _ glomerular endothelium 100x more than other capillaries

Reabsorption

A. Introduction

- 1. Concept _ selective removal of substances from filtrate
- 2. Amount _ of 180 L/day filtrate, only 1.0-1.8 L urine
- 3. Locations
 - a. From filtrate in rest of nephron & collecting lumen _ mostly proximal
 - b. To interstitial (tissue) fluid around nephron
 - c. Into peritubular capillaries & vasa recta to be carried away
- 4. Significance
 - a. Filtration was massive, but nonselective
 - b. Reabsorption determines urine composition _ mostly [*secretion later*]
 - c. Not inefficient, despite having to reverse most of filtration _ [*evidence later -- counter-current*]

B. Water

- 1. General

- a. Normally 97-99% reabsorbed from filtrate
- b. 65% from proximal convoluted & straight

2. Obligatory

- a. This must be reabsorbed
- b. Majority _ from proximal
- c. Passive _ from osmotic gradient created by reabsorption of solutes from filtrate [*details later*]

3. Facultative

- a. Variable amounts, depending on homeostatic needs
- b. From distal convoluted & collecting
- c. Controlled by ADH
 - Permeability in direct proportion
 - Reason for osmotic gradient [*later -- counter-current*]
- d. Diabetes insipidus
 - Absence of ADH
 - Excretion of 15-20 L/day of mostly aqueous urine

C. Minerals

1. Sodium

- a. 99% reabsorbed from filtrate
- b. Mechanisms
 - Actively transported from tubule cell cytoplasm into interstitial fluid
 - Concentration gradient causes diffusion from tubule lumen _ most facilitated by carrier, which makes it more efficient

c. Significance

- Its movement is basis for co-transport of other solutes & part of osmotic reabsorption of water
- Central role in counter-current mechanism [later]

d. Variations in nephron segments

- Proximal _ as described above
- Distal _ variable
 - Less permeable cell membranes
 - Hormonal control _ aldosterone

2. Chloride

a. 99% reabsorbed

b. Mechanisms

- Most directly follows sodium, to maintain electrical balance
- Some by co-transport

3. Potassium

a. Some reabsorbed

b. Mechanisms

- Due to Na^+/K^+ pump, transported opposite sodium _ into tubule cells from interstitial fluid
- Tends to diffuse back out through sides at intercellular junctions, though

4. Calcium

a. Most reabsorbed

b. Mechanism _ co-transport

5. Magnesium

- a. Some reabsorbed
- b. Mechanism _ co-transport

6. Bicarbonate

- a. Almost all reabsorbed
- b. Mechanism _ complicated
 - Tubule lumen _ CO₂ diffuses out
 - In cell _ CO₂ + H₂O = H₂CO₃ = H⁺ + HCO₃⁻
 - Bicarbonate into interstitium by co-transport

7. Others

- a. Phosphate, sulfate & nitrate _ some reabsorbed
- b. Mechanism _ co-transport

D. Nitrogenous Wastes

1. Urea

- a. 50% reabsorbed
- b. Mechanism _ passive, follows water

2. Urate

- a. 98% reabsorbed
- b. Mechanism _ co-transport

3. Creatinine

- a. None is reabsorbed
- b. [see below -- secretion]

E. Organic Nutrients

1. General
 - a. Glucose, amino acids, vitamins (water soluble), & ketone bodies
 - b. Normal amounts completely reabsorbed _ vital
 - c. Mechanisms
 - Co-transport from lumen into tubule cells
 - Facilitated diffusion from cells into interstitium
2. Proteins
 - a. Completely reabsorbed
 - b. Mechanism _ special handling, since non-permeable
 - From tubule lumen by pinocytosis
 - Hydrolyzed into amino acids _ now handled as already described
3. Sucrose, oxalates & citrates

None reabsorbed

Secretion

- A. Introduction
 1. Concept
 - a. Addition to filtrate of substances which were not filtered
 - b. Opposite direction from reabsorption
 - From peritubular capillary blood
 - Into interstitial fluid

- Enters tubule lumen

2. Locations

- a. Distal convoluted tubule
- b. Collecting tubule & duct

3. Significance

- a. Permits maximum excretion of certain substances, making up for ultrafiltrate inadequacy
- b. Some toxic substances cannot be filtered

B. Substances

1. Ammonia

- a. Too toxic for body fluids
- b. NH_3 + glutamic acid = glutamine (nontoxic)
- c. DCT reverses reaction

2. Hippuric acid

- a. Benzoates _ toxic
- b. Benzoic acid (e.g.) + glycine = hippuric acid (nontoxic)
- c. DCT reverses reaction

3. Creatinine

- a. None was reabsorbed _ secretion adds to amount excreted in urine
- b. Mechanism _ active transport

4. Potassium & hydrogen

- a. DCT & collecting tubules
- b. Mechanisms

- Counter-transport _ earlier portions

- From active sodium reabsorption
 - More negative tubule lumen attracts positive ions
 - Active transport _ latter portions
 - K^+ _ aldosterone control
 - H^+ _ special cells, for pH homeostasis
5. Others
- a. e.g. _ organic acids & bases; neurotransmitters
 - b. Mechanism _ active transport
6. Abnormal
- a. e.g. _ drugs
 - b. Mechanism _ active transport

Counter-current Mechanism

A. Introduction

1. Urine/filtrate difference
 - a. Urine typically hyperosmotic to original filtrate
 - b. Most water usually needed in body fluids
2. Progressive concentration
 - a. Would seem to occur from capsule to collecting
 - b. Not possible
 - Would require active transport of water
 - Osmotic gradient 900x greater than exists
3. Variable filtrate osmotic conditions

[all will be compared with original capsular filtrate]

- a. Isosmotic (no change) _ PCT & thick descending
- b. Hyperosmotic (more concentrated) _ loop of Henle
- c. Isosmotic (same as filtrate) _ thick ascending
- d. Hypoosmotic (more dilute) _ DCT
- e. Hyperosmotic _ latter DCT & collecting

4. Significance

- a. Permits concentration of solute wastes
- b. Conserves water
- c. Accomplished via simple fluid principles
- d. Variable due to hormonal influences _ more dilute urine can be produced if excess water excretion needed [*later*]

B. Underlying Principles

1. Concentration gradients

- a. Increased when going from cortex into medulla
- b. Decreased when going from medulla into cortex

2. Innate behavior from physical relationships

a. Physical setup

- Parallel tubes
- Hairpin connections
- Solution flowing in opposite directions
- Semipermeable walls
- Fluid surrounding tubes

b. Results

- Setup will cause a small concentration difference to be multiplied continuously through the tubes
- Must be this type of setup for production of concentrated urine _ straight, or differently configured tubes would work poorly or not at all

3. Gradient maintenance

a. Loop of Henle

- Establishes gradient
- From descending/ascending differences [later]

b. Vasa recta

- Maintains gradient established by loop
- Own separate counter-current multiplier _ coordinated with nephron/collecting, though

c. Collecting tubule & ducts

- Finish the process, producing final urine
- Variable, due to ADH [later]

4. Osmotic counter "currents"

a. Entire mechanism based on osmotic currents

b. Created by continuously circulating filtrate, interstitial fluid & blood _ form positive feedback loops

c. Opposite currents in descending & collecting as compared with ascending

d. Opposite currents in ascending & descending limbs of vasa recta

C. Mechanisms of Action

1. Proximal convoluted tubule
 - a. Results
 - 65%+ volume reduction of capsular filtrate
 - Proportional, though _ isosmotic to filtrate
 - b. Events
 - Active sodium (with chloride) reabsorption
 - Passive osmosis of water _ follows sodium
2. Ascending thin & thick
 - a. This is the next logical step
 - Filtrate itself is next in descending portions
 - Ascending events control those in descending
 - b. Results
 - Change to isosmotic _ was hyper- at bottom of loop
 - Hypoosmotic by DCT
 - c. Events
 - Active chloride (with sodium) transport out
 - No osmosis follows _ impermeable to water
3. Descending thick & thin
 - a. Results _ very hyperosmotic by bottom of loop
 - b. Events
 - Sodium diffuses in
 - Water diffuses out by osmosis
 - c. Cause _ hyperosmotic medullary fluid [*later*]
4. Distal convoluted & collecting tubules
 - a. Results

- Progressively less hypoosmotic
 - Variable _ from hypo- to hyperosmotic
- b. Events
- Osmosis out _ no longer impermeable
 - ADH responsible for variable amount _ direct proportion
- c. Causes
- Active sodium (with chloride) transport out
 - Hyperosmotic medullary fluid attracts water
5. Medullary tissue fluid
- a. Result
- Perpetually kept hyperosmotic
 - More hyperosmotic higher to lower
- b. Causes
- Active salt transport out of ascending
 - Active salt transport out of collecting
 - Passive salt transport out of thin descending
 - Passive urea transport out of collecting _ follows water
 - Vasa recta leaves behind excess sodium [later]
6. Vasa recta
- a. Result _ prevents medullary blood from removing excess solutes
- b. Causes
- Sluggish blood flow _ only 1-2% of kidney total

- Counter-current exchange mechanism
 - Removes excess water from medulla _ recall diffusion from descending
 - Leaves behind excess sodium

D. Summary

1. Production of concentrated urine
 - a. Basic counter-current mechanism
 - b. Increased ADH
2. Production of dilute urine
 - a. Basic counter-current mechanism
 - b. Decreased ADH

URINE COMPOSITION

[from laboratory work -- note the Study Questions]

MICTURITION

A. Concept

1. Expulsion of urine from the bladder

2. Commonly termed urination or voiding

B. Mechanisms

1. Muscles

- a. Detrusor _ general smooth muscle of bladder wall
- b. Internal urethral sphincter
 - Smooth muscle
 - Around beginning of urethra
- c. External urethral sphincter
 - Skeletal muscle
 - Below internal sphincter
- d. Rectus abdominis

2. Volumes

- a. 200-300 ml _ threshold for initiation
- b. 500 ml
 - Total effective capacity
 - Very little ability to retain more without considerable discomfort

3. Pressure receptors

- a. Within bladder wall
- b. Respond to stretch from filling
- c. Impulses to sacral segments of spinal cord
- d. Initiate reflex muscle responses eventually leading to micturition
- e. May completely occur locally _ brain may intervene

4. Muscle responses

a. Detrusor

- Parasympathetic impulses from spinal cord
- Wave-like rhythmic contractions
 - Towards urethral outlet
 - Periodic & widespread until maximum capacity reached

b. Internal sphincter

- Remains contracted via sacral reflex to prevent micturition
- Relaxation under different conditions
 - <500 ml _ only when external sphincter relaxed
 - >500 ml _ from intense detrusor contractions

c. External sphincter

- Remains contracted via sacral reflex _ inhibition causes relaxation
- Relaxation under different conditions
 - <500 ml _ conscious decision
 - >500 ml _ unconscious, along with internal sphincter

d. Rectus abdominis

- Contracted to increase intra-abdominal pressure
- Pressure on full bladder assists

5. Brain centers

a. Cerebral cortex

- Responsible for learned reflex which contracts

external sphincter

- Initiates conscious relaxation of external sphincter for micturition
- Can override spinal micturition reflex, if volume not extreme

b. Brainstem

- Pons & medulla
- Unconscious facilitation or inhibition of spinal reflex

C. Pathology

1. Incontinence

a. Concept

- Loss of bladder control
- From slight to inability to retain any urine

b. Normal in infants _ insufficient development of nervous pathways between brain & sacral cord

c. Abnormal

- Several sites of damage _ bladder, cord or brain
- Would determine severity

2. Retention

a. Concept _ inability to void

b. Causes

- Obstruction
- Spasmodic sphincter contraction
 - Nerve damage
 - Psychological factors _ e.g. stress

FLUID BALANCE & DYNAMICS

Blood Pressure Regulation _ Urinary Related

A. Autonomic Nervous Control

1. General

- a. Affects kidneys only _ rest of body unaffected
- b. Sympathetic division alone _ parasympathetic not utilized to produce opposite effects

2. Pressure increase

- a. Moderate impulse level
- b. Afferent & efferent constricted proportionately
- c. Vasoconstriction raises glomerular pressure

3. Pressure decrease

- a. Intense impulse level
- b. Afferent more constricted than efferent
- c. Arteriolar diameters closer to the same
- d. Pressure lowered _ size disparity negated

B. Autoregulation

1. General

- a. Local _ not from outside (e.g. nervous) influences
- b. Purpose _ maintains constant effective filtration rate
- c. Mechanism

- Involves nephron & arterioles
 - Accomplished chemically
- d. Significance
- More important than nervous
 - More attuned to needs
2. Structure _ juxtaglomerular apparatus (JGA) or complex
- a. Indistinct _ merger of 3 parts of larger structures
- First part of distal convoluted tubule
 - Afferent arteriole
 - Efferent arteriole
- b. Each JGA from parts of same nephron/corpuscle
- c. Modified cells in wall of contact areas
- Macula densa _ distal tubule
 - Juxtaglomerular cells _ arterioles
3. Mechanisms
- a. Sodium & chloride levels monitored _ distal filtrate
- Too low if insufficient filtration pressure _ too much reabsorption in ascending
 - Too high if excessive filtration pressure _ insufficient reabsorption in ascending
- b. To increase pressure & filtration rate
- Afferent arteriole dilated by macula densa
 - Efferent arteriole constricted by juxtaglomerular cells _ indirect
 - Increased renin secretion into blood

- Plasma angiotensinogen converted to angiotensin
 - Angiotensin targets efferent arteriole
- c. To decrease pressure & filtration rate
- Afferent arteriole constricted
 - Efferent arteriole dilated

C. Systemic Control

1. General

- a. Overall BP changes throughout body
- b. Kidneys affected as well
- c. Sympathetic & autoregulation can counteract

2. Causes

- a. Cardiac output influences on BP
- b. Peripheral resistance _ e.g. widespread autonomic
- c. Respiratory needs requiring BP adjustments

Osmotic Pressure Regulation

A. Scope

- 1. Affects the entire body
- 2. Important homeostatic mechanism _ controls ECF/ICF interchanges
- 3. Intricate & interrelated _ very simple consideration here

B. Increases

1. Concept _ hyperosmotic condition in body fluids
2. Causes
 - a. Solute retention
 - Ingestion _ more salt (solute) intake
 - Kidney diseases _ excessive reabsorption
 - Hormonal
 - Hyperglycemia
 - Aldosterone hypersecretion & no ADH change _ usually vary together
 - b. Water loss
 - Ingestion _ too little intake
 - Fluid loss _ solutes lost as well, but water causes more dramatic effects
 - Diarrhea
 - Vomiting
 - Excess sweating
 - Hormonal
 - Hyperglycemia _ water drawn from tissues
 - Hyposecretion of ADH _ diabetes insipidus

C. Decreases

1. Concept _ hypoosmotic condition in body fluids
2. Causes
 - a. Solute loss
 - Ingestion _ insufficient salt (solute) intake

- Kidney infection _ e.g. glomerulonephritis
- Hormonal
 - Hypoglycemia
 - Aldosterone hyposecretion
- b. Water retention
 - Ingestion _ excess intake
 - Kidney failure
 - Hormonal _ ADH hypersecretion

D. Control Mechanisms

1. Osmoreceptors
 - a. Within hypothalamus
 - b. Monitor osmotic pressure of body fluids
 - c. Activity level
 - Hyperosmotic causes more activity
 - Hypoosmotic causes less activity
2. Antidiuretic hormone (ADH)
 - a. Secreted by hypothalamus
 - b. Stored within pars nervosa
 - c. Amounts
 - More from increased osmoreceptor activity
 - Less from decreased osmoreceptor activity
3. Water reabsorption
 - a. In DCT & collecting tubules/ducts

- b. Direct proportion with ADH amount
 - More reabsorption dilutes hyperosmotic body fluids
 - Less reabsorption excretes excess water from hypoosmotic body fluids
- 4. Drinking center
 - a. Within hypothalamus
 - b. Controls thirst
 - c. Precise amount needed consumed
 - Immediate relief _ prevents further desire
 - Takes 30⁺ min. for ingested water to actually dilute body fluids, though

Extracellular Fluid Volume Regulation

- A. Scope
 - 1.
 - 2. *[same as for osmotic pressure]*
 - 3.
 - 4. Not any particular component of fluids as in osmotic changes _ the water is of critical importance, though
- B. Increases
 - 1. General _ all produce solute and water retention
 - 2. Ingestion
 - a. Increased solutes & water
 - b. Malnutrition
 - 3. Hormonal _ aldosterone & ADH hypersecretion

4. Kidney diseases _ e.g. chronic renal failure (insufficiency)
5. Cardiovascular diseases
 - a. Hypertension
 - b. Congestive heart failure
6. Drugs
 - a. All would increase ADH
 - b. e.g. _ nicotine, morphine, barbiturates, anesthetics

C. Decreases

1. General _ caused by any general body fluid loss
2. Ingestion _ general decrease (e.g. undernourishment)
3. Hormonal _ aldosterone &/or ADH hyposecretion
4. Diseases
 - a. Kidney reabsorptive deficiencies
 - b. Systemic infections
5. Fluid losses
 - a. Excessive sweating or severe burns
 - b. Vomiting or diarrhea
 - c. Hyperventilation
6. Drugs
 - a. All diuretics
 - b. e.g. _ alcohol, caffeine, lithium

D. Control Mechanisms [Example of fluid volume decrease]

1. Sodium reabsorption
 - a. Renin _ secretion from JGA
 - b. Angiotensin I _ renin converts from angiotensinogen
 - c. Angiotensin II
 - More active form
 - Derived from angiotensin I
 - Converted by lung enzyme
 - d. Aldosterone
 - Secretion stimulated by angiotensin II
 - Increased sodium/chloride reabsorption
 - e. Atrial natriuretic factor
 - Secreted by heart wall
 - Proportionate with blood volume
 - Inhibits sodium/chloride reabsorption
 - f. Salt appetite
 - Hypothalamic center
 - Regulates desire to consume salt
 - More active under 2 body fluid conditions
 - Less sodium concentration
 - Decreased fluid volume

2. Water reabsorption
 - a. Osmoreceptors
 - Detect hyperosmotic body fluids
 - Gradient purposely caused by sodium/chloride

reabsorption

- b. ADH
 - Secretion increased
 - Water reabsorption increased
 - Counteracts hyperosmolality
 - Increases body fluids _ ultimate goal

Electrolyte Balance

A. General

- 1. Scope
 - a. Principal ions only
 - b. Others important _ e.g. phosphate, sulfate
- 2. General effects
 - a. Determine water distribution in body
 - b. Acid-base balance
 - c. Cell membrane irritability _ nerve & muscle

B. Potassium

- 1. Functions _ principal intracellular cation
 - a. Cytoplasmic osmotic pressure maintenance
 - b. Membrane electrical potentials _ nerve & muscle
 - c. Enzyme activation
- 2. Influences upon potassium
 - a. Aldosterone

- Sodium reabsorption causes potassium secretion
- Excess potassium increases aldosterone
- b. pH
 - Acidosis causes more K^+ reabsorption
 - To cause secretion of H^+ via ion exchange
- c. Sodium
 - Basically moves opposite from potassium
 - Kidneys handle Na^+ better _ if both low, it is more reabsorbed

C. Sodium

1. Functions _ principal extracellular cation
 - a. Extracellular osmotic pressure maintenance _ tissue fluid & blood
 - b. Sodium pump
 - Establishes basic membrane gradients
 - Permits transport of other substances
 - c. Membrane electrical potentials _ nerve & muscle
2. Influences upon sodium
 - a. Aldosterone _ [*previously covered*]
 - b. Atrial natriuretic factor _ [*previously covered*]
 - c. Glomerular filtration rate (GFR)
 - Indirect proportion for GFR : sodium excretion
 - Conserves sodium when filtration in excess

- d. Other solutes _ glucose (e.g.)
 - Hyperglycemia leads to glycosuria
 - Sodium displaced by glucose
 - More sodium excretion than desirable

D. Calcium

- 1. Functions _ most abundant cation (most in bones)
 - a. Stabilizes membranes
 - b. Regulates muscle contraction _ intracellularly
 - c. Enzyme regulation _ as co-factor
 - d. Adherence of adjacent cells
- 2. Influences upon calcium
 - a. Hormonal
 - PTH _ [*previously covered*]
 - Thyrocalcitonin _ [*previously covered*]
 - b. Digestive absorption
 - Vitamin D enhances
 - Phosphates inhibit
 - c. Excretion
 - Most via feces _ vitamin D & phosphate control
 - Some via urine _ handled like sodium, under PTH influence

E. Magnesium

- 1. Functions _ equally distributed
 - a. Membrane stabilization _ nerve & muscle

- b. Enzyme co-factor _ e.g. ATPase & peptidases
 - c. Calcium antagonist _ often
2. Influences upon magnesium
- a. Hormonal
 - T_3 , T_4 , GH & PTH _ [*previously covered*]
 - Via movements in/out of cells & bones
 - b. Excretion
 - Most reabsorbed _ PTH control
 - Direct nephron effect _ excess excreted

F. Chloride

1. Functions _ principal extracellular anion
- a. Counteracts cations
 - b. Osmotic pressure maintenance
 - c. Acid-base balance _ usually via HCl
2. Influences upon chloride
- a. Sodium _ follow each other (except nerve/muscle)
 - b. Digestive _ part of gastric HCl
 - c. Bicarbonate
 - Normally balance each other
 - Excess Cl^- loss (e.g.) _ alkalosis

Acid-Base Balance

A. Extracellular Buffering System

1. Dual function _ absorbs excess ions of opposite types
 - a. Acidic _ H^+
 - b. Basic _ e.g. OH^-
2. Systems utilized
 - a. Bicarbonate _ mixture of H_2CO_3 & $NaHCO_3$
 - b. Phosphate
 - c. Protein
3. Mechanism _ using bicarbonate system
 - a. Acid buffering
$$HCL + NaHCO_3 = H_2CO_3 + NaCl$$
 - b. Basic buffering
$$NaOH + H_2CO_3 = NaHCO_3 + H_2O$$

B. Lung Excretion

1. Frees CO_2 from blood in carbonic acid form
2. Dysfunctions
 - a. Respiratory acidosis
 - From hypoventilation
 - Normal correction _ breathing control system increases ventilation
 - b. Respiratory alkalosis
 - From hyperventilation
 - Uncommon

C. Kidney Excretion

1. Bicarbonate _ adjusted by varying reabsorption
2. Hydrogen
 - a. Exchanged for sodium [*previously covered*]
 - b. Secondary frees bicarbonate which was utilized for neutralizing H^+ in body fluids
 - c. H^+ neutralized within urine
 - Combined with phosphate
 - Combines with ammonia _ ties up potentially harmful ammonia as well