Urinary System
(Chapter 26)
Lecture Materials
for
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Primary Sources for figures and content:

Functions:
1. Excretion (kidney):
   - remove organic wastes from blood
2. Elimination (UT):
   - discharge wastes to environment
3. Regulation of plasma volume and solute concentration (kidney):
   - blood volume, BP
   - conc. of ions
   - stabilize blood pH
   - conserve nutrients
   - assist liver: deamination, detoxification
4. Other kidney functions:
   A. gluconeogenesis during starvation
   B. produce renin (regulate BP)
   C. produce erythropoietin (RBC production)
   D. convert Vitamin D to calcitriol (Ca++ absorption in GI)

Kidneys
- 1% body weight
- retroperitoneal, posterior abdominal wall
- adrenal gland anchored superior
- 3 layers CT anchor kidneys:
  1. Renal capsule: collagen fibers covering organ
  2. Adipose capsule: adipose cushion around renal capsule
  3. Renal fascia: collagen fibers fused to renal capsule and deep fascia of body wall and peritoneum

Renal ptosis = floating kidney: starvation or injury, kidney loose from body wall, could twist blood vessels or ureters
-Hilum: where renal arteries, renal veins, ureters enter/exit
-Hilum opens to renal sinus
-Renal sinus lined with renal capsule, contiguous with outside

Kidney has two layers:
1. Cortex: superficial, contact renal capsule, houses filtration structures (nephrons)

Kidney divided into sections: renal lobes
Renal lobe = renal pyramid + surrounding cortex called renal columns, lobe is complete site of urine production

Urine production:
- nephron (cortex) → collecting ducts (medulla) → papilla → minor calyx → major calyx → renal pelvis

Renal pelvis: fills majority of renal sinus, funnels urine into ureter

Pyelonephritis = inflammation of kidney, infection usually enters from ureter and spreads up through ducts to nephron

Blood Supply and Innervation to kidney:
- receives 20-25% cardiac output
- highly vascularized, many capillaries involved in filtration (nephrons)
- Innervation from Renal Plexus controlled by ANS
- Most is sympathetic to
  1. Adjust rate of urine formation (change BP and flow at nephron)
  2. Stimulate release of renin (restricts water and Na+ loss at nephron)

Nephron:
- smallest functional unit of kidney
- more than 1 million per kidney
- two major parts:
  1. Renal corpuscle = glomerular capsule + glomerulus
  2. Renal tubule = proximal convoluted tubule (PCT) + nephron loop + distal convoluted tubule (DCT)

Two important capillary beds associated with each nephron:
1. Glomerulus: filtration
2. Peritubular capillaries: reclaim filtrate, concentrate urine
Both connected to arterioles only (not for O2 exchange)
afferent arteriole → capillary → efferent arteriole
Two types of nephrons:
1. Cortical nephrons: majority, in cortex, short nephron loops
2. Juxtamedullary nephrons: 15%, at cortex/medulla interface, long nephron loops, important for water conservation and concentrated urine

Renal Corpuscle:
- site of filtration
- 2 parts:
  1. Glomerular capsule: thin parietal epithelium, forms capsule around glomerulus
  2. Glomerulus: fenestrated capillaries covered by podocytes = visceral epithelium, intertwine to create filtration slits on surface of capillaries, slits smaller than fenestrations in glomerular capillaries to restrict filtration of large molecules

Golmerulonephritis = inflammation of glomeruli, prevents filtration, can be result of antigen/Ab complexes trapped in filtration slits following allergy or blood infection

Renal Tubule:
- reabsorption to process raw filtrate into urine
- 3 parts:
  1. PCT: simple cuboidal epithelium with microvilli, reabsorbs organic nutrients, ions, water, and small plasma proteins from filtrate exiting glomerular capsule
  2. Nephron loop: simple squamous epithelium, reabsorbs Na\(^+\), Cl\(^-\), and H\(_2\)O from filtrate, important to regulate volume and solute conc. of urine, has descending and ascending limbs
  3. DCT: simple cuboidal epithelium, flat surface, has four important functions:
     1. Secretion: removal of wastes from peritubular capillaries into filtrate
     2. Reabsorb Na\(^+\) and Ca\(^{2+}\) from filtrate
     3. Optional H\(_2\)O reabsorption from filtrate under hormonal control
     4. Contribute to formation of Juxtaglomerular Apparatus
Juxtaglomerular Apparatus (JGA):
- consists of two cell types:
  1. Endocrine cells of DCT = macula densa
  2. Granular cells of afferent arteriole = juxtaglomerular cells
-together cells monitor blood and produce:
  1. Renin: enzyme, restricts Na+ and H2O at nephron
  2. Erythropoietin: hormone, stimulates RBC production

Collecting System:
- collecting ducts + papillary ducts
  nephrons → 1 collecting duct (renal pyramid)
  many collecting ducts → 1 papillary duct
- final osmotic concentration of filtrate
  adjusted by collecting duct, after this urine is complete and exits kidney:
  papillary duct (renal papilla) → minor calyx → major calyx → renal pelvis → ureter

Polycystic kidney disease = genetic, cysts form that cause swelling of kidney tubules, compression reduces function

Renal Physiology
- urinary system functions to regulate blood volume and conc., remove wastes, and produce urine
Filtrate = everything in blood plasma except large proteins and cells
Urine = metabolic waste, 1% filtrate

Common wastes:
1. Urea: from catabolism of amino acids
2. Creatinine: from catabolism or damage of skeletal muscle tissue (creatine phosphate is energy storage of muscle)
3. Uric Acid: from recycling of RNA
4. Urobilin: from breakdown of hemoglobin (yellow color)
All wastes excreted as solution in water
Loss of filtering → toxic waste buildup, death in few days
Dialysis = blood filtering machine, used for patients with kidney failure

Urine Formation:
1. Glomerular Filtration: blood hydrostatic pressure forces water and solutes through glomerular wall
2. Tubular Reabsorption: selective uptake of water and solutes from filtrate
3. Tubular Secretion: transport of wastes from capillaries to tubules

1. Glomerular Filtration
- occurs through filtration membrane:
  1. Fenestrated endothelium of glomerular capillaries (restricts cells)
  2. Podocytes (visceral epithelium of capsule), filtration slits restrict solutes protein sized and larger
  3. Fused basal lamina for both

- filtration is passive but all small solutes escape e.g. glucose, amino acids etc.
-filtration depends on:
  1. Large surface area
  2. High glomerular BP
  3. Good permeability

Glomerular Filtration Rate (GFR) = amount of filtrate kidneys produce / minute
  
  ~125ml/min → 180L/day
  
  -99% reabsorbed, 1% lost as urine
  
  -drop in BP = ↓GFR (↓15%BP = 0 GFR)

Regulation to maintain constant GFR
  (on handout)

2. Tubular Reabsorption
-transport proteins in renal tubule cells return substances from filtrate to plasma
  -when carrier proteins are saturated by substance they carry (transporting at max.
  velocity) the renal threshold for that substance has been reached, additional
  amounts of substance will be lost in urine

DCT reabsorption:
-aldosterone promotes Na\(^+\) uptake and K\(^+\)
  loss via sodium potassium pump
-parathyroid hormone and calcitriol promote Ca\(^{2+}\) uptake
-ADH stimulates water uptake

3. Tubular Secretion
-selectively removes solutes from blood, delivers them to filtrate
  1. Dispose of drugs and wastes that were not filtered
  2. Eliminate wastes that were reabsorbed
  3. Rid body of excess K\(^+\)
  4. Control blood pH: remove H\(^+\)

  \[ CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^- \]

  Bicarbonate ions used to buffer blood pH but H\(^+\) must be secreted into filtrate

  -secretion carried out mostly by DCT, but some also occurs in collecting ducts

Control of Water Volume
-obligatory water reabsorption occurs by osmosis in PCT and descending nephron
  loop (cannot be prevented)

-facultative water reabsorption can occur in DCT and collecting ducts (usually
  impermeable):

e.g. Glycosuria = glucose in urine:
  glucose levels in blood/filtrate exceed renal threshold

PCT reabsorption:
  -PCT reabsorbs 60-70% of filtrate
  1. Reabsorption of 99% of organic nutrients by facilitated diffusion and cotransport
  2. Passive reabsorption of ions by diffusion
  3. Selective reabsorption of ions by active transport: ion pumps controlled by
  hormones
  4. Reabsorption of water by osmosis (water follows ions)

Nephron loop reabsorption:
  -functions to concentrate filtrate
  -reabsorbs half remaining water and 2/3 Na\(^+\) and Cl\(^-\) by countercurrent
  multiplication: ascending limb pumps ions from filtrate to medulla, high ion
  conc. then causes water to move by osmosis out of descending limb

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  impermeable):
-ADH causes formation of water channels by triggering insertion of aquaporin proteins in cell membranes of DCT and collecting duct cells -aquaporins allow more osmosis to concentrate urine and conserve water

Diuretics = substances that cause water loss
-Osmotic diuretics = substances that cannot be reabsorbed and thus take water with them
-Hypertension and Edema meds = prevent Na+ uptake (water follows salt)
-Alcohol = inhibits ADH preventing facultative water reabsorption

Diabetes insipidus = not enough ADH, produce large quantities of dilute urine, up to 24 L/day (1.2 L normal)
Anuria = low urinary output, less than 150 ml/day, usually due to events that block filtration (nephritis, immune reactions, crushing injuries)

Urine Transport, Storage and Elimination
-urine production and modification: renal tubules and collecting system
-once in renal pelvis, urine complete, excreted via ureters, bladder, urethra

Nephrolithiasis = blockage of urinary passage e.g. Calculi (kidney stone); crystalized deposits of calcium, magnesium, or uric acid, form in renal pelvis, can become lodged in ureters. Large ones may need disruption by a lithotripter.

Ureters
-connect renal pelvis to urinary bladder
-wall layers:
  1. Mucosa with transitional epithelium
  2. Muscularis with two layers of smooth muscle
  3. Adventitia, attaches to posterior body wall
-contractions occur every 30 sec to force urine toward bladder

Urethra
-single tube, connects bladder to environment
-lined with pseudostratified columnar epithelium
-passes through band of skeletal muscle that forms external urethral sphincter, under voluntary control, relaxation results in micturition

Micturition Reflex
-when bladder contains ~200 ml urine, stretch receptors triggered, signal conscious awareness of pressure and stimulates contraction of detrusor muscle
-voluntary maintenance of contracted external urethral sphincter prevents urination, detrusor will relax (opening will open internal urethral sphincter allowing urination)
-continued increase in urinary volume will repeatedly trigger reflex
-if volume exceeds ~500ml, forced relaxation of internal and external urethral sphincters will result in non-voluntary urination/micturition

**Incontinence** = inability to voluntarily control urine excretion, due to: loss of muscle tone, damage to sphincters, damage to nerves or control centers in brain

**Age Related Changes:**
- decline in functional nephrons
- reduction in GFR (damage or ↓ blood flow)
- reduced sensitivity to ADH = dilute urine
- problems with micturition:
  - incontinence
  - urinary retention (enlarged prostate)