Chapter 25
Urinary System

Functions of the Urinary System
1. Excretion:
   – removal of organic wastes from body fluids
2. Elimination:
   – discharge of waste products
3. Homeostatic regulation:
   – of blood plasma volume and solute concentration

Organs
• Kidneys: organs that excrete urine
  – Filter 200 liters of blood daily, allowing toxins, metabolic wastes, and excess ions to leave the body in urine
• Urinary Tract: organs that eliminate urine:
  – ureters (paired tubes, transport)
  – urinary bladder (muscular sac, provides storage)
  – urethra (exit tube)

Urination or Micturition
• Process of eliminating urine
• Contraction of muscular urinary bladder forces urine through urethra, and out of body

Homeostatic Functions of Urinary System
• Regulate blood volume and blood pressure:
  – by adjusting volume of water lost in urine
  – releasing erythropoietin and renin
• Regulate plasma ion concentrations:
  – sodium, potassium, and chloride ions (by controlling quantities lost in urine)
  – calcium ion levels (through synthesis of calcitriol)

Homeostatic Functions of Kidneys
• Help stabilize blood pH:
  – by controlling loss of hydrogen ions and bicarbonate ions in urine
• Conserve valuable nutrients:
  – by preventing excretion while excreting organic waste products
• Assist liver to detoxify poisons
• Gluconeogenesis during prolonged fasting
• Activation of vitamin D
Kidneys

We already covered the anatomy in lab so here I will just highlight a few things.

Already discussed:

- Renal capsule, adipose capsule, renal fascia, hilum
- Cortex, medulla, renal pyramids, renal columns
- Urine flow: Renal papilla, minor calyx, major calyx, renal pelvis, ureter

Position of Kidneys

- Is maintained by:
  - overlying peritoneum
  - contact with adjacent visceral organs
  - supporting connective tissues
- Floating kidney: kidney loses attachments to connective tissue, can twist vessels or ureter

Gross Anatomy of the Urinary System

Internal Anatomy (Frontal Section)

- Cortex – the light colored, granular superficial region
- Medulla – exhibits cone-shaped medullary (renal) pyramids separated by columns
  - The medullary pyramid and its surrounding capsule constitute a lobe
- Major calyces – large branches of the renal pelvis
  - Collect urine draining from papillae
  - Empty urine into the pelvis
- Renal Sinus: internal cavity within kidney, lined by fibrous renal capsule
- Renal Pelvis: flat funnel shaped tube lateral to the hilus
  - Flat, funnel-shaped chamber within the renal sinus consisting of 2 or 3 major calyces
  - Fills most of renal sinus
  - Connected to ureter, which drains kidney

Blood Supply to the Kidneys
Blood Supply to Kidneys

- Kidneys receive 20–25% of total cardiac output
- 1200 ml of blood flows through kidneys each minute
- Arterial flow into and venous flow out of the kidneys follow similar paths
  - Kidney receives blood through renal artery, returns through renal vein

Renal Vasculature

- Renal artery → Afferent Arterioles
  Deliver blood to capillaries supplying individual nephrons
- Efferent Arterioles → peritubular caps and vasa recta → renal vein

Sympathetic Innervation

- Adjusts rate of urine formation by changing blood flow and blood pressure at nephron
- Stimulates release of renin which restricts losses of water and salt in urine by stimulating reabsorption at nephron

Functional Anatomy of Nephron and Collecting System

- Nephron: the structural and functional units that form urine, consisting of:
  - Renal tubule
    - Long, coiled, tubular passageway
  - Renal corpuscle: each is 150–250 µm in diameter
    - Bowman’s capsule (cup-shaped chamber, surrounds glomerulus)
      - Connected to initial segment of renal tubule
      - Forms outer wall of renal corpuscle
      - Encapsulates glomerular capillaries
    - glomerulus (capillary network)
Renal Corpuscle: Anatomy of the Bowman’s Capsule

- Outer wall is lined by simple squamous parietal epithelium continuous with visceral epithelium which covers glomerular capillaries (like pericardium)
- The two layers are separated by a capsular space
- The external parietal layer is a structural layer while the visceral layer consists of modified, branching epithelial podocytes
- Extensions of the octopus-like podocytes terminate in foot processes (pedicels) that wrap around the specialized lamina densa of glomerular capillaries
  - Filtration slits – openings between the foot processes that allow filtrate to pass into the capsular space

Renal Corpuscle: Glomerulus

- Consists of 50 or so intertwining capillaries
- Blood delivered via afferent arteriole
- Blood leaves in efferent arteriole, then flows into peritubular capillaries
  - Kind of like an arterial portal system (two capillary beds: one in glomerulus, one surrounding tubules)
- Glomerular endothelium – fenestrated epithelium that allows solute-rich, virtually protein-free filtrate to pass from the blood into the glomerular capsule

Function of Renal Corpuscle

- **Filtration**: blood pressure forces water and dissolved solutes out of glomerular capillaries into capsular space
- Produces protein-free solution (filtrate) similar to blood plasma (except the proteins)
- Special supporting cells between adjacent capillaries control diameter and rate of capillary blood flow and thus rate of filtration

Renal Tubule: Segments

- In renal cortex:
  - proximal convoluted tubule (PCT)
  - distal convoluted tubule (DCT)
- Loop of Henle separates them:
  - U-shaped tube that extends partially into medulla (more so in juxtamedullary nephrons)

Filtration and Reabsorption

- **Filtration** occurs in the Renal Corpuscle
  - It’s throw the baby out with the bathwater… but then you get the baby back:
    - Blood pressure forces water and small solutes across membrane into capsular space, larger solutes, such as plasma proteins, are excluded
  - Occurs passively
    - Basically, everything smaller than a protein enters capsular space including:
      - metabolic wastes and excess ions
      - glucose, free fatty acids, amino acids, and vitamins
- **Reabsorption** occurs in the renal tubule
  - Useful materials are recaptured before filtrate leaves kidneys
  - Much of reabsorption occurs in proximal convoluted tubule (PCT)

Flow Through the Nephron

- Filtrate becomes tubular fluid when it enters the renal tubule, travels along tubule and gradually changes composition
- Each segment of the tube has specific functions (adds or removes water or solutes)
- By the end of the tubule, most of the filtrate will have been reabsorbed, leaving behind urine to be eliminated
- Empties into the collecting system, a series of tubes carrying prospective urine away from nephron
Types of Nephrons

- **Cortical Nephrons**
  - 85% of all nephrons
  - Located mostly within superficial cortex of kidney (only a small portion extends into medulla)

- **Juxtamedullary Nephrons**
  - 15% of nephrons
  - Have long loops of Henle that extend deep into medulla and have extensive thin segments

Nephrons: Blood Supply

- **Cortical**:
  - Loop of Henle is relatively short
  - Efferent arteriole delivers blood to a network of peritubular capillaries which surround entire renal tubule

- **Juxtamedullary**:
  - Have same peritubular capillaries, but they connect to a vasa recta: long, straight capillaries parallel with loop of Henle

**KEY CONCEPT**

- Kidneys remove waste products from blood
- Nephrons are primary functional units of kidneys
- Kidneys help regulate:
  - blood volume and pressure
  - ion levels
  - blood pH
Histology

Renal Tubule: Functions
1. Reabsorb useful organic nutrients that enter filtrate
2. Reabsorb almost all water in filtrate
3. Secrete waste products that failed to enter renal corpuscle through filtration at glomerulus

The Proximal Convoluted Tubule (PCT)
- Is the first segment of renal tubule
- Entrance to PCT lies opposite from the point of connection of glomerulus with the afferent and efferent arterioles
- PCT epithelium:
  - simple cuboidal with microvilli on apical surfaces
  - Reabsorbs water and solutes from filtrate and secretes substances into it

Tubular Cells
- Absorb organic nutrients, ions, water, and plasma proteins from tubular fluid
- Release them into peritubular fluid (interstitial fluid around renal tubule)
- From here, they enter peritubular capillaries or vasa recta

Blood
Filtrate
Tubular fluid
Peritubular fluid
Peritubular Capillary/Vasa Recta
The Loop of Henle

- PCT portion of renal tubule turns toward renal medulla, leads to loop of Henle:
  - Descending limb: fluid flows toward renal pelvis, mostly thin
  - Ascending limb: fluid flows toward renal cortex, mostly thick
- Each limb contains:
  - thick segment (cuboidal or columnar)
  - thin segment (simple squamous)

Loop of Henle

- Thick descending limb has functions similar to PCT: pumps sodium and chloride ions out of tubular fluid
- Ascending limbs of juxtamedullary nephrons in medulla create high solute concentrations in peritubular fluid
- The thin segments are freely permeable to water but NOT to solutes
  - Water movement helps concentrate tubular fluid

The Distal Convoluted Tubule (DCT)

- DCT is third and final segment of the renal tubule (and of the nephron)
- DCT begins where Loop of Henle ends: just after thick ascending limb makes a sharp angle near the renal corpuscle
- Initial portion loops back and passes between afferent and efferent arterioles
- Has a smaller diameter to PC, but the cuboidal epithelial cells but lack microvilli
  - Functions more in secretion than reabsorption

Connecting Tubules

- The distal portion of the distal convoluted tubule nearer to the collecting ducts
- Two important cell types are found here
  - Intercalated cells
    - Cuboidal cells with microvilli
    - Function in maintaining the acid-base balance of the body
  - Principal cells
    - Cuboidal cells without microvilli
    - Help maintain the body’s water and salt balance

Processes of the DCT

1. Active secretion of ions, acids, drugs, and toxins
2. Selective reabsorption of sodium and calcium ions from tubular fluid
3. Selective reabsorption of water concentrates tubular fluid

The Collecting System

- The distal convoluted tubule opens into the collecting system
- Functions:
  - Transports tubular fluid from nephron to renal pelvis
  - Adjusts fluid composition
  - Determines final osmotic concentration and volume of urine
Collecting Ducts

- Start of the collecting system
- Each collecting duct begins in cortex, descends into medulla
- Several Individual nephrons drain into a nearby collecting duct
- Several collecting ducts converge into a larger papillary duct (in renal papilla) which empties into a minor calyx → major calyx → renal pelvis → urinary tract

Juxtaglomerular Apparatus (JGA)

- Where the distal tubule lies between the afferent and efferent arterioles
- An endocrine structure formed by:
  - macula densa
    - Tall epithelial cells of DCT with densely clustered nuclei, near renal corpuscle and adjacent to JG cells
  - juxtaglomerular (JG) cells
    - Enlarged smooth muscle cells in wall of afferent arteriole, contain renin vesicles and act as mechanoreceptors
- JGA secretes:
  - erythropoietin
  - renin

Kidney Function

- Why do we need kidneys?
- Basically, you must constantly get rid of organic wastes along with some water
- Because you must rid yourself of wastes (or they become dangerous), not concentrating them in urine will lead to fatal dehydration – if you peed out plasma, you would need to take in like 10x more water then you currently do

Renal Physiology

- The goal of urine production is to maintain homeostasis by regulating volume and composition of blood including: excretion of metabolic waste products and retention of organic nutrients and necessary vitamins and electrolytes.

Organic Waste Products

- Are dissolved in bloodstream
- Eliminated only while dissolved in urine (cannot be removed as solids) so removal is accompanied by water loss
- Include:
  - Urea
  - Creatinine
  - Uric acid
An Overview of Urine Formation

Urine Formation - overview

• Water and solute reabsorption occur primarily along proximal convoluted tubules
• Active secretion occurs primarily at proximal and distal convoluted tubules
• Collecting system and the long loops of Henle of the juxtamedullary nephrons regulate final volume and solute concentration of urine

Urine formation

• The kidneys filter the body’s entire plasma volume 60 times each day
• The filtrate:
  – Contains all plasma components except protein
  – Loses water, nutrients, and essential ions to become urine
• The urine contains metabolic wastes and unneeded substances

3 Basic Processes of Urine Formation

1. Filtration
2. Reabsorption
3. Secretion

Kidney Filtration

• Hydrostatic pressure (blood pressure) forces water and small solute molecules through pores (occurs only in renal corpuscle)
• Larger solutes and suspended materials are retained
• Similar to what occurs across capillary walls as water and dissolved materials are pushed into interstitial fluids but on a much larger scale
• Specialized filtration membrane restricts all circulating proteins (filtration slits formed by pedicels are too small)
Reabsorption and Secretion

- Osmosis
- Diffusion
  - passive
  - channel-mediated
- Carrier-mediated transport

Regional Differences

- Loop of Henle in cortical nephron:
  - is short and does not extend far into medulla
- Loop of Henle in juxtamedullary nephron:
  - is long and extends deep into renal pyramids
  - functions in water conservation is critical to the formation of concentrated urine

Osmolarity

- Is the osmotic concentration of a solution:
  - total number of solute particles per liter measured in milliosmoles per liter (mOsm/L)
- Body fluids have an osmotic concentration of about 300 mOsm/L
- Kidneys can produce concentrated urine that is 1200–1400 mOsm/L (4 times plasma concentration)

Glomerular Filtration Membrane

- Filter that lies between the blood and the interior of the glomerular capsule-
  1. Capillary endothelium (fenestrated)
     - pores 60–100 nm diameter
     - prevent passage of blood cells
     - allow diffusion of solutes, including plasma proteins
  2. Fused Basal lamina allows diffusion of only:
     - small plasma proteins, nutrients, ions
  3. Filtration slits: spaces in the visceral membrane of the glomerular capsule (between the pedicels of podocytes)
     - have gaps only 6–9 nm wide so are the finest filters
     - prevent passage of most small plasma proteins
### Filtration Pressures
- Glomerular filtration is governed by the balance between:
  - hydrostatic pressure (blood pressure)
  - colloid osmotic pressure (of materials in solution)

### Vascular Resistance in Microcirculation
- Blood pressure declines from 95 mm Hg in renal arteries to 8 mm Hg in renal veins
- Resistance in afferent arterioles:
  - Protects glomeruli from fluctuations in systemic blood pressure
- Resistance in efferent arterioles:
  - Reinforces high glomerular pressure
  - Reduces hydrostatic pressure in peritubular capillaries

### Glomerular Hydrostatic Pressure ($HP_g$)
- Blood pressure in glomerular capillaries tends to push water and solute molecules out of plasma into the filtrate
- Is significantly higher than capillary pressures in systemic circuit (averages about 50 mm Hg) due to arrangement of vessels at glomerulus:
  - the efferent arterioles have smaller lumens than the afferent arterioles, exerting backpressure in the glomeruli
- Basically, the efferent arteriole produces resistance that requires relatively high pressures to force blood into it

### Capsular Hydrostatic Pressure ($HP_c$)
- Opposes glomerular hydrostatic pressure
- Pushes water and solutes out of filtrate and back into plasma
- Not usually present in systemic caps
- Results from resistance to flow along nephron and conducting system because putting new fluid into the tubule requires pushing along the fluid that is already there
- Averages about 15 mm Hg

### Net Hydrostatic Pressure (NHP)
- Is the difference between glomerular hydrostatic pressure and capsular hydrostatic pressure
  - $NHP = HP_g - HP_c$
  - 50 - 15 = 35 mm Hg

### Glomerular Colloid Osmotic (Oncotic) Pressure ($OP_g$)
- Tends to pull water out of filtrate back into plasma (thus opposes filtration)
- Averages 25 mm Hg (like elsewhere in the system)
- $OP_c$: capsular colloid osmotic pressure, like interstitial COP, is usually zero, unless plasma proteins enter the capsular space.
Net Filtration Pressure (NFP)

- Is the average pressure forcing water and dissolved materials out of glomerular capillaries into capsular spaces (like Net Filtration Pressure in systemic caps)
- \( FP = NHP - NCOP \)
- \( FP = 35 - 25 = 10 \) mm Hg
- Kidneys are equisitely sensitive to BP changes: note that a reduction in BP of 10% causes filtration to cease entirely
- If \( OP_g \) goes up, what happens to NCOP? To NFP? How might this happen

Glomerular Filtration Rate (GFR)

- Is the amount of filtrate kidneys produce each minute
- About 10% of fluid delivered to kidneys leaves bloodstream enters capsular spaces!
- Averages 125 ml/min
- 180L/day! Only about 1.8L leaves as urine, thus 99% reabsorbed in renal tubules
- If GFR too high, you can’t reabsorb needed substances; if it’s too low, reabsorb wastes too

Filtration Pressure

- Glomerular filtration rate depends on:
  - Total surface area available for filtration
  - Filtration membrane permeability
  - Net filtration pressure
- Any factor that alters net filtration pressure alters GFR
- Changes in GFR normally result from changes in glomerular blood pressure
- Best way to raise GFR is to increase GHP by constricting efferent arterioles

3 Levels of GFR Control

1. Renal autoregulation (local level)
   - Maintains GFR despite changes in local blood pressure and blood flow by changing diameters of afferent arterioles, efferent arterioles, and glomerular capillaries (myogenic and JGA)
2. Hormonal regulation (initiated by kidneys)
   - renin-angiotensin system
   - natriuretic peptides (ANP and BNP)
3. Autonomic regulation (by sympathetic division of ANS)

Autonomic Regulation of GFR

- When the sympathetic nervous system is at rest:
  - Renal blood vessels are maximally dilated
  - Autoregulation mechanisms prevail
- Sympathetic activation:
  - constricts afferent arterioles
  - decreases GFR
  - slows filtrate production
- Wait until the crisis has passed to return to normal levels
- Sympathetic activation also causes renin release
Hormonal Response to Reduction in GFR

The Renin–Angiotensin System

• 3 triggers cause the juxtaglomerular apparatus (JGA) to release renin
  – Reduced stretch of the granular JG cells due to decline in blood pressure at glomerulus
  – Stimulation of the JG cells by activated macula densa cells
  – Direct stimulation of the JG cells via sympathetic innervation due to decline in osmotic concentration of tubular fluid at macula densa

Angiotensin II

• Directly constricts efferent arterioles of nephron, elevating glomerular pressures and filtration rates
• Stimulates reabsorption of sodium ions and water at PCT
• Stimulates secretion of aldosterone by adrenal cortex (Accelerates sodium reabsorption in DCT and cortical portion of collecting system)
• Stimulates thirst
• Triggers release of antidiuretic hormone (ADH): stimulates reabsorption of water in distal portion of DCT and collecting system

Increased Blood Volume

• Automatically increases GFR to promote fluid loss (by increasing glomerular hydrostatic pressure above normal 50 mmHg)
• Natriuretic Peptides (from where?) act at kidneys to further increase GFR accelerating fluid loss in urine
  – dilates the afferent glomerular arteriole, constricts the efferent glomerular arteriole