The Urinary System

Urine production and elimination are one of the most important mechanisms of body homeostasis

all body systems are directly or indirectly affected by kidney function

eg. composition of blood is determined more by kidney function than by diet

main function of kidneys is to get rid of metabolic wastes

→typically referred to as "**excretory system**"

excretory wastes = **metabolic wastes**

→ chemicals & toxins produced by cells during metabolism

General Functions of Urinary System:

1. removal of **metabolic wastes** & **toxins**

but we have several organs that serve an **excretory function** other than kidneys:

1. **kidneys**
2. **skin**
   sweat glands rid body of water, minerals, some nitrogenous wastes (ammonia)
3. **lungs**

rid body of CO_2 from energy metabolism of cells

4. **liver**
   liver excretes bile pigments, salts, calcium, some toxins

2. elimination of excess nutrients & excess hormones

3. helps to regulate **blood volume** & **pressure**

blood pressure is directly affected by the volume of fluids retained or removed from body:

eg. excessive salts promote water retention
greater volume → increases BP

eg. dehydration
lower volume → decreases BP

4. regulation of **electrolytes** & body **pH**

5. regulates **erythropoiesis**

kidneys produce hormone = **erythropoietin** that regulates erythropoiesis:

hypoxic → secretes more erythropoietin
excessive O_2 inhibits hormone production

6. aids in **calcium absorption**

affects the absorption of Calcium from intestine by helping to activate Vitamin D circulating in blood

Anatomy of Urinary System

Organs:
kidneys – clean and filter blood
ureters – tubes that take urine to bladder
bladder – stores urine until eliminated
urethra – removes urine from body

1. kidneys

dorsal body wall

retroperitoneal → behind parietal peritoneum

just above waist

surrounded by **renal capsule**

→ barrier against trauma and spread of infections

hilum = indentation where vessels and ureter attach

Frontal Section of Kidney

cortex
outer zone of kidney

medulla
interior of kidney

extensions of the cortex = **renal columns**
divides the medulla into 6-10 **renal pyramids**

papilla of each pyramid nestled in cup shaped **calyces**

calyces converge to form **renal pelvis**

2. ureters

the rest of urinary system is "plumbing"

renal pelvis funnels urine to paired **ureters**
→tubular extensions of renal pelvis

peristalsis moves urine along to bladder

3. bladder

small, size of walnut when empty

can hold up to 800 ml (24 oz) voluntarily
up to 2000 ml (60 oz) when obstructed

wall consists of 4 layers (same as GI tract)

mucosa -innermost layer

secretes mucous for protection from corrosive effects of urine

submucosa -fibrous connective tissue

muscularis -several smooth muscle layers

serosa -visceral peritoneum

involuntary **internal** & voluntary **external urethral sphincters**

as bladder expands to hold urine

→ activates stretch receptors in wall that monitor volume

→ when volume exceeds 200 ml the receptor signals enter our conscious perception = desire to urinate

4. urethra

male:

dual function:

→ rid body of urine
→ release of seminal fluid during orgasm

female:

single function: rids body of urine

shorter

→ more prone to UTI's

Histology of Kidney

nephron = functional units of kidneys

each kidney is composed of over 1 million nephrons

two basic parts:

1. **nephric tubule**
   = microscopic, highly convoluted tubule
2. associated **blood supply**

can find various parts of the nephron and its blood supply in the **cortex** and **medulla** of kidney

Nephric Tubule

the nephric tubule is organized into several discrete structures:

Bowman's Capsule
cup shaped mouth of nephron
usually in cortex

Proximal Convoluted Tubule
attached to Bowman's Capsule
highly coiled (convoluted)
inner surface contains microvilli

Loop of Henle
large loop consisting of:
descending limb & ascending limb
extends down into medulla

Distal Convoluted Tubule
appears similar to PCT

Collecting Tubule
many DCT's drain into one collecting tubule
bundles of collecting tubules = **pyramids**

Pyramids drain into **Calyces** (sing. = **calyx**)

Calyces coalesce to form **pelvis**

Blood Supply

kidneys are highly vascularized

every minute, 1200 ml/min of blood flows through kidneys

→=1/5th of cardiac output

45 gallons/day; all blood ~60x's/day

more blood perfuses the kidney per weight than any other organ

(much more than eg. brain, heart, liver, etc)

within the kidney, bloodflow is greatest in the cortex where glomeruli are located; flow decreases with depth in the medulla

Renal Artery

brings blood to kidney

→branches eventually into afferent arterioles

Afferent Arteriole
bring blood to individual nephrons

Glomerulus
dense capillary bed
formed by afferent arteriole
inside Bowman's capsule

Bowman's Capsule + Glomerulus = Renal Corpuscle

Efferent Arteriole
blood leaves glomerulus via efferent arteriole
[→ artery→capillary bed→ artery]

Peritubular Capillaries
efferent arteriole divides into another capillary bed
surrounds the rest of the nephric tubule
(PCT-LH-DCT-CT)

Renal Vein
returns blood to vena cava

Urinary Physiology

urine formation in nephrons occurs by:
1. **filtration**
2. **reabsorption**
3. **secretion**

1. **Filtration**

occurs in **renal corpuscle**:

Glomerulus → Bowmans Capsule

water, salts, small molecules and wastes are filtered out of blood

capillaries of glomerulus:

fenestrated capillaries
→ act like sieve
molecules less than 10,000MW

have **higher filtration pressure** than other capillaries of body

afferent arteriole is larger than efferent arteriole

→ increases pressure in glomerulus
pressure ~55mmHg

(vs 35mmHg in most capillaries)

kidneys can maintain a fairly constant filtration rate

→ changes in arterial pressure from 80 to 180 mmHg produce little change in blood flow and filtration rate in glomerulus

if blood pressure is reduced below this urine formation slows down

filtrate is essentially the same composition as **plasma** without formed elements or proteins

solutes (filtrate) enter Bowmans capsule

2. **Tubular Reabsorption**

urine is not the same composition as this filtrate

Composition of Plasma, Filtrate & Urine
(solids in grams/24hrs; water in liters/24 hrs)

	Plasma	Filtrate	Reabsorbed Amount	Reabsorbed %	Urine
Proteins	8,000	15	15	100.0%	0
Glucose	180	180	180	100.0%	0
Salts	1,498	1,498	1,486	99.1%	12
Water	180	180	178	99.2%	1.5
Urea	50	50	25	50.0%	25
Uric Acid	8	8	7.2	90.0%	0.8
Creatinine	1.5	1.5	0	0.0%	1.8

most of the filtrate is reabsorbed

overall, ~99% of glomerular filtrate gets reabsorbed
→only ~1% of original filtrate actually leaves the body as urine

→reabsorption is more selective

needed nutrients are conserved
wastes and toxins are eliminated
blood levels of fluids, salts, acidity etc are actively regulated

main metabolic wastes removed by kidneys are "nitrogen wastes":
1. urea
2. uric acid
3. creatinine

1. urea
main nitrogen containing waste produced during metabolism
formed in liver as result of protein breakdown

concentration in urine mainly determined by dietary intake\

2. uric acid
end product of nucleic acid metabolism
some is also secreted by PCT

3. creatinine
normal end product of muscle metabolism

occurs all along nephric tubule

but different substances are reabsorbed back into blood from different parts of tubule:

Proximal Convoluted Tubule

~80% of materials to be reabsorbed are reabsorbed in PCT

cells lining PCT have microvilli

all small proteins, glucose, amino acids are reabsorbed

most water, most salts are reabsorbed

Loop of Henle

additional Cl^+ and Na^+ ions are reabsorbed by active transport

under the control of **aldosterone** (mineralocorticoids)

secretion controlled by salt concentrations in tissue fluids

also affects reabsorption of water (water follows salt)

Distal Convoluted Tubule & Collecting Tubule

additional water is reabsorbed

under control of **ADH** (antidiuretic hormone)

No ADH → tubules are practically impermeable to water

with ADH → tubules are permeable to water

3. Tubular Secretion

cells of DCT and CT can also actively **secrete** some substances

esp K^+ and H^+ HCO_3^-
NH_4
some drugs (eg. penecillin)

usually urine is slightly acidic

→ normal diet produces more acid than alkaline waste products

Urine Analysis

the kidneys perform their homeostatic functions of controlling the composition of internal fluids of body

the by-product of these activities is **Urine**

urine contains a high concentration of **solutes**

in a healthy person, its volume, pH and solute concentration vary with the needs of body

during certain pathologies, the characteristics of urine may change dramatically

an analysis of urine volume, physical and chemical properties can provide valuable information on the internal conditions of the body

Physical Characteristics

eg. Volume

normal = 1000 – 1800ml/day (2-3.5 pints)

influenced by:
- blood pressure
- blood volume
- temperature
- diuretics
- mental state

- general health

eg. Color

normal = yellow-amber (from hemoglobin breakdown)

influenced by:
- ratio of solutes
  - → >solute conc.
    = darker yellow to brownish
  - → <solute conc.
    = less color to colorless
- diet (eg. beets)
- blood in urine

eg. pH

normal urine is slightly acidic: 5.0 - 7.8

influenced by:
- diet
  - eg. high protein → acidic
    vegetables → alkaline
- metabolic disorders:
  - eg. lungs, kidneys, digestive system, etc

eg. Cells and Castings

normal find epithelial cells and some bacterial cells

Bacteria
- < 100-1000/ml = contamination by normal flora
- >100,000/ml = indicates active colonization of urinary system

RBC's & WBC's
- presence is almost always pathological
- inflammation of urinary organs

- pus from infections

Chemical Characteristics

eg. proteins

normally too large to filter out
presence indicates increased permeability of glomerular membrane due to:
- injury
- high blood pressure
- irritation
- toxins

eg. glucose

normally, all is filtered and all reabsorbed
body reabsorbs as much as is needed

when it appears in urine indicates high blood sugar concentrations
→ symptom of diabetes mellitis

eg. ketones

produced when excessive quantities of fats are being catabolized

high quantities may be caused by:
- diabetes
- starvation
- dieting
  - →too little carbohydrates in diet

The Aging Urinary System

kidneys show lots of atrophy in old age
→ from ages 25 to 85; number of nephrons declines by 30 – 40%
→ up to 1/3rd of remaining glomeruli become atherosclerotic, bloodless and nonfunctional

kidneys of 90 yr old man are 20 – 40% smaller than those of a 30 yr old and receive only half as much blood

proportionately less efficient at clearing wastes
→ while renal function remains adequate there is little reserve capacity

reduced renal function is a significant factor in overmedication of the aged
→drug doses often have to be reduced

water balance is more difficult
→ kidneys become less responsive to ADH and sense of thirst is blunted

voiding and bladder control become problematic:
~80% of men over 80 are affected by benign prostatic hyperplasia that compresses the urethra
→ reduces force of urine stream
→ makes it harder to empty bladder

older women become increasingly subject to incontinence
→ esp if pelvic wall muscles have been weakened by pregnancy and childbearing

incontinence can also result from senescence of sympathetic NS

Disorders of Urinary System

Acute or Chronic Renal Failure (or renal insufficiency)

most serious disorder of urinary system

nephrons can regenerate and restore kidney function after short-term injuries or individual nephrons can enlarge to compensate
→ a person can survive with as little as 1/3rd of one kidney

when 75% are lost the remaining cannot maintain homeostasis

result is azotemia and acidosis

may also lead to anemia

Cystitis (=bladder infection)

most are ascending infections→ move up urethra from outside

especially common in women

if untreated bacteria can spread up ureters to cause pyelitis or infection of pelvis

if infection reaches renal cortex and nephrons = pyelonephritis

kidney infections can also result from invasion by blood borne pathogens (=descending infection)

Kidney Stones

=Renal Calculus is a hard granule of calcium, phosphate, uric acid and protein

form in renal pelvis

usually small enough to pass into urine flow

sometimes are up to several centimeters and block pelvis or \ ureter
→ leads to destruction of nephrons as pressure builds in kidney

a large, jagged stone passing down ureter can stimulate strong contractions that can be excruciatingly painful

can also damage ureter and cause hematuria

causes:
hypercalcemia
dehydration
pH imbalances
frequent UTI's
enlarged prostate causing urine retention

(largest stone on record: 3 lbs 16" x14" in body cavity)

Fluid & Electrolyte Balance

body is ~2/3^{rds} water (males=63%; women=52%)

balance means: **input = output**

Inputs

1. **digestive tract**: food and drink

   food ~1200ml/d; beverages ~1000ml/d

2. **metabolism**: each cell produces water in catabolism of glucose

   250-300ml/d

Outputs

1. **urine** (kidneys)

   main loss, ~1500ml/d

2. **lungs**: water vapor expired with air

   at rest skin and lungs loose ~900ml/d

3. **sweat** (skin)

   in hot environment with vigorous exercise can lose up to 4L/h

4. **feces** (intestines)

   normally small losses, ~100ml

output is crucial element in control of fluids and electrolytes

most important output organ is kidney

major control of urine volume is reabsorption of water

reabsorption can be controlled to make output match input

controlled by two major hormones:

ADH
Aldosterone

additional factors that can affect fluid loss:

1. urine volume can also be affected by amount of **solutes** in urine

   → the more solutes the more urine

   Diabetes mellitis
   excess glucose spills over into urine
   causes excess water to enter nephric tubule by osmosis
   results in excessive water loss & dehydration

2. **hyperventilation**

   over extended time can lose significant water from lungs

may result in dehydration

3. excessive **sweating**
   up to 4L/hour

4. prolonged **vomiting or diarrhea**

Electrolyte Composition of Fluids

fluids in the body contain critical electrolytes and other solutes:

cations: Na^{+}; Ca^{++}; K^{+}; Mg^{++}
anions: Cl^{-}; $CHO3^{-}$; $HPO4^{--}$; Proteins

These electrolytes function:

1. essential nutrients or building blocks

2. serve critical role in regulation of various metabolic pathways

3. affecting membrane potentials of muscle and nerve cells

4. control water movement between compartments by affecting osmotic pressures

5. help to regulate pH of body fluids

Water Balance Disorders

eg. dehydration

output > input

caused by:
excessive sweating
water deprivation
chronic diarrhea
excessive vomiting

eg. athletes can lose up to 4l of water/hour but can only safely take in ~2l/hr

Blood loses water → ECF loses water → cells lose water

infants & elderly more likely to suffer dehydration since their kidneys are less able to conserve water

treatment: replace water *and* lost electrolytes

eg. water intoxication

input > output

often happens after dehydration
→ water is taken in too quickly without electrolytes

input → to blood → to tissue spaces → to cells can cause edema as water collects in ISF

causes cells to swell as it moves from tissue spaces into cells

especially affects cells sensitive to ion concentrations: muscle and nerve cells

can result in:
- heat cramps
- convulsions
- confusion
- coma

eg. edema

=abnormal accumulation of water in ECF

caused by:
- decreases in plasma proteins due to
  - liver disease
  - kidney disease
  - starvation
- obstruction of lymphatic vessels
- increased venous pressure
- increased capillary permeability
  - eg. inflammation
    - sunburn

Acid/Base Balance

some of most critical ions in body fluids are H^+ (hydrogen) and OH^- (hydroxyl) ions

the concentrations of these two ions affect the acidity or alkalinity of body fluids

acidity/alkalinity is measured on pH scale
- 1pH unit = 10 fold change in $[H^+]$
- pH of 7 is neutral
- pH < 7: more H^+, fewer OH^-
- pH > 7: fewer H^+, more OH^-

large organic molecules, especially proteins, are extremely sensitive to changes in pH

→ easily denatured

since proteins serve a wide variety of roles in the body (enzymes, fibers, carriers, hormones, oxygen transport, immunity, etc)

variations in pH affect almost every aspect of physiology and cell metabolism

even slight changes in pH can be fatal
- blood = 7.35 – 7.45
- ≤7 or ≥7.8 is fatal

various acids and bases continually enter and leave body:
- in foods and drink
- gastric secretions
- bicarbonates from pancreas

- etc

acids and bases are also made as a normal part of metabolism:

- breakdown of proteins, carbohydrates lipids and nucleic acids produce acids: amino acids, fatty acids, pyruvic acid, etc
- waste products like CO_2 and ammonia are turned into acids in the blood

need some mechanism to neutralize them:

body is protected against large changes in pH in two step process:

1. **buffers** – absorb excess hydrogen or hydroxyl ions to prevent drastic changes in pH
2. **elimination** – acids (or bases) are removed from body by:
   - **kidneys** - can secrete H^+ and HCO_3^-
   - **lungs** – as CO_2 is eliminated H^+ are converted to water
   - **skin** – can excrete some acids in sweat

<u>Buffers</u>

a buffer is a substance that prevents marked changes in pH of a solution when acids or bases are added

eg. 1 drop of HCl in pure water

pH = 7 ⟶ 3.5

1 drop of HCl in plasma

pH = 7.41 ⟶ 7.27

→ blood is buffered

buffers act by combining with strong acids or bases and taking them out of solution

→ "absorbs" the H or OH ions

major buffers in body fluids:
- bicarbonate
- phosphate
- hemoglobin
- plasma proteins

all buffers have limited capacity

→buffering alone cannot maintain homeostasis indefinitely

at some point the acids and bases must actually be removed from the body

two main removal systems:

1. Respiratory Mechanisms
2. Excretory Mechanisms

<u>Respiratory Mechanisms</u>

respiration plays vital role in removing excess acids

with each expiration, CO_2 and therefore H^+ are removed

$$CO_2 + H_2O \xrightarrow{\text{carbonic anhydrase}} H_2CO_3 \longrightarrow H^+ + HCO_3^-$$

pH receptors in arteries can increase or decrease respiratory rate based on buildup of acids in blood

acidosis → stimulates hyperventilation

Excretory Mechanisms

cells of DCT and CT can secrete H^+ & HCO_3^-

if blood pH decreases below normal levels tubules will increase secretion of H^+

more efficient mechanism than respiratory system

usually urine is slightly acidic
→ normal diet produces more acid than alkaline waste products

Acid/Base Imbalances

1. Acidosis
→ accumulation of excess acids
→ excessive loss of bases

a. Respiratory Acidosis
hypoventilation; factors that cause buildup of CO_2 in blood

generally due to factors that hinder pulmonary ventilation

may also be caused by strokes, meningitis and brain tumors

symptoms:
labored breathing
cyanosis
depression of CNS → drowsiness, disorientation
coma → death

can be compensated for by kidneys

b. Metabolic Acidosis
accumulation of non-respiratory acids or excessive loss of bases
eg. poor kidney function
prolonged diarrhea
severe vomiting → loss of duodenal fluids
diabetes mellitis → ketone bodies are acidic

2. Alkalosis
→accumulation of excess bases
→excessive loss of acids

a. Respiratory Alkalosis
caused by **hyperventilation**

hyperventilation causes too much CO_2 to be ventilated causing an increase in pH

anxiety

fever, inflammation and severe liver disease
some poisonings
hyperventilation sometimes accompanies pulmonary diseases such as asthma, pulmonary edema, and pulmonary embolism
maternal hyperventilation often occurs throughout pregnancy possibly caused by effects of hormones on CNS

many underwater swimmers have died when they hyperventilated to try to prolong their time underwater

symptoms:
light headedness
agitation
tingling
dizziness

b. Metabolic Alkalosis
caused by:
gastric drainage (lavage)
prolonged vomiting of stomach contents
too many antacids