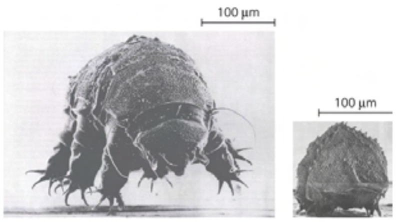
Anhydrobiosis: Life without water?



(a) Hydrated tardigrade (85% water)

(b) Dehydrated tardigrade (2% water)

Water is needed to maintain the structure & function of macromolecules.

How to acquire body water?

- **Drink water & dilute fluids**
- **Moisture in food**
- **Metabolic water**

Organic food molecules + $O_2 \rightarrow CO_2$ + $\mathbf{H_2O}$ + energy

Fat yields 2.5x as much energy and **2.5x as much water** per gram than do carbs or proteins!

Osmoregulation

The exchange of water and ions between the environment and the body fluids of an organism to maintain a constant internal environment (homeostasis).

- Balance between water gain & water loss

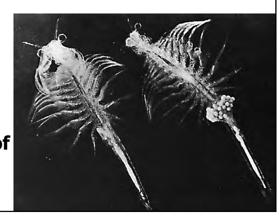
Which is related to

- Balance between electrolyte (salt) gain & loss

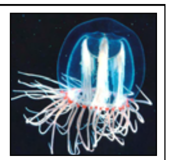
Osmoconformers & Osmoregulators

- **Osmoconformers** don't adjust osmolarity
- **Osmoregulators** adjust **osmolarity** by
  - pumping water in or out
  - pumping ions in or out

brine shrimp spend 30% of metabolism on osmoregulation



Osmoregulation



Osmoconformers:

- body fluids are isotonic to their environment
  - *Different* solutes, but same total Osm
    - Must maintain membrane potential of cells with certain ion gradients
- do not have to actively maintain water balance
- include most marine invertebrates

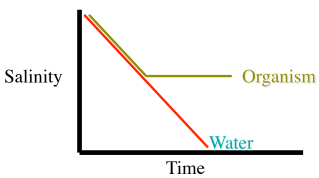
Osmoregulation

Osmoregulators:

- body fluids are **not** isotonic to their environment
- have to actively maintain water balance
- Include bony fish, marine mamms, freshwater, & terrestrial organisms

Osmoconformers & Osmoregulators

- **Stenohaline** cannot tolerate Δ osmolarity
- **Euryhaline** can tolerate Δ
  - Estuaries, tidepools
  - – some are facultative osmoregulators

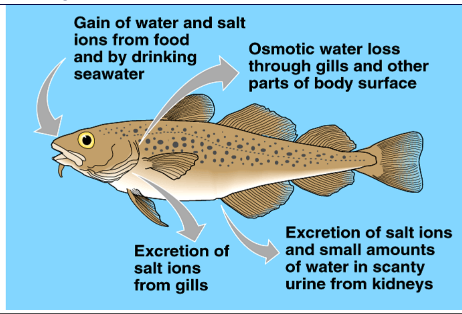


Aquatic animals — most water & salt exchange occurs in **gills**

- Large, thin exposed surface area to exchange gases
- Permeable to water

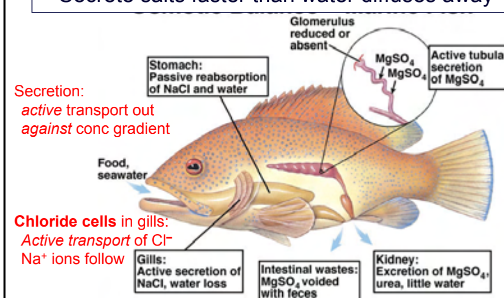
Osmoregulation: A Marine Fish

- Seawater = 3.5% NaCl (1 Osm); Body fluids = 1% (0.3 Osm)
- Across gills — salt diffuses in; water diffuses out



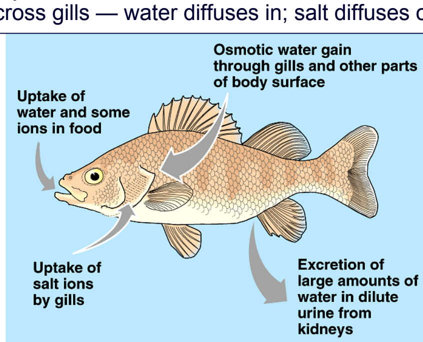
Osmoregulation: A Marine Fish

- Replace lost water by drinking large volumes
- Secrete salts faster than water diffuses away



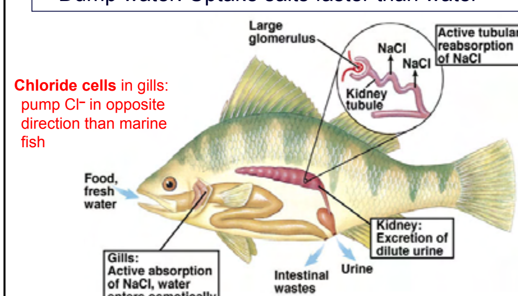
Osmoregulation: A Freshwater Fish

- Body fluids = 1% NaCl; Freshwater <0.01%
- Across gills — water diffuses in; salt diffuses out



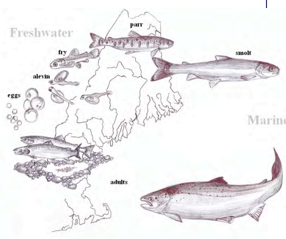
Osmoregulation: A Freshwater Fish

- No drinking. Consume salts & some water in food
- Dump water. Uptake salts faster than water



Osmoregulation: Euryhaline fish

- **Anadromous**: juveniles in freshwater; adults at sea
  - Salmon, striped bass
- **Catadromous**: juveniles in saltwater; adults in fresh
  - Anguillid eels
- Must transition gills & kidneys before migrating
  - Chloride cells must reverse direction
  - **Smoltification**



Life Cycle of Atlantic Salmon http://www.nefsc.noaa.gov/sos/spsyn/af/salmon/images/fig41_2.gif

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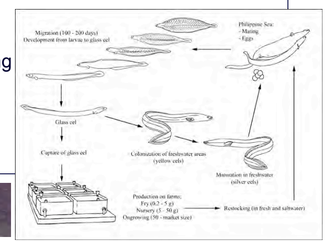
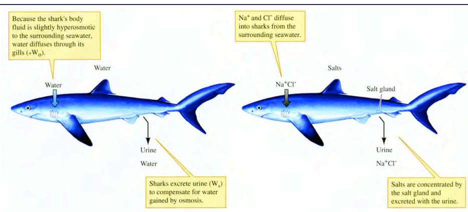


Life Cycle of Japanese eel (unagi) http://www.fao.org/fishery/culturedspecies/Anguilla_japonica/en

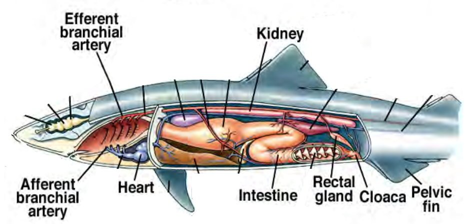
Osmoregulation: Sharks & Rays
almost osmoconformers

- Tissue salt concentration same as bony fish
- Make up the difference from seawater with **urea**
  - Need carnivorous diet for sufficient organic nitrogen
  - Use trimethylamine oxide (**TMAO**) to block toxic effect of high urea on protein structure
- Actually overcompensate: slightly hypertonic to seawater
  - Passively gain water. Do not need to drink.



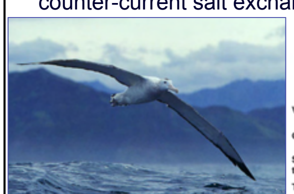
Osmoregulation: Sharks & Rays
almost osmoconformers

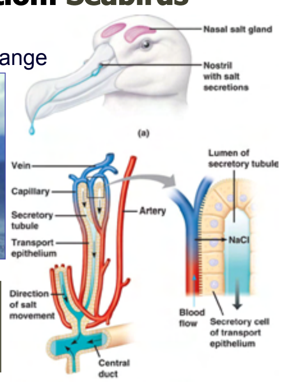
- Kidneys retain urea
- Don't need to worry about water, but must dump salt
- Chloride cells in gills, intestines, kidney & and rectal gland actively secrete



Osmoregulation: Seabirds

- **Transport epithelia** & counter-current salt exchange





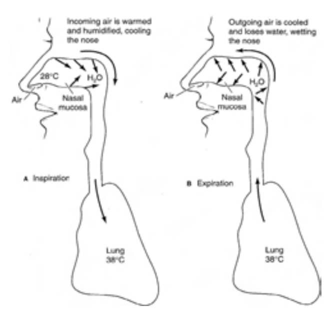
- Similar salt gland tissue in nasal passages of marine iguanas & tear glands of sea turtles

Speaking of noses, …

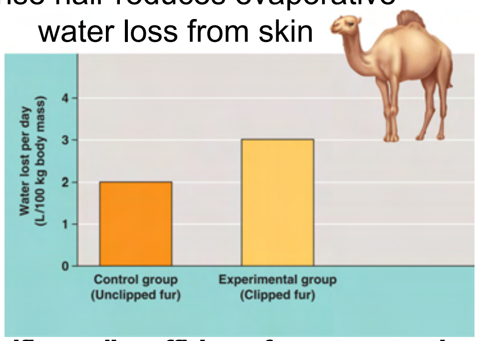
Water reclamation in mammals

Turbinals: ↑sa in nasal passages

1. Inspired air warmed & humidified
2. Evaporative cooling of nasal surface
   - May also cool cerebral blood flow
3. **Expired air cooled → water reclaimed**



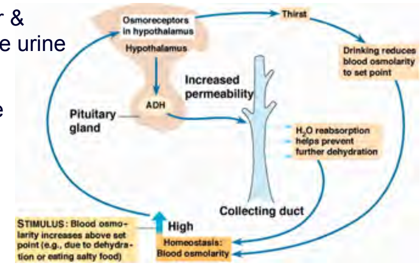
Dense hair reduces evaporative water loss from skin



Sacrifice cooling efficiency for water retention

Terrestrial animals — most regulation of water & salt exchange occurs in **excretory system**

- ↑Osm → drink water & concentrate urine
- ↓Osm → dilute urine



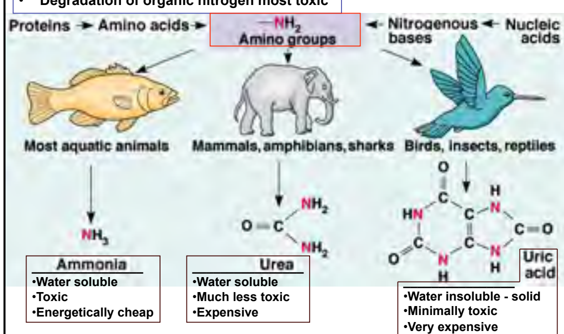
Excretory Systems

"Conditioning" the body fluids

- Water & electrolyte balance
- Maintain extracellular fluid volume (ECF)
  - Including blood plasma volume & P_B
- Remove waste products
  - esp., nitrogenous wastes
- Retain nutrients

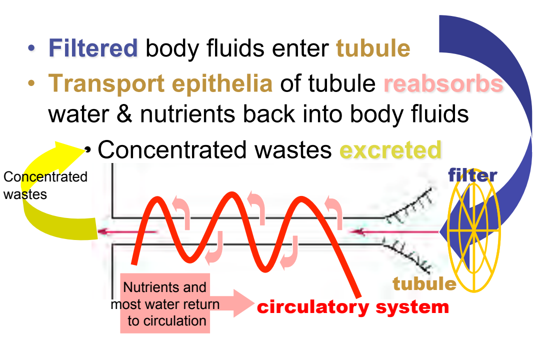
Nitrogenous wastes

- Waste by-products of metabolism
- Degradation of organic nitrogen most toxic



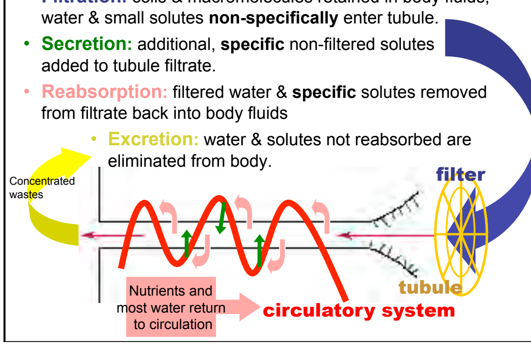
Excretory System **Components**

- **Filtered** body fluids enter **tubule**
- **Transport epithelia** of tubule **reabsorbs** water & nutrients back into body fluids
  - Concentrated wastes **excreted**



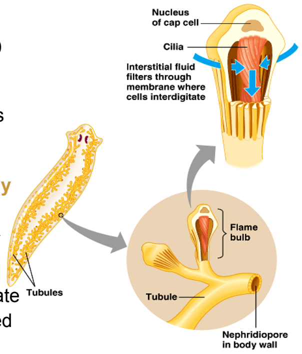
Excretory System **Processes**

- **Filtration:** cells & macromolecules retained in body fluids; water & small solutes **non-specifically** enter tubule.
- **Secretion:** additional, **specific** non-filtered solutes added to tubule filtrate.
- **Reabsorption:** filtered water & **specific** solutes removed from filtrate back into body fluids
  - **Excretion:** water & solutes not reabsorbed are eliminated from body.



Protonephridial Excretory System

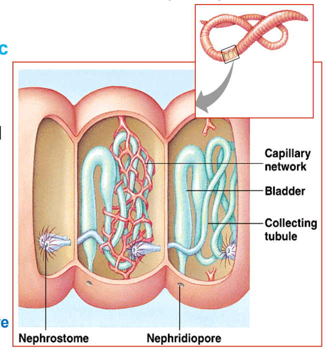
Platyhelmintes (*Planaria*)
Freshwater flatworm
- Flame bulb: cap cell (flame cell) interdigitates with tube cell
- Cap cell cilia beat
  - draw **interstitial body fluid** through slits
  - filter excludes cells & proteins
  - selected solutes reabsorbed from filtrate
  - excess water excreted via **nephridiopore**



Metanephridial Excretory System

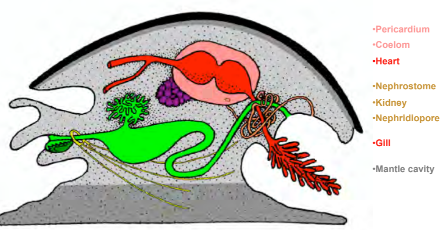
- Ciliated **nephrostome** draws filtered **coelomic fluid** into tubule
- Tubule reabsorbs nutrients, most salt & water into capillary bed
- Concentrated wastes collect in bladder until excreted

Annelid worm
- Pair of metanephridia in each segment
- Nephrostome draws from adjacent segment
- Excretion via **nephridiopore**
  - External or into gut



- http://www.biology.ualberta.ca/courses.hp/zool250/animations/Excretion.swf

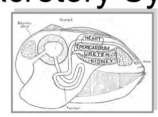
Metanephridial Excretory System

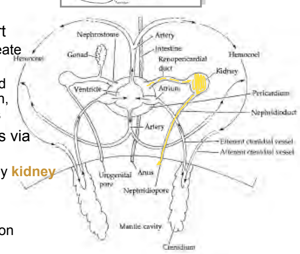


Mollusc
- Ultrafiltration of hemolymph across thin wall of cardiac atrium into pericardial coelom
- Paired **nephrostomes** draw **coelomic fluid** into metanephridia tubules consolidated into **kidney**
- Excretion via **nephridiopore** into mantle cavity
- Probably **not** homologous to annelid metanephridia
  - (annelid origin = mesoderm; mollusk origin = ectoderm)

Metanephridial Excretory System

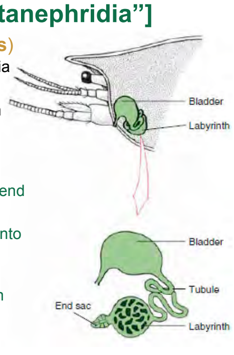
Aquatic **Mollusc** (clam)
- Hemolymph drawn by afferent vein to gill (ctenidium)
  - Lose ammonia to water flowing through the mantle cavity
- Hemolymph continues from gill by efferent vein to atrium of heart
  - Water and small solutes permeate into pericardial (coelom) fluid
  - Cells, respiratory pigments, and proteins retained in hemolymph, pumped by ventricle to arteries
- Coelomic fluid drawn into tubules via ciliated **nephrostomes**
  - Essential solutes reabsorbed by **kidney**
- Excretion via **nephridiopore** into **mantle cavity**
  - Swept away via excurrent siphon



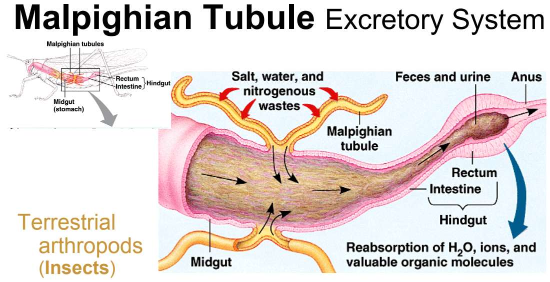


antennal gland nephridia
[“saccate metanephridia”]

Aquatic arthropods (**Crustaceans**)
- Most water/salt balance and ammonia excretion in **gills**
- Additional secretion & excretion from **antennal gland**
- Most body cavity is the hemocoel. Coelom reduced to small end sac.
- Ultrafiltration of hemolymph through end sac to form tubule filtrate.
- Hydrostatic pressure pushes filtrate into tubules for selective reabsorption.
  - Remember — No cilia!
- Wastes excreted via nephidiopore on base of antennae.
- Esp. large in freshwater spp. — need to dump water.



Malpighian Tubule Excretory System



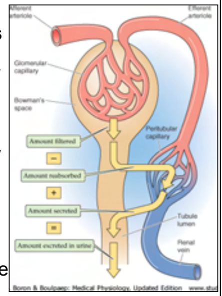
Terrestrial arthropods (**Insects**)
- Wastes secreted from hemolymph into tubules. Water follows ➔ flushes into gut
- Nitrogenous waste precipitated as uric acid. Water & salts reabsorbed in hind gut
- Almost solid feces+wastes excreted

Vertebrate **Renal** Excretory System

Nephron: functional unit of the vertebrate **kidney**

- Tubule + associated capillary beds

- **Filtration**: P_B pushes plasma water & small (non-protein) solutes from first (glomerular) capillary bed into tubule
- **Reabsorption**: vital components (nutrients, most salt & water) actively/ specifically transported back into second (peritubular) capillary bed
- **Secretion**: specific wastes or salt actively/specifically transported from second capillary bed into tubule filtrate
  - ↑F and/or ↑S → ↑excretion
  - ↑R → ↓excretion



Mammal **Renal** Excretory System

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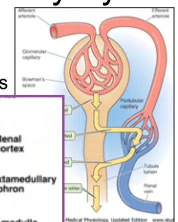
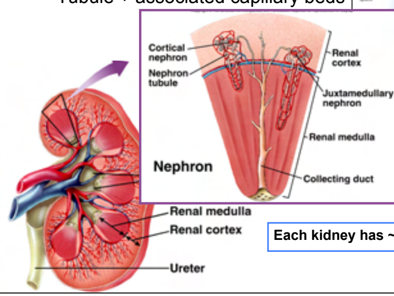
- Tubule + associated capillary beds

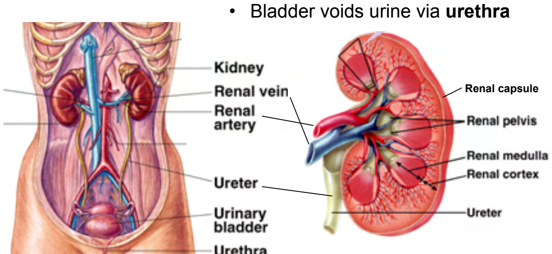




Each kidney has ~1 million nephrons!

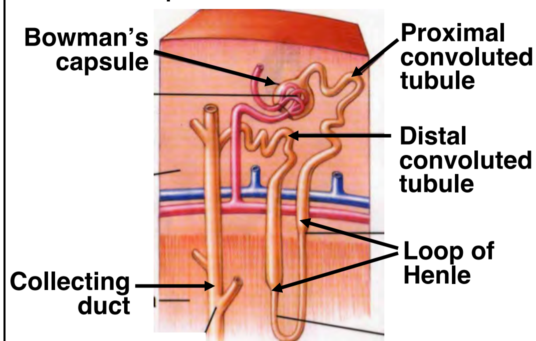
Human **Renal** Excretory System

- 20% of systemic blood circulation flows through kidney
- Urine from >1 million nephrons converges at renal pelvis
- Urine flows via **ureter** from each kidney to **bladder**
  - Bladder voids urine via **urethra**

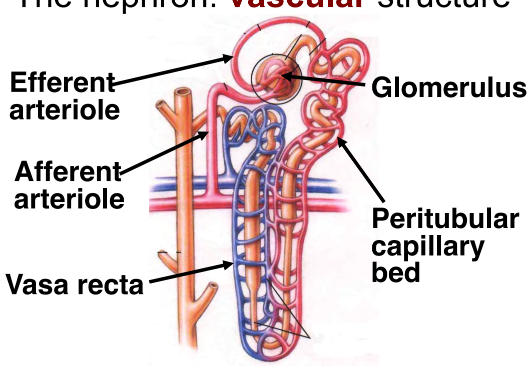


✧All blood passes through kidney 200-300 times/day.
✧Highest blood flow & metabolic rate per gram of any

The nephron: **tubule** structure



The nephron: **vascular** structure



Filtration, *Reabsorption* & *Secretion* in Tubule

Renal Corpuscle
Ultrafiltrate from glomerulus to Bowman's capsule

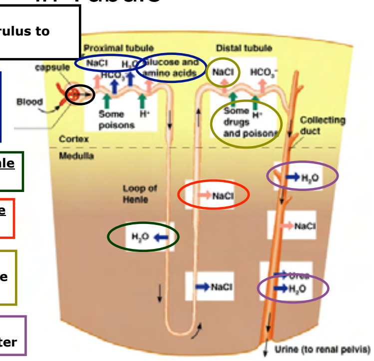
Proximal Tubule
Reabsorb nutrients (Glucose, aa's) + most water & salt

Descending Loop of Henle
Get back more Water

Ascending Loop of Henle
Pump back more Salt

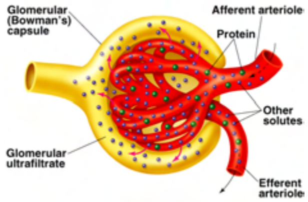
Distal Tubule
Secrete Drugs Into Urine
Reabsorb more Salts

Collecting Duct
Get Back Additional Water

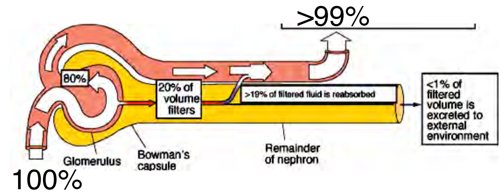


Glomerular Ultrafiltrate

- Fluid in glomerular capsule is called **ultrafiltrate**.
  - Glomerular filtration:
    - Mechanism of producing ultrafiltrate under hydrostatic pressure of the blood.
      - Process similar to the formation of tissue fluid by other capillary beds.
- Glomerular filtration rate (GFR):
  - Volume of filtrate produced by both kidneys each minute.
    - Averages ~120ml/min (115 ml/min. in women; 125 ml/min. in men.)

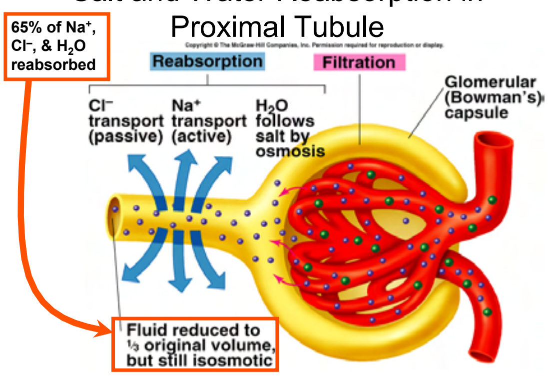


Glomerular Filtration

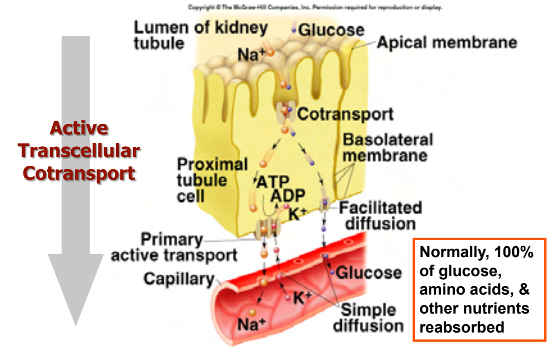


- 20% of plasma that enters glomerulus is filtered into nephron
- Kidneys filter 180 liters of fluid per day, but produce only ~1.5 liter of urine
- Minimum of 400 ml/day urine necessary to excrete metabolic wastes (obligatory water loss).

Salt and Water Reabsorption in Proximal Tubule

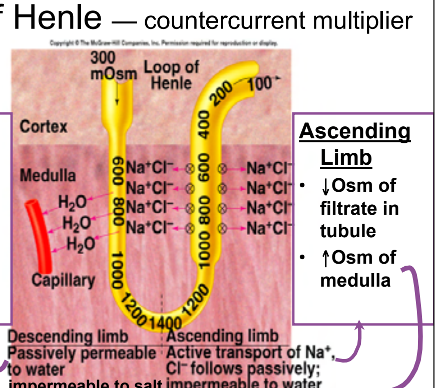


Reabsorption of Circulating Energy Substrates in **Proximal Tubule**



Loop of Henle — countercurrent multiplier

Decending Limb
- ↑Osm of filtrate in tubule
- ↓volume of filtrate in tubule

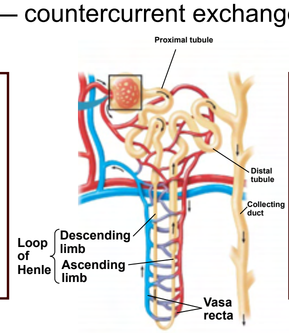


Ascending Limb
- ↓Osm of filtrate in tubule
- ↑Osm of medulla

Loop of Henle & the Vasa Recta

— countercurrent exchange

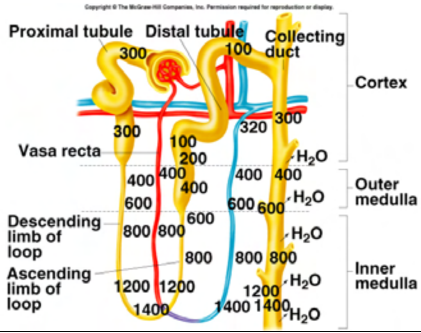
Ascending Vessel
- Collects H_2O from Decending Limb
- ↓ Osm & ↑ volume of plasma



Decending Vessel
- Collects NaCl from Ascending Limb
- ↑Osm of plasma

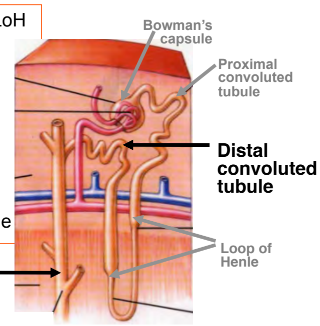
After PCT & LoH, 90% of NaCl & 85% of H_2O reabsorbed

Osmolality of Different Regions of the Kidney



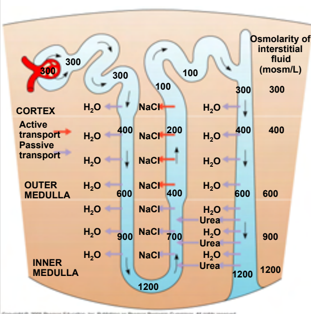
Distal Convoluted Tubule & cortical region of Collecting Duct

- Filtrate hypotonic from LoH
- Continue active Na^+ transport & Cl^- cotransport
- 98–100% of filtered NaCl now reabsorbed
  - Actual amount regulated by **aldosterone** hormone

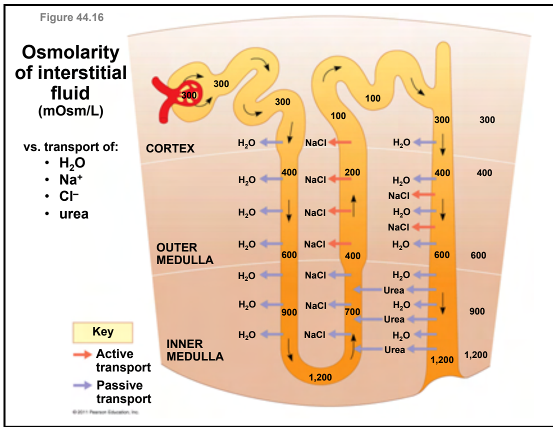


Collecting Duct

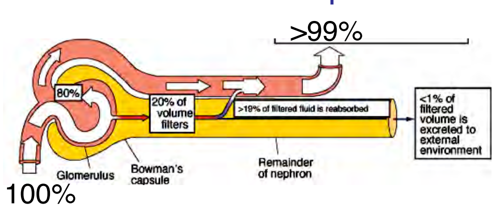
DCTs of several nephrons converge on each collecting duct



- Filtrate travels through collecting duct back through medulla
- Becomes isotonic to medulla by losing water
- Some urea diffuses out → adds to medulla Osm
- Rate of water reabsorption depends on # of **aquaporins** in tubule membrane
- # of aquaporins & urea transporters regulated by **antidiuretic hormone (ADH)**



Water Reabsorption

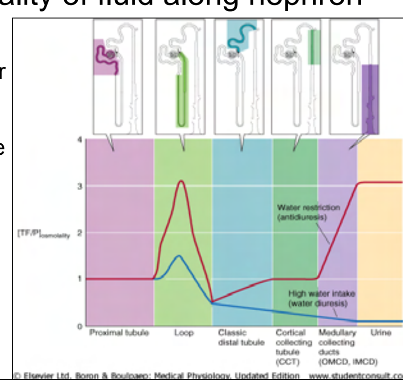


Kidneys filter 180 liters of fluid per day, …

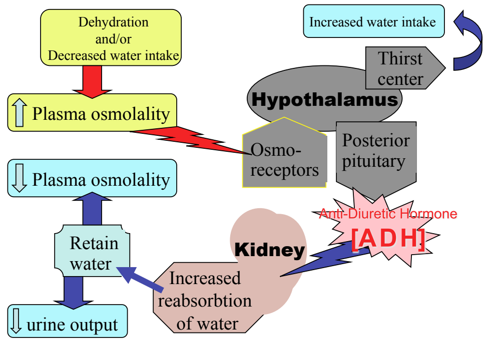
- No ADH → 99.2% of filtered H2O reabsorbed
  - … but produce only ~1.5 liter of urine
- Maximum ADH → 99.8% of filtered H2O reabsorbed
  - Minimum of 400 ml/day urine necessary to excrete metabolic wastes (obligatory water loss).

Osmolality of fluid along nephron

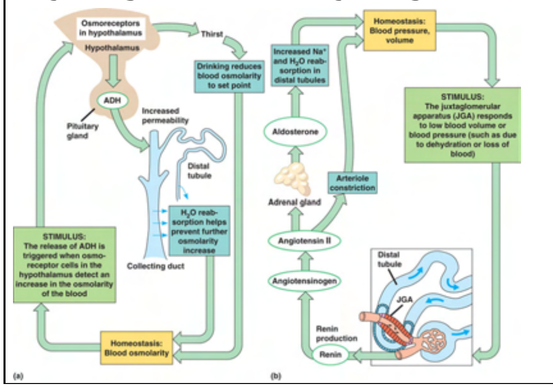
- Red = water restriction
- Blue = high water intake



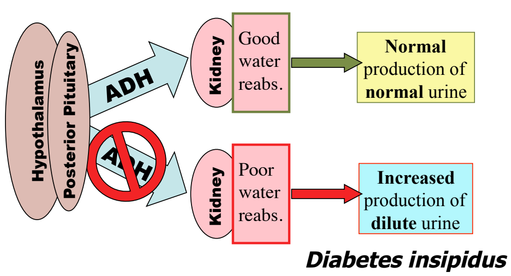
Regulation of plasma osmolarity



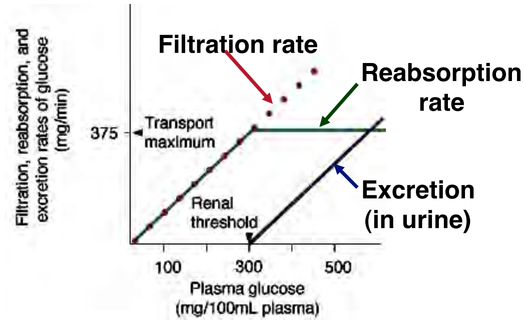
Adjusting the Urine ⇔ Adjusting the Blood



ADH Insufficiency



Glucose handling by nephron



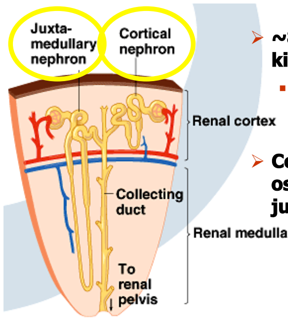
Glucosuria: glucose in urine

- Glucose completely reabsorbed under normal conditions
- ***Diabetes mellitis***: insulin deficiency causes blood glucose levels to exceed renal threshold (more than can be reabsorbed)
- Excess **glucose excreted in urine**
- Glucose in urine osmotically holds more water in urine

"Diabetes" = increased urine output

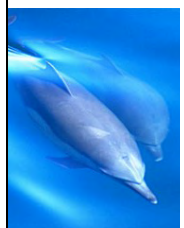
Type	*Etiology*	*Primary effect*	*Symptom*	*Urine Osm*
Diabetes insipidus	insufficient ADH action	renal tubule water permeability impaired	**increased urine output**	dilute; "bland urine"
Diabetes mellitus	insufficient insulin action	elevated osmotic pressure of renal filtrate	**increased urine output**	high [glucose]; "sweet urine"

Two kinds of nephrons



- **~85% of nephrons in human kidney are cortical nephrons.**
  - **short Loops of Henle extend only to outer medulla**
- **Cortical nephrons use the osmotic gradient created by juxtamedullary nephrons.**

Living in extreme environments — no fresh water



Marine Mammals

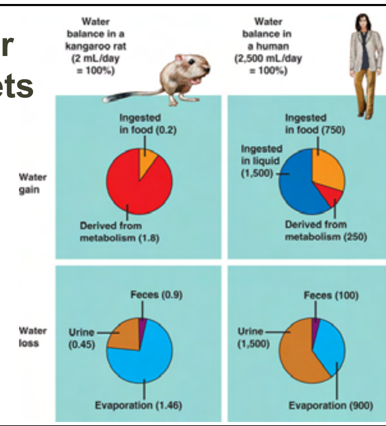
- Higher proportion of juxtamedullary nephrons with very long Loops of Henle
  - ↑Osm of renal medulla → ↑Osm of urine
- Can drink seawater and dump salt for net water gain
  - Human would take 135 ml of urine to dump salt from 100 ml seawater → net water loss
  - Dolphin takes only 65 ml urine to dump salt from 100 ml seawater → net water gain

Living in extreme environments — no fresh water

Desert Mammals — **Kangaroo Rat**

- Forage at night; hide in humid burrow in daytime
- Extensive nasal turbinates
- Large kidney with higher proportion of juxtamedullary nephrons with very long Loops of Henle
  - ↑Osm of renal medulla → ↑Osm of urine
- Does not drink! — **Metabolic water**
- Eats almost exclusively seeds with high oil content
  - ↑fat → ↑water & energy yield
  - ↓↓protein → ↓↓nitrogenous wastes
  - ∴ no need to produce much urine

Water Budgets



Avian **Renal** Excretory System

- Drink little — Cannot afford the weight of excess water
- Juxtamedullary nephrons only have short Loops
- ∴ urine only slightly hypertonic to tissues
- But since nitrogenous wastes excreted as solid paste of uric acid, ∴ no need to produce much urine
- Water reabsorbed in cloaca
  - Transport epithelia

Reptilian **Renal** Excretory System

- Ectothermic — hot habitats
- Cortical nephrons only!
  - **no** Loops of Henle
  - (only in mamms & birds)
- ∴ urine only isotonic to tissues
- But since nitrogenous wastes excreted as solid paste of uric acid, ∴ no need to produce much urine
- Water reabsorbed in cloaca