Basic Dialysis Theory

John Sweeny
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Functions of the Kidney

Excretory functions
- fluid balance
- electrolyte balance
- acid/base balance
- removal of metabolic waste products

Hormonal functions
- regulation of blood pressure
- red blood cell production
- vitamin D metabolism
Kidney Fluid Balance

Blood flow through the kidney is about 20% of each heart beat (about 1200 ml/min.)

A person’s total blood supply circulates through the kidneys approximately 12 times/hr.

125 ml/min. of fluid is removed from the blood, however 124 ml/min. of fluid is returned to the blood

1 ml/min. of urine is produced (1500 ml/day)
Nephron Structure – Tubular Component

Illustration from Baxter’s Aquaduct CD
Bowman’s capsule - surrounds the glomerular capillaries and receives the “filtrate”

- Glomerular TMP = Blood Pressure (45 mmHg) – Colloid Osmotic Pressure (28 mmHg) – Back Pressure (10 mmHg) = 7 mmHg
- Kidney $K_{UF} = \frac{GFR}{TMP} = \frac{7,500 \text{ mL/hr}}{7 \text{ mmHg}} = 1070$

Proximal convoluted tubule
- glucose, amino acids, water, salts and some urea is reabsorbed in this area
- acid/base balance begins here
- drugs are secreted
- volume of filtrate is decreased by 65%
Nephron Structure – Tubular Component (continued)

**Descending Loop of Henle**
- water is reabsorbed in this area
- salts (sodium and potassium) are reabsorbed and secreted
- “concentrating” of the filtrate

**Ascending Loop of Henle** - salts are reabsorbed

**Distal convoluted tubule**
- water and sodium are reabsorbed
- ammonia and potassium are secreted
Nephron Structure – Tubular Component
(continued)

Collecting tubule

- water is reabsorbed
- acid/base regulation continues
- **Aldosterone** functions here to regulate sodium, chloride and potassium metabolism
- **Antidiuretic hormone (ADH)** functions here to increase the resorption of water
- “filtrate” has now changed to “urine”
Excretory Functions

Electrolyte balance

- **Proximal convoluted tubule** - glucose, amino acids, water, salts and some urea is reabsorbed

- *Aldosterone* is secreted by the adrenal gland which causes sodium retention and secretion of potassium and hydrogen ions in the tubules

- *Parathyroid hormone (PTH)* is secreted by the parathyroid glands which causes reabsorption of calcium and phosphorous in the tubules
Excretory Functions

Acid/base balance is primarily regulated by the kidneys

- catabolism increases acid (carbon dioxide) production
- acids are produced by metabolism of fats and carbohydrates
- some bases are created by protein metabolism
- compensation is what the body does to maintain a balance of acid and base
  - the kidneys increase or decrease bicarbonate reabsorption and increase or decrease hydrogen ions secretion
  - the lungs also compensate by increasing or decreasing respirations to correct
Excretory Functions

Removal of metabolic waste products

- Urea (Normal BUN = 10 – 20 mg/dL)
  - a by-product of protein metabolism
- Creatinine (Normal = 0.6 – 1.2 mg/dL)
  - a by-product of muscle metabolism
- Uric Acid (Normal = 2.0 – 7.5 mg/dL)
  - a by-product of protein/purine metabolism (which comes from organ meats, fish, beans, alcohol)

These are just three of a great number of waste substances created in the process of protein metabolism

Principals of Hemodialysis
Semi-permeable Membrane

Designed to keep blood components like red blood cells, platelets and large proteins on the blood side – they cannot pass through the membrane.

The membrane has pores, or openings, that are large enough to allow small molecules to pass, and others not.

Has the ability to also allow water molecules to pass through.

Think “sponge” not “Swiss cheese”.

Blood
Salt
Toxin
Membrane Transport Mechanisms

Solute + Solvent = Solution
Toxin/salt removal (solute)
- Diffusion (toxins and electrolytes)
- Convection (larger molecules > 1,000 daltons)

Water removal (solvent)
- Osmosis (body fluid shifts)
- Ultrafiltration (plasma water removal)
Removal of toxins from the blood is accomplished by:

- **Diffusion**
  - Toxins and electrolytes

- **Convection**
  - Large molecules (> 1,000 daltons)

- **Adsorption**
  - Largest molecules (beta-2-microglobulin)
Toxin Removal - Diffusion

Graham’s Law:

The rate of diffusion of molecules is inversely proportional to the square root of their masses.

Fick’s Law:

Diffusion is the movement of a solute from an area of greater to lesser concentration of solute until the concentration is equal.

The amount of blood that is completely “cleared” of a solute/toxin in a specific amount of time is called the ‘clearance’ measured in mL/min.
Concentration Gradient

The difference in concentration of solute from one solution to another
# Dialysate Chemistry vs. Blood Chemistry (milliEquivalents/Liter)

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Dialysate</th>
<th>Blood</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium</td>
<td>137 – 145</td>
<td>136 – 148</td>
</tr>
<tr>
<td>Potassium</td>
<td>0 – 4</td>
<td>3.5 – 5</td>
</tr>
<tr>
<td>Calcium</td>
<td>0.0 – 4.0</td>
<td>4.25 – 5.25</td>
</tr>
<tr>
<td>Magnesium</td>
<td>0.0 – 1.5</td>
<td>1.5 – 2.5</td>
</tr>
<tr>
<td>Chloride</td>
<td>101 - 108</td>
<td>95 - 103</td>
</tr>
<tr>
<td>Bicarbonate</td>
<td>25 - 40</td>
<td>22 - 26</td>
</tr>
<tr>
<td>Acetate</td>
<td>2.0 – 4.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Dextrose</td>
<td>70 – 100 mg/dL</td>
<td>0.0 – 250 mg/dL</td>
</tr>
<tr>
<td>Carbon Dioxide</td>
<td>35 – 70 mmHg</td>
<td>40 mmHg</td>
</tr>
</tbody>
</table>
Concentration Gradient - Flow Geometry

- **Blood In** (Urea = 80 mg/dL)
- **Dialysate In** (Urea = 0 mg/dL)
- **Dialysate Out** (Urea = 36 mg/dL)
- **Blood Out** (Urea = 8 mg/dL)
Membrane Surface Area and Wall Thickness

- **Internal Diameter**
  - Blood / Membrane Exposure vs. Ease of Blood Passage through Fiber

- **Wall Thickness**
  - Strength and Ease of Molecule Passage through Membrane vs. Strength of Fiber Wall

- Internal Diameter: 190 µ
- Wall Thickness: 100 µ
Resistance to Flow (KoA)
Diffusion Coefficient

Blood Film Layer...Resistance reduced by Thin Blood Channel Height and Rapid Blood Flow Rates

Membrane Thickness and Porosity is Fixed

Dialysate Film Layer...Reduced by More Rapid Dialysate Flow Rates

Clearance for a dialyzer can be calculated once the blood flowrate, dialysate flowrate, and KoA are known. KoA range = 250 - 1,400
Diffusion vs. Molecular Weight Chart

Sieving Coefficient = The ratio of the average concentrations of a substance across the membrane

![Diagram showing diffusion vs. molecular weight for different substances and membranes.]

- Conventional Membrane
- High Flux Membrane
- Normal Kidney

Solute Molecular Weight
Toxin Removal - Convection

The movement of solute in the same concentration as it exists in water, when water moves across a membrane.

Also called ‘solute drag’

Small molecules: Diffusion
Large molecules: Convection
Toxin Removal - Adsorption

Adsorption is not the same as Absorption
- Absorption – think sponge
- Adsorption – think clothing dye
  - Molecules bind permanently.

Membranes all adsorb to varying degrees
- Function of membrane material
- Only molecules that have a charge can be adsorbed (bound to the membrane)
- Dialysis membranes (currently) are not designed to bind specific molecules
Water Removal - Osmosis

The movement of a solvent (water) from an area of greater solvent concentration to an area of lesser solvent concentration, or from an area of lesser solute concentration to an area of greater solute concentration across a Semi-Permeable Membrane until the concentration is equal.

Semi-permeable Membrane

Salt  Water
Water Removal - Ultrafiltration

• The movement of a solvent from an area of greater hydraulic pressure to an area of lesser hydraulic pressure across a semi-permeable membrane
In dialysis, the movement of fluid through the membrane (dialyzer) is due to pressure being exerted by the dialysis machine

- Typically, ultrafiltration is from blood side to dialysate side
- Can go the opposite direction – backfiltration
Suggested Reading and Reference Material


