Osmoregulation II: Kidney Structure & Function

- Basic unit is called **nephron**, 1,000,000 of these make up a kidney.
- A nephron is a tube but its functioning is complex!
Migratory salmon

Freshwater breeding ground

Young salmon migrate downstream

Sexually mature adults return to fresh water to breed

Most salmon spend 3–5 years in the open ocean, feeding and growing

Ocean
Young salmon in freshwater

Gill filament

Electrolytes IN

Chloride cells located on lamellae of gill filaments import electrolytes

Young salmon in seawater

Gill filament

Electrolytes OUT

Chloride cells located at base of gill filaments secrete electrolytes
(a) Responses of gill proteins to transitions between freshwater and seawater

- Transferred to seawater
- Transferred to freshwater
- Trout acclimating to seawater
- Trout acclimating to freshwater

![Diagram of protein abundance changes over time](image)

- The abundance of each protein is expressed per unit of gill tissue (in arbitrary units).

(b) Gill tissue in which Na-K-2Cl transporter is stained for identification

- Acclimated for >60 days to seawater
- Acclimated for >60 days to freshwater

![Stained tissue images](image)
terrestrial animals
<table>
<thead>
<tr>
<th></th>
<th>mOsm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seawater</td>
<td>1100</td>
</tr>
<tr>
<td>Freshwater</td>
<td>2-8</td>
</tr>
<tr>
<td>Air</td>
<td>~0</td>
</tr>
<tr>
<td>Marine vertebrates</td>
<td></td>
</tr>
<tr>
<td>sharks</td>
<td>~1075</td>
</tr>
<tr>
<td>teleosts</td>
<td>310-450</td>
</tr>
<tr>
<td>Freshwater vertebrates</td>
<td></td>
</tr>
<tr>
<td>teleosts</td>
<td>280-320</td>
</tr>
<tr>
<td>frog</td>
<td>210</td>
</tr>
<tr>
<td>Terrestrial vertebrates</td>
<td></td>
</tr>
<tr>
<td>Reptiles</td>
<td>~250</td>
</tr>
<tr>
<td>Mammals</td>
<td>~300</td>
</tr>
</tbody>
</table>
(a) Northern fulmar

Salt-gland secretions exit by way of the nostrils, which are positioned high on the bill in tube-nosed birds such as fulmars, but at the end of the bill in most birds.

(b) Herring gull

Each gland consists of many longitudinal lobes, each of which contains a large number of branching, radially arranged secretory tubules that discharge into a central canal.
salt droplets
Reptiles, birds

- Salt gland: hypertonic NaCl
- Drinks sea water
- Gut
- Kidney

- Isotonic urine 300 mOsm (slightly hyperosmotic in some birds)

- ≈ 300 mOsm
- ≈ 1000 mOsm

Mammals

- No drinking
- Gut
- Kidney

- Hypertonic urine (1200–1500 mOsm)

- ≈ 300 mOsm
- ≈ 1000 mOsm
What about mammals and humans?

Q. To what aquatic osmotic gradient are humans most similar?
Osmotic pressure (mOsm)

Seawater 1100
Freshwater 2-8
Air ~0

Marine vertebrates
- sharks ~1075
- teleosts 310-450

Freshwater vertebrates
- teleosts 280-320
- frog 210

Terrestrial vertebrates
- Reptiles ~250
- Mammals ~300
What Does the Kidney Regulate?

- Blood volume and blood pressure
- Plasma ion concentrations
- Blood pH
- Valuable nutrients (e.g., glucose)
- Nitrogenous waste from protein catabolism
Water: largest constituent of body; 55-65% of body weight

<table>
<thead>
<tr>
<th>Intake</th>
<th></th>
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<tbody>
<tr>
<td>In liquids</td>
<td>1200 ml</td>
</tr>
<tr>
<td>In food</td>
<td>1000 ml</td>
</tr>
<tr>
<td>Metabolically produced</td>
<td>350 ml</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2550 ml</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Output</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Insensible loss (skin and lungs)</td>
<td>900 ml</td>
</tr>
<tr>
<td>Sweat</td>
<td>50 ml</td>
</tr>
<tr>
<td>In feces</td>
<td>100 ml</td>
</tr>
<tr>
<td>Urine</td>
<td>1500 ml</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2550 ml</strong></td>
</tr>
</tbody>
</table>
Gross Anatomy

Typical adult kidney:
- ~10 cm long
- 5.5 cm wide
- 3 cm thick
- 150 g

Filtrate->Resorption/Secretion->Excretion
Gross Anatomy

Either side of vertebral column:
- left kidney lies superior to right kidney
- superior surface capped by adrenal gland

Position is maintained by:
- overlying peritoneum
- contact with adjacent visceral organs
- supporting connective tissues
Blood Supply

~20% of Cardiac Output
- Filters 60x Plasma Volume/day
In Cross Section

- Note path of urine (green)
- Filters 60x Plasma Volume/day
- Nephrons = functional units of the kidney
- Located in cortex & medulla of kidney in the renal pyramids
- Drain into renal pelvis
- ~1 million nephrons
- Path of urine flow shown in green
Nephron

Diversity of Nephron morphology
Filtration: Glomerulus and Bowman’s Capsule

- Efferent arteriole
- Glomerular capillary
- Capsular space
- Parietal epithelium
- Pedicels
- Visceral epithelium
- Proximal convoluted tubule
- Distal convoluted tubule
- Macula densa
- Juxtaglomerular cells
- Juxtaglomerular apparatus
- Afferent arteriole
- Bowman’s capsule
- Podocyte
- Pores
- Supporting cell
- Capillary endothelial cell
- Filtration slits
- Lamina densa
- RBC
- Capsular space
Filtration: Glomerulus and Bowman’s Capsule
Filtration: Glomerulus and Bowman’s Capsule
Filtration: Glomerulus and Bowman’s Capsule

Filtrate from opposing pressures:

hydrostatic pressure from the heart favors filtration, osmotic and hydrostatic pressure of the filtrate oppose it.

<table>
<thead>
<tr>
<th>Forces</th>
<th>mmHg</th>
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<tbody>
<tr>
<td><strong>Favoring filtration:</strong></td>
<td></td>
</tr>
<tr>
<td>Glomerular capillary blood pressure ((P_{GC}))</td>
<td>60</td>
</tr>
<tr>
<td><strong>Opposing filtration:</strong></td>
<td></td>
</tr>
<tr>
<td>Fluid pressure in Bowman’s space ((P_{BS}))</td>
<td>15</td>
</tr>
<tr>
<td>Osmotic force due to protein in plasma ((\pi_{GC}))</td>
<td>29</td>
</tr>
<tr>
<td><strong>Net glomerular filtration pressure</strong></td>
<td>16</td>
</tr>
<tr>
<td>(P_{GC} - P_{BS} - \pi_{GC})</td>
<td></td>
</tr>
</tbody>
</table>
Countercurrent multiplier

Ascending limb is impermeable to water

Q. Is composition of filtrate the same along nephron?
Countercurrent multiplier

Ascending limb is impermeable to water
The geometry of the vasa recta parallels the renal counter-current multiplier system, assuring that the blood in these vessels does not "wash out" or dilute the medullary osmotic gradient.
Because plasma volume is about 3L, all plasma is filtered about 60x a day.

**Urea** is the main nitrogenous waste product: some is excreted, and some is retained as a solute within the medulla.