Osmoregulation and Excretion

Presentation by Laurie, Slides by Slidesgo

01

Osmoregulation

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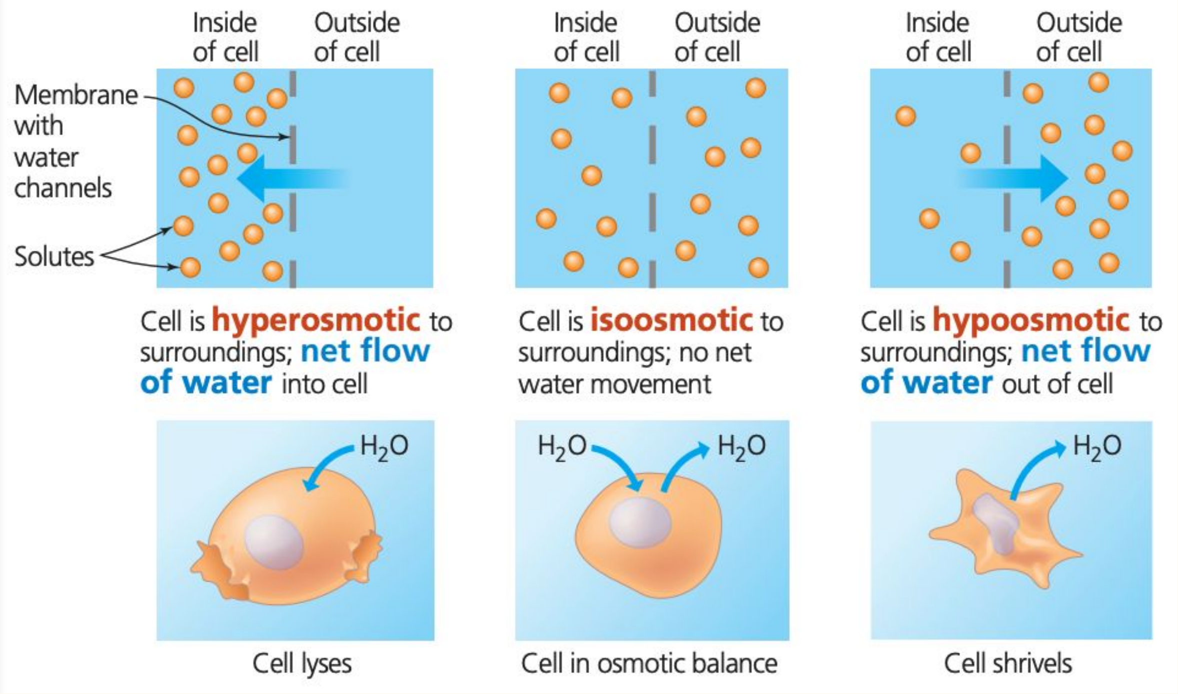
Osmosis


Inside of cell
Outside of cell
Membrane with water channels
Solutes
Cell is hyperosmotic to surroundings; net flow of water into cell
Cell is isoosmotic to surroundings; no net water movement
Cell is hypoosmotic to surroundings; net flow of water out of cell
H_2O
H_2O
H_2O
H_2O
Cell lyses
Cell in osmotic balance
Cell shrivels

Terminology

Osmoregulation – how animals manage solute concentrations and water gain/loss
Excretion – eliminating waste products

- Nitrogenous waste products from proteins and nucleic acids

Osmolarity – moles of solute/L of solution

- Human blood = 300 mOsm/L
- Seawater = 1000 mOsm/L

Categories in Osmoregulation

Osmoconformer - isoosmotic with surroundings

- Marine animals

Osmoregulator – control internal environment

- Discharge water in hypoosmotic environment, intake water in hyperosmotic environment

Stenohaline – cannot tolerate big changes in environment’s osmolarity

- Most animals

Euryhaline – can tolerate big changes in environment’s osmolarity

- Osmoconformers: barnacles, mussels in estuaries
- Osmoregulators: bass, salmon

Osmoregulation in Marine Animals

LOSE water

Invertebrates

- Most are osmoconformers; no issues with water balance
- Active transport of specific solutes with concentrations that differ from the ocean's
  - Atlantic lobster – Mg^{2+} concentration = 9 mM in hemolymph, 50 mM in environment

Vertebrates

1. Bony fishes (ray-finned and lobe-finned fishes, such as cod)
   a. Drink seawater
   b. Eliminate salts through gills and kidneys
2. Marine sharks and other chondrichthyans (cartilaginous)
   a. High concentration of other solutes – urea, trimethylamine oxide (TMAO)
   b. Water actually enters shark; expelled through urine made by kidneys along with salt that diffuses into body

Osmoregulation in Freshwater Animals

GAIN water

Perch + many others

- Excrete large amounts of dilute urine
- Drink no water
- Eat salt and take up salt through gills

Salmon + other euryhaline fishes

- Osmoregulate like freshwater fishes in rivers/streams
- Acclimatize in saltwater
    - Produce lots of cortisol → more and bigger salt-secreting cells
    - Produce little urine

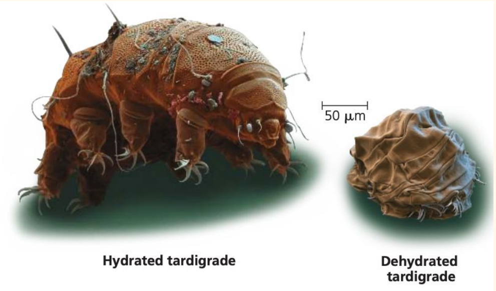
Osmoregulation in Temporary Waters

Desiccation = bad
Anhydrobiosis

- Tardigrades
- Trehalose replaces water
  - Helps with transport of samples

Land Organisms

- Waxy cuticle
- Waxy exoskeletons, shells
- Keratinized skin cells
- Nocturnal
- Special adaptations for arid areas
  - Camels – can lose 25% of body water



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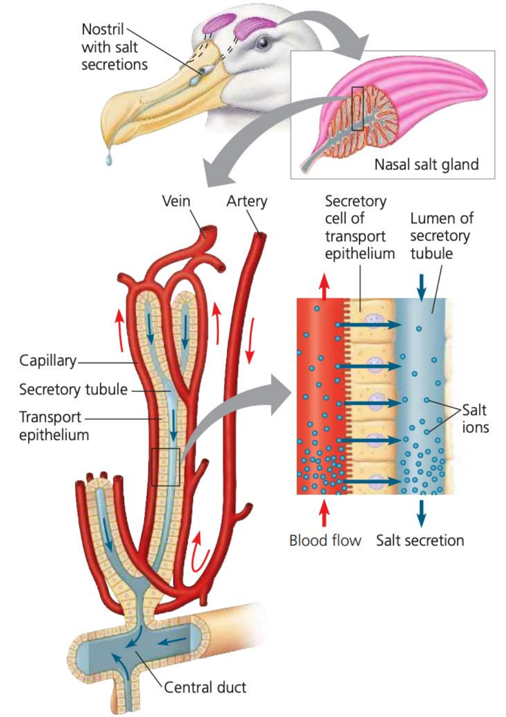
Transport Epithelia in Osmoregulation

Solute concentration in cells usually indirectly controlled through interstitial fluid

Transport epithelia – 1+ layers of epithelial cells for moving solutes

- Albatross nose gland



02
Waste

Forms of Nitrogenous Waste

Must get rid of ammonia from proteins/nucleic acids through excretion

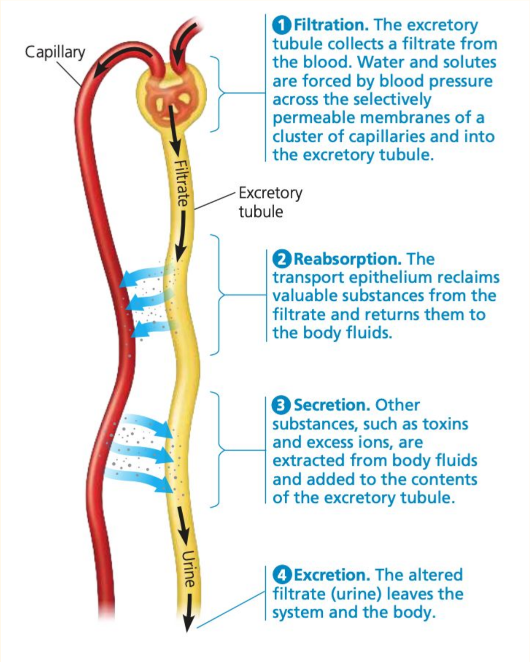
1. Ammonia
   a. Very toxic; NH_4^+ interferes with oxidative phosphorylation
   b. Aquatic animals – have lots of water to dilute ammonia
   c. Leaves by diffusion
2. Urea
   a. Combine ammonia with carbon dioxide in liver
   b. Low toxicity, high solubility
   c. Frogs use urea but tadpoles use ammonia
3. Uric acid
   a. Insects, land snails, reptiles, birds
   b. Nontoxic, not soluble – semisolid paste, little water loss
      i. Good for cleidoic eggs
   c. Small amounts generated in humans and other animals
      i. Uric acid stones in bladders of certain Dalmations
      ii. Gout

Increasing energy to make

03
Excretory Systems

General Excretory System

1. Filtration
    a. Transport epithelium's selectively permeable membrane contacts body fluid
        i. Cells and large molecules don't pass
        ii. Filtrate – Water and small solutes pass
    b. Driven by hydrostatic pressure (such as bp)
2. Reabsorption
    a. Filtrate converted to waste fluid – transport of materials in/out of filtrate
        i. Recovers useful molecules and water
            1. Glucose
            2. Salts
            3. Vitamins
            4. Hormones
            5. Amino acids
3. Secretion
    a. Nonessential solutes/wastes left in/added to filtrate
    b. Active transport
    c. Determines direction of osmosis
4. Excretion
    a. Processed filtrate released as urine

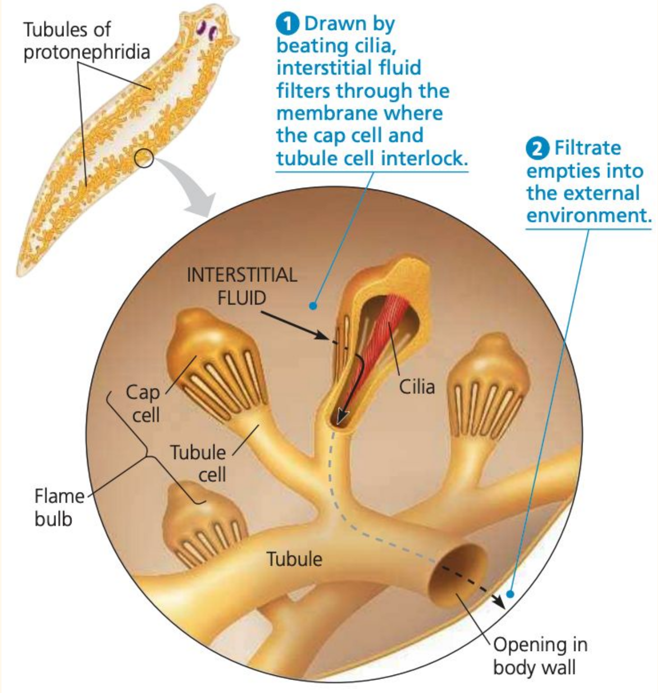


Protonephridia

Used by:
- Flatworms lacking coelom
  - Freshwater worms – osmoregulation
  - Parasitic worms – isoosmotic to host environment; use protonephridia for waste
- Rotifers
- Annelids
- Mollusc larvae
- Lancelets

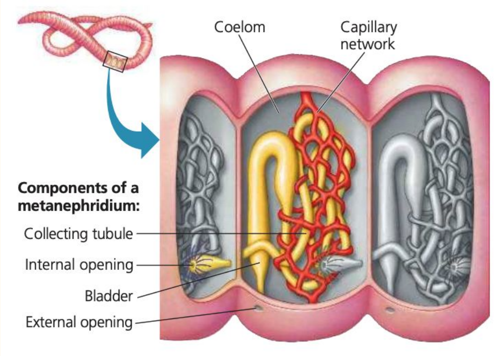
Structure
- Network of dead-end tubules that branch throughout body
- Flame bulb – caps each branch
  - Tubule cell
  - Cap cell
  - Tuft of cilia projects into tubule

Process
- Cilia beats and draws water + solutes into flame bulb
- Filtrate released into tubule network
- Processed filtrate empties as urine



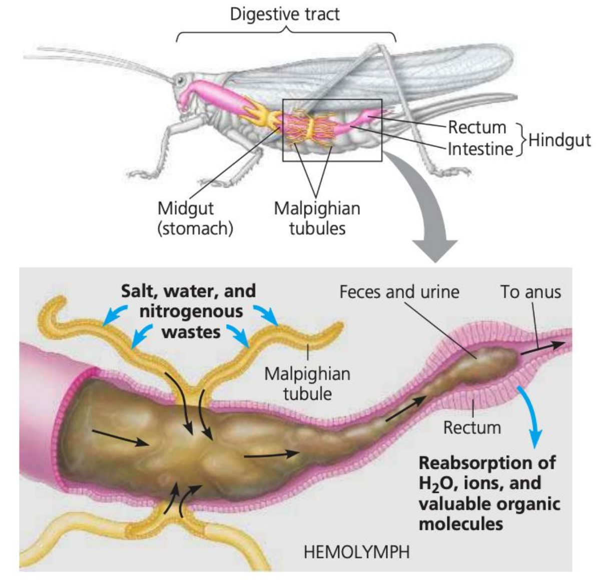
Metanephridia

- Users
  - Annelids, such as earthworms
    - Have coelom
  - Live in damp environment
  - Excrete dilute urine to balance water gain
  - Osmoregulation and nitrogenous wastes
- Structure
  - One pair in each segment
  - Immersed in coelomic fluid, enveloped by capillary network
  - Ciliated funnel around each internal opening of each metanephridium
- Process
  - Cilia beat
  - Fluid drawn into a collecting tubule from coelom
  - Collecting tubule has storage bladder that opens to outside
  - Reabsorbs most solutes – returned to blood
  - Nitrogenous wastes excreted



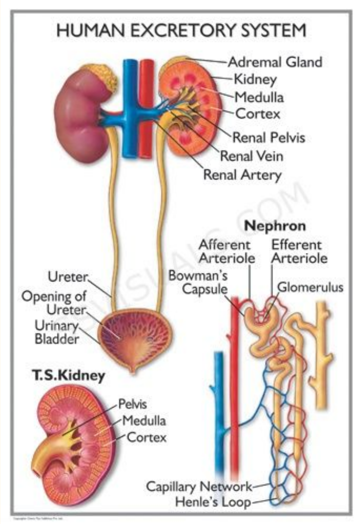
Malpighian Tubules

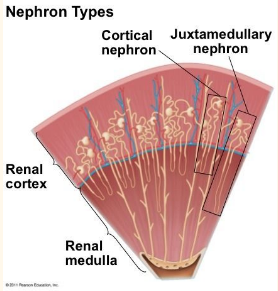
- Users
  - Insects
  - Terrestrial Arthropods
  - Very good at conserving water
  - Osmoregulation and excretion
- Structure
  - Dead end tips → opens to digestive tract
- Process
  - No filtration step
  - Transport epithelium lining tubules secretes solutes from hemolymph to lumen of tubule
    - Includes nitrogenous wastes
    - Water flows in via osmosis
  - Most solutes pumped back into hemolymph
    - Water reabsorbed via osmosis
  - Uric acid eliminated nearly dry with feces



Kidneys

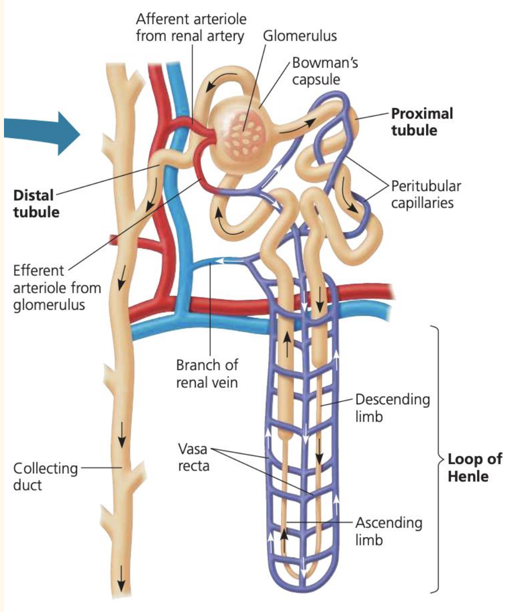
- Users
  - Vertebrates
  - Some other chordates
  - Osmoregulation and secretion
- Structure
  - Lots of highly arranged tubules associated with capillaries
  - Typically nonsegmented
    - Hagfishes have segmented kidneys though
- Mammals
  - 2 kidneys; 10 cm long
  - Renal cortex – outer
  - Renal medulla – inner
  - Renal artery
  - Renal vein – nearly all fluid returns via it
  - Tightly packed excretory tubules and blood vessels
  - Renal pelvis – remaining fluid collected here to go to ureter
  - Nephrons
    - 1 mil
    - 85% cortical nephrons (short distance)
    - 15% juxtamedullary nephrons
    - Produce hyperosmotic urine



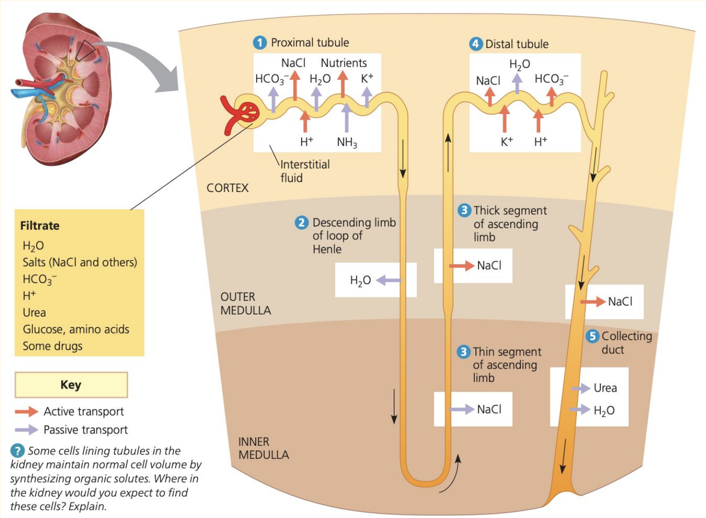


Kidneys Cont.

- Nephron organization
  - Stats
    - 1600 L blood thru a pair of kidneys each day
    - 180 L initial filtrate
    - 99% of water, almost all sugars, AA, vitamins, nutrients absorbed
    - 1.5 L of urine transported to bladder
  - Glomerulus – ball of capillaries
  - Tubule
    - Bowman’s capsule – surrounds glomerulus, collects filtrate
    - Proximal tubule
    - Loop of Henle
    - Distal tubule
    - Collecting duct
  - Blood
    - Afferent arteriole supplies blood
    - Efferent arteriole comes from same caps, converge
    - Form peritubular capillaries that surround proximal and distal tubules
    - Vasa recta – serve renal medulla
- Ureter – urine exits kidney
- Urinary bladder – ureter drains here
- Urethra – expels urine from bladder
- Sphincters near junction of urethra and bladder regulate

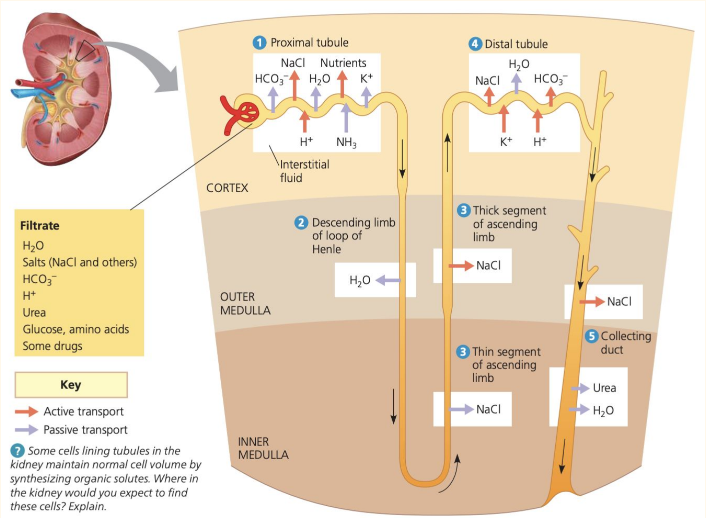


Kidney - Proximal Tubule



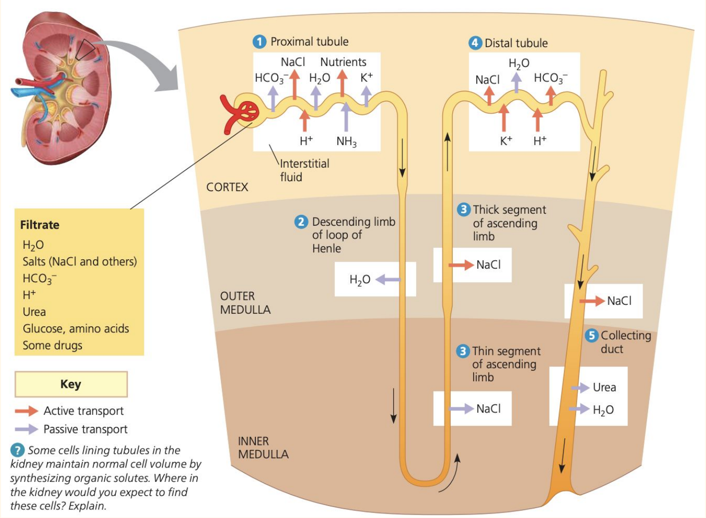
1. Reabsorb Ions, water, nutrients, NaCl
   a. Facilitated diffusion + cotransport moves to transport epithelium
   b. Water follows via osmosis
   c. Salt and water diffuse into peritubular capillaries
2. Processing of filtrate maintains pH
   a. Transport epithelium secretes H+ and ammonia (to trap H+ as NH4+) into tubule
      i. More ammonia for more acidity
   b. Absorbs 90% of buffer bicarbonate
3. Filtrate more concentrated
   a. Wastes leave body fluids and remain in filtrate
      i. Urea reabsorbed much slower than salt and water
      ii. Drugs and toxins from liver → peritubular capillaries → actively transported into lumen of tubule
   b. Water and salts reabsorbed

Kidney - Descending Loop of Henle



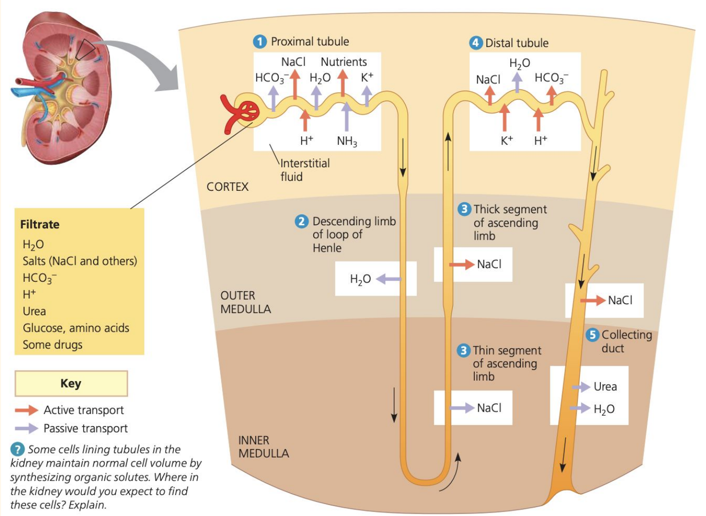
1. Lots of water reabsorption
    a. Lots of aquaporins + few other channels
    b. Progressively higher osmolarity into medulla
        i. 1200 mOsm/L at elbow

Kidney - Ascending Loop of Henle



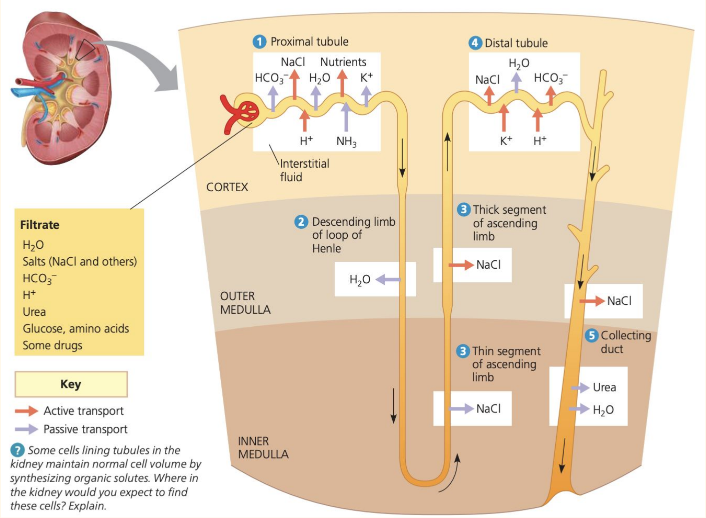
1. Thin
    a. No aquaporins but LOTs of NaCl channels
    b. NaCl diffuses out
    c. Maintains osmolarity of medulla interstitial fluid
2. Thick
    a. More NaCl moves out
    b. Active transportation into interstitial fluid
    c. More dilute filtrate

Kidney - Distal Tubule



1. Regulates K+ and NaCl concentration of body fluids
   a. Variates amount of K+ secreted into filtrate and amount of NaCl absorbed from filtrate
2. pH regulation
   a. Controlled secretion of H+ and reabsorption of HCO_3^-

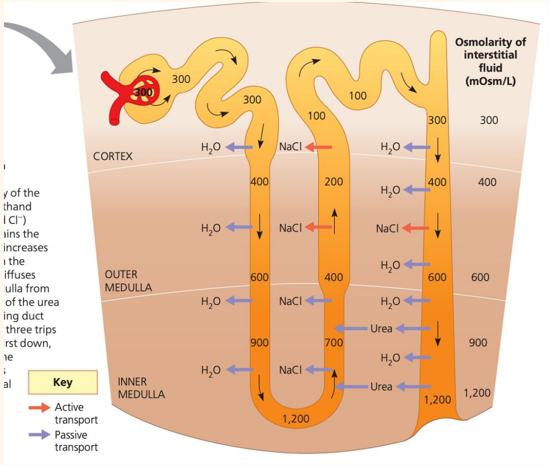
Kidney - Collecting Duct



1. Filtrate → urine → renal pelvis
2. Hormones determine concentration
   a. Conserving water
      i. Aquaporins open
      ii. Epithelium impermeable to salt and urea (in cortex)
      iii. More and more concentrated filtrate
      iv. Permeable to urea in inner medulla
         1. High urea concentration in filtrate
         2. Diffusion of urea into interstitial fluid
            a. Contributes to high osmolarity
   b. Dilute urine
      i. Collecting ducts actively absorb salts
      ii. No aquaporins
      iii. NaCl actively transported out

Solute Gradients & Water Concentration

- Terrestrial mammals need to conserve water → hyperosmotic urine
    - Lots of energy spent
    - NaCl in loop of Henle and urea in collecting duct affect osmolarity
- Concentrating Urine in the Mammalian Kidney
    1. Bowman’s capsule + proximal tubule - same osmolarity as blood
        a. Water *and* salt reabsorbed
    2. Descending limb - high osmolarity
        a. Water leaves tubule via osmosis
        b. Solutes become more concentrated
    3. Ascending limb - hypoosmotic
        a. Salt diffuses out of tubule
        b. High osmolarity of interstitial fluid of renal medulla
    4. Collecting duct - hyperosmotic
        a. Water moves out via osmosis
        b. Salt, urea, solutes concentrated
        c. Some urea passes out to contribute to high interstitial molarity of inner medulla
            i. Urea recycled by diffusing into loop of Henle but continued leakage maintains high interstitial concentration
- Vasa Recta
    - Carries blood in opposite directions through osmolarity gradient
        - Descending – water lost from blood, NaCl gained via diffusion
        - Ascending – water regained, salt diffuses out
- Kidney has super high metabolic rate



Adaptations

- Mammals
  - Super hyperosmotic urine – desert animals
    - Lots of juxtamedullary nephrons that maintain steep gradients
    - Urine becomes super concentrated in collecting ducts
  - Dilute urine – aquatic and freshwater mammals
    - Mostly cortical nephrons
  - Intermediate urine – moist conditions
    - Medium-long loops of Henle
  - Ex. vampire bats
    - Drink lots of blood and excrete dilute urine so they can fly
    - Need to digest proteins without a lot of water – excrete concentrated urine
- Birds
  - Only non-mammals with juxtamedullary nephrons
  - Shorter loops of Henle
  - Main water conservation adaptation is uric acid
  - Ostriches

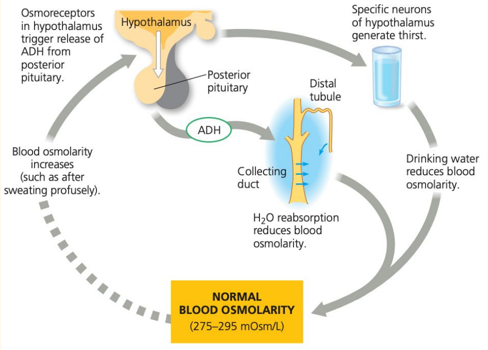
Adaptations

- Reptiles
  - Only cortical nephrons
  - Isosmotic or hypoosmotic urine
  - Cloaca
    - Reabsorbs water from epithelium used for excretion
  - Uric acid
- Freshwater Fishes
  - Lots of dilute urine
  - Cortical nephrons produce filtrate at high rate
  - Salt conversation via reabsorption of ions from distal tubules
- Amphibians
  - Frogs in freshwater excrete dilute urine; skin actively accumulates salts
  - Frogs on land reabsorb water across epithelium of bladder
- Marine Bony Fishes
  - Low filtration rate and very little urine excreted
    - Fewer and smaller nephrons without distal tubule
    - Small or nonexistent glomeruli
  - Main function is to get rid of divalent ions (Ca^{2+}, Mg^{2+}, SO_4^{2-}) from drinking seawater
    - Secreted into proximal tubules of nephrons and excreted in urine
  - Chloride cells in gills maintain monovalent ion levels
    - Establish ion gradients that allow excretion of Na^+ and Cl^-

04
Regulation

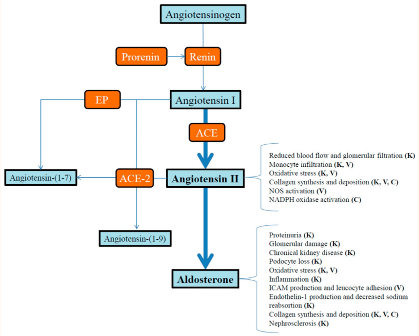
Vasopressin/ADH (Antidiuretic hormone)

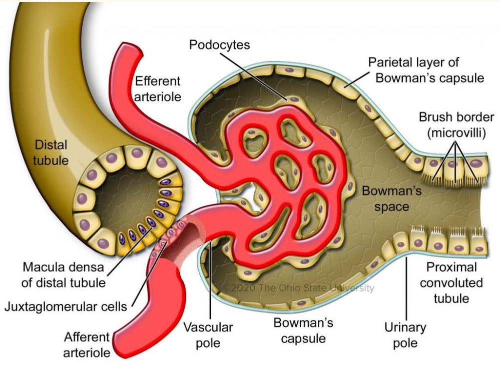
- Produced in the posterior pituitary gland when blood osmolarity is too high
- Process
  - Bind to membrane receptors on collecting duct cells
  - Cascade inserts aquaporins into duct membrane
- Less urine produced (antidiuretic) – more water recapture
- Caffeine has no effect
- Alcohol inhibits ADH release → excessive urinary water loss and dehydration → hangover symptoms
- Diabetes insipidus
  - Mutations interfering with ADH production and activation
  - Severe dehydration
  - Copious dilute urine



Renin-Angiotensin-Aldosterone System (RAAS)

- How body responds to loss of blood volume (that doesn't affect osmolarity)
- Juxtaglomerular apparatus (JGA) – tissue made of cells of and around afferent arteriole
  - Bp drops in afferent arteriole (such as bc of dehydration) → JGA releases renin
- Renin → plasma protein angiotensinogen cleaved → angiotensin II created
- Angiotensin II → vasoconstriction to increase bp and decrease blood flow
  - Drugs blocking it used for hypertension
    - Many block ACE (angiotensin converting enzyme)
- Angiotensin II → adrenal gland stimulated to release aldosterone → distal tubules reabsorb more Na+ and water to increase blood volume and pressure
- Feedback circuit





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Coordinated Control

- Both ADH and RAAS increase water reabsorption
    - ADH lowers blood Na+ concentration by reabsorbing water
    - RAAS maintains body osmolarity by reabsorbing Na+
- Atrial natriuretic peptide (ANP) opposes RAAS
    - Released by heart atria walls in response to increased blood volume and pressure
    - Inhibits renin release, inhibits NaCl reabsorption by collecting ducts, and reduces aldosterone release from adrenal glands
- Thirst
- Drinking too much water → hyponatremia
    - Too little sodium in blood
    - Disorientation
    - Respiratory distress

Practice

Name all the following four components of the human kidney that extend into the kidney medulla: 1) proximal convoluted tubule, 2) distal convoluted tubule, 3) Bowman’s capsule, 4) ascending limb of the Loop of Henle.

What component of the nephron establishes and maintains a salt gradient used to concentrate urine?
W) Bowman’s capsule
X) Proximal convoluted tubule
Y) Distal convoluted tubule
Z) Loop of Henle

Animals excrete various forms of nitrogenous [ny-TROJ-uhnuhs] wastes that are mainly the result of the catabolism of which of the following?

W) Cellulose and triglycerides [try-GLIS-uh-ryds]
X) Proteins and nucleic acids
Y) Glycolipids and glycerol
Z) Starches and proteins

In mammalian kidneys, reabsorption of water occurs mostly in which of the following:
W) glomerulus
X) descending limb of the loop of Henle (read as: HEN-lee)
Y) proximal convoluted tubule
Z) Bowman's capsule

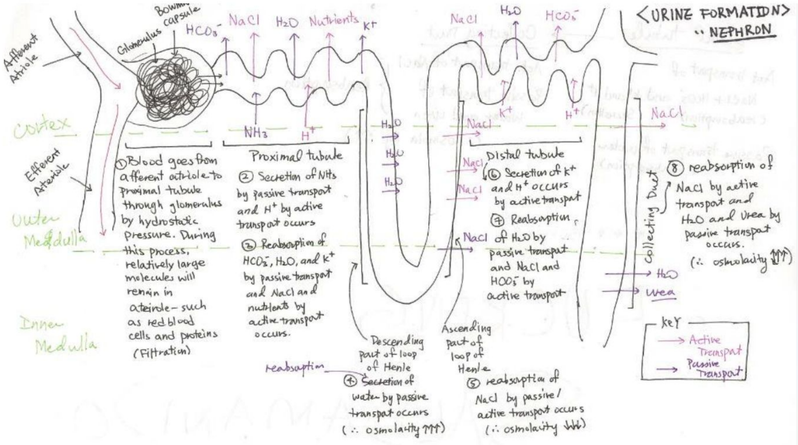
2017 Opens

28. Select ALL of the following parts of the nephron where water is reabsorbed from the filtrate:

A. Collecting duct.
B. Proximal tubule.
C. Bowman's capsule.
D. Ascending limb of loop of Henle.
E. Descending limb of loop of Henle.

2016 Opens

24. In your high school biology course, you were assigned to draw a diagram of the formation of urine in human. A figure shown below is homework you did for your high school biology course. Now, you would like to double check before you submit this to your teacher, Dr. Lee. Is there anything wrong with this figure? If so, why?



A. No, there is nothing wrong with this figure.
B. Yes, afferent and efferent arterioles are reversed.
C. Yes, ascending part of loop of Henle should be thicker than descending part.
D. Yes, NaCl should be absorbed first and then water should be re-absorbed in loop of Henle.
E. Yes, the order of the layer in kidney should be inner medulla, outer medulla, and cortex. The sequences for those are reversed.

2013 Opens

29. If one were to compare the length of the Loop of Henle and collecting ducts to the overall length of each mammal below, which would have the highest ratio?

A. Asian elephant
B. Brazilian rabbit
C. Harbor seal
D. Kangaroo rat
E. Flying squirrel

Thanks!