Excretion
Structure and Function of the Nephron

Blood flow from Interlobular art.
Afferent arteriole
Visceral layer parietal layer capsular space \{Bowman’s capsule

DCT location in Juxtaglomerular Apparatus
Vascular pole

Efferent arteriole

Glomerulus

Proximal convoluted tubule

Peritubular cap

Distal convoluted tubule

Medulla

1 = Filtration - Pressure forces water and dissolved substances from glomerular blood into Bowman’s capsule. Amounts to 125 ml/min.

2 = Reabsorption - The return of substances from the filtrate to the blood and interstitial fluid. Water by osmosis; NaCl, glucose, and amino acids by active transport

3 = Secretion - The active release of substances by the tubular lining cells into the nephron tubule. (A) Gets rid of toxins and residues, (B) electrolyte balance, mostly releasing K^+, (C) acid base balance by releasing H^+, NH_4^+.
Retention, Filtration and Reabsorption

- Retention (Not filtered) - proteins, blood cells
- Filtered 95% of plasma - water, glucose, amino-acids, sodium (Na\(^+\)) etc.
- Re-absorbed - water, glucose, amino-acids, sodium (Na\(^+\)), K\(^+\), Ca\(^{++}\), phosphate, chloride etc.
  - Active transport with ATP expended
  - Passive (e.g. H\(_2\)O following ions)
  - Counter current mechanism (next slide)
Each nephron is served with blood by the **afferent arteriole**. This vessel brings blood into a capillary tuft called the **glomerulus**. Blood leaving the glomerulus flows into the **efferent arteriole**.
A capillary tuft differs from a capillary bed in that it does not perfuse a tissue like a capillary bed does. Instead this capillary tuft is a condensed mass of capillaries which allows substances to escape by filtration. The capillaries of this tuft are surrounded by specialized cells which form the inner (visceral) layer of Bowman's capsule. The parietal layer is composed of simple squamous cells with tight junctions that form an outer wall which contains the filtrate.
Structure of the Nephron: Tubules

- Afferent arteriole
- Glomerulus
- Bowman's capsule
- Proximal convoluted tubule
- Descending limb
- Loop of Henle
- Distal convoluted tubule
- Ascending limb
- Collecting tube (duct)
Vascular System of the Nephron

- Afferent arteriole
- glomerulus
- Bowman’s capsule
- Proximal convoluted tubule
- Distal convoluted tubule
- Loop of Henle
- Collecting tube
- Peritubular capillaries
- Vasa recta: Ascending limb
- Descending limb
- Cortex
- Medulla
Cortical nephrons have short loops of Henle which barely enter the medulla. Longer loops which dip much further into the medulla belong to juxtamedullary nephrons. These nephrons are important for concentrating the urine by absorbing extra water.
Step 1 in urine formation, **Filtration** - Fluid pressure forces water and dissolved substances out of the blood into Bowman's capsule. Filtration averages 125 ml/min for your two kidneys. This amounts to about 180 Liters per day. Since we urinate an average of 1500 ml per day, more than 99% must be returned to the blood. Filtration involves the small molecules: water, electrolytes, urea, glucose, amino acids. It does **not** involve the blood proteins or cells. The large amount of filtration is the result of the porous glomerular membrane and filtration slits in the visceral layer of Bowman's capsule.
1. Filtration

Filtration – Hydrostatic pressure (blood pressure) forces water and dissolved substances out of the glomerular blood into Bowman’s capsule.

$H_2O, \ glucose, \ amino \ acids, \ electrolytes, \ wastes$

Averages 125 ml/min for both kidneys $\rightarrow$ 180 liters/day

The vast majority of the filtrate must be taken back!

Filtration is a product of the blood pressure and the nature of the fenestrated capillaries which make up the **glomerulus**.
Filtration

Effective filtration pressure =
Blood pressure in afferent glomerular artery -
(osmotic pressure of blood colloids +
capsular pressure attributable to Bowman’s capsule)
The capillaries of the glomerulus are surrounded by specialized cells which form the inner (visceral) layer of Bowman's capsule. (See Figures 26.7 and 26.8) These specialized cells are called podocytes (foot cells) because they have processes called pedicels which interdigitate or interlace producing openings called filtration slits. The capillaries are fenestrated in order to allow a large amount of filtration. The outer (parietal) layer of Bowman's capsule consists of epithelial cells with tight junctions and serves to contain the filtrate in the capsular space.
The filtration membrane is a double layered membrane composed of the endothelial cells of the capillary wall juxtaposed with the podocytes of the visceral layer of Bowman’s capsule. Substances make their way through the capillary fenestrations, then through the combined basement membranes of capillary and podocyte cells, and through the filtration slits into the capsular space.
Step 2: Reabsorption

Reabsorption – the return of substances from filtrate in the nephron tubule to the blood or interstitial fluid.

$\text{H}_2\text{O} - \text{osmosis}$

$\text{NaCl} - \text{active transport}$

Glucose, amino acids - active co-transport
Reabsorption of materials from the proximal convoluted tubule back into the blood.
Locations of Reabsorption

- Afferent arteriole
- Efferent arteriole
- Glomerulus
- Bowman’s capsule
- Proximal convoluted tubule
- Distal convoluted tubule
- Loop of Henle
- Collecting tube
- Peritubular capillaries
- Ascending limb
- Descending limb
- Vasa recta
Reabsorption from Proximal Convoluted Tubule

A) H₂O – pulled by osmosis into hypertonic blood. 65% occurs in PCT
B) NaCl – active transport of either Na⁺ or Cl⁻, pulls water along.
C) 100% of glucose and amino acid transported - occurs in PCT by active co-transport.

Water is reabsorbed by osmosis. Entering the proximal convoluted tubule the filtrate is very dilute compared to the blood. 65% of water reabsorption occurs from the PCT as a result of this osmotic gradient.
As the filtrate enters the descending limb of the loop of Henle, especially in juxtamedullary nephrons with long loops, it is exposed to increasingly hypertonic medulla. This pulls at least another 20% of absorbable water out of the filtrate. Reabsorption in this area is termed obligatory because it must occur due to the osmolarity of the surrounding interstitial fluid.
1) The **counter-current multiplier** – increases the amount of $\text{H}_2\text{O}$ reabsorbed because of opposite movement in the two limbs of the loop of Henle.

The **Countercurrent Multiplier** - This mechanism works in the loop of Henle to increase water reabsorbed from the descending limb as a result of salt reabsorbed from the ascending limb. The term countercurrent comes from the fact that fluid is moving in opposite directions in the two limbs of the loop. This magnifies the effect of transport from one limb on transport from the other limb. The same principle is at work in heat exchangers used in industry.
The Counter-Current Multiplier

NaCl absorbed from the ascending limb pulls more water from the descending limb than it would if their fluid were passing in the same direction.

The nephron tubule is impermeable to water from the thin segment of the ascending limb to the collecting tube, thus preventing reabsorbed water from escaping into the urine.

As the filtrate enters the thin segment of the ascending limb the tubule becomes impermeable to water. Otherwise it might actually diffuse back into the tubule as the osmotic gradient reverses.
The Counter-Current Mechanisms

1) The counter-current multiplier – increases the amount of H₂O reabsorbed because of opposite movement in the two limbs of the loop of Henle.

2) The countercurrent exchange of salt – increases the reabsorption of H₂O by retaining NaCl in the medulla.

The countercurrent exchange of salt in the vasa recta. The vasa recta has descending and ascending limbs too. Blood flowing into the medulla in the descending limb picks up salt from the hypertonic medulla. As the surrounding medullary fluid becomes more and more salty toward the papilla the gradient increases and more and more salt is picked up by the descending vasa recta limb. But as the blood heads back up to the cortex in the ascending limb of the vasa recta, the interstitial fluid becomes less and less salty. This causes the gradient to reverse and salt diffuses back out of the vasa recta into the medulla. This helps to conserve salt and keep the medulla hypertonic.
1) NaCl is picked up by the descending limb of the vasa recta. 2) NaCl is released into the medulla by the ascending limb of the vasa recta. This mechanism recycles the salt and keeps the deep medulla hypertonic.

From the ascending limb of Henle’s loop through the distal convoluted tubule the nephron is impermeable to water. This prevents the reabsorbed water from being lost to the urine.
Reabsorption of NaCl from the distal convoluted tubule is controlled by **aldosterone** from the adrenal cortex.
Importance of sodium

- 90% of extra-cellular cations
- Little in cells
- No reserve
- Conservation important
- 97-98% Na+ reabsorbed by countercurrent mechanism.
- Hormone aldosterone - More sodium retained (2-3% of filtered Na+ under its control)
Aldosterone

- Acts to retain/re-absorb $\text{Na}^+$ and loss of $\text{K}^+$
- Mineralocorticoid
- Produced by the adrenal cortex
- Steroid
- Control of release
  - Renin-angiotensin (juxta-glomerular apparatus and cells, macula densa)
  - Adrenocorticotropic hormone (ACTH)
Arginine vasotocin (AVT)

- Also, acts on collecting ducts to retain/re-absorb water and $\text{Na}^+$
- It is the avian version of ADH (antidiuretic hormone)
- Peptide
- Released by the posterior pituitary gland
- Lack - diabetes insipidus
From the ascending limb through the DCT the tubule is nearly impermeable to water, thus little water moves back into the filtrate.

As filtrate in the collecting tube passes through the hypertonic medulla water reabsorption again takes place under control of ADH.

Facultative Reabsorption of Water from the Collecting Tube

Anti-diuretic Hormone (ADH) from the posterior pituitary makes the collecting tube permeable to water.

When the filtrate, now nearly urine, passes through the medulla again in the collecting tubule it is once again exposed to the hypertonicity of the deep medulla. This has the potential to pull more water out by osmosis. But reabsorption of water from the collecting tubule is facultative because it is under control of the hormone ADH.
Facultative Reabsorption of Water: The ADH Mechanism

$2^{nd}$ stimulus is decreased blood volume and pressure.

↑ Blood Osmolarity → Hypothalamus → Posterior Pituitary

Negative feedback can turn off ADH secretion

Increased H$_2$O reabsorption from the collecting tube

Anti-Diuretic Hormone

Drinking plain water dilutes the blood and turns off ADH secretion. To avoid loss of water to urine drink isotonic saline solution (e.g. Gatorade)
High blood osmolarity → Hypothalamic osmoreceptors → ADH secretion → ADH release from pituitary gland → ADH inhibits water reabsorption → Increased permeability → Water reabsorption → Lower blood osmolarity
Thirst

• Thirst (hypothalamus) is to overcome:
  – Insensible water loss - respiration
  – Sensible water loss - urine (+ feces)
Step 3: Secretion

- Secretion is the active release of substances into the nephron tubule by the tubular lining cells.
Secreted Substances

Secretion is the active release of substances into the nephron tubule by the tubular lining cells.

Toxins and drug residues.

Electrolyte balance: $K^+$ exchanged for $Na^+$

Acid-base balance: $H^+$, $NH_4^+$
$Cl^-$ exchanged for $HCO_3^-$

$H^+$ are obtained from reaction of $CO_2$ and water. Bicarbonate ions are always kept in exchange for chloride.
Abnormal Constituents of Urine

Glucose - Recent intake of sugary foods, diabetes m. 
Protein - Physical exertion, high protein; hypertension, glomerulonephritis. 
Ketone bodies - Starvation, untreated diabetes mellitus 
Hemoglobin - Hemolytic anemia, severe burns 
Bile pigments - Hepatitis, cirrhosis, bile obstruction 
Erythrocytes - Bleeding due to trauma, kidney stones, infection, cancer. 
Leucocytes - Urinary tract infection
Nasal Salt Glands

• Glands above beak that secret a saline (salt) solution to lower osmolarity and prevent excessive water loss.

• Can concentrate salt to 5x that of sea water.

• Found mostly in marine birds that drink salt water and eat fish.

• But also found in terrestrial birds.
Nasal Salt Glands

• Roadrunners and Savannah Hawks have active salt glands and can produce hypertonic secretions in response to their protein-rich diets.

• Other desert birds, such as the Sand Partridge and the Ostrich have functional salt glands that are stimulated in response to high temperature (conserve water).
Southern giant petrel portrait showing nasal salt gland
Nasal Salt Glands
How do they work?

• When a bird drinks seawater, sodium enters the blood plasma from the intestine and the solute concentration of the blood plasma increases.

• Then water moves out of cells (osmosis), increasing the extracellular fluid volume (ECFV). The increases in blood plasma solute concentration and ECFV stimulate salt gland secretion.
**Artery**

**Vein**

**Capillaries**

**Secretory tubule**

**NaCl**

**Lumen**

**Blood flow**

**Secretory cells**

Central canal (carries salt solution to the nasal cavity)
<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
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<tbody>
<tr>
<td>Total body water</td>
<td>60–70 ml/100 g body mass</td>
</tr>
<tr>
<td>Extracellular fluid volume</td>
<td>20–25 ml/100 g body mass</td>
</tr>
<tr>
<td>Plasma volume</td>
<td>3.5–6.5 ml/100 g body mass</td>
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<tr>
<td>Plasma osmolality</td>
<td>320–370 mosmol/kg water</td>
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<tr>
<td>Plasma Na⁺</td>
<td>150–170 meq/liter</td>
</tr>
<tr>
<td>Plasma K⁺</td>
<td>2–5 meq/liter</td>
</tr>
<tr>
<td>Plasma uric acid</td>
<td>0.1–1 mmol/liter</td>
</tr>
</tbody>
</table>

*Values are typical for adult birds. Data are taken primarily from Skadhauge (1981), which should be consulted for references to original literature; the ranges presented encompass most of the variability among data compiled in that review.*