Kidney Dialysis Simulation: How to the human body gets rid of metabolic waste products.
(Adapted from Wards Kidney Dialysis Simulation Lab Activity)

Background
For an organism to survive, it needs to get rid of metabolic waste materials, as well as maintain proper concentrations of various necessary materials. For example, human food consists of carbohydrates, fats, proteins, various salts, and water. As these materials are metabolized or broken down, certain waste products are produced, such as carbon dioxide, water, urea and related nitrogenous compounds, salts, and various minerals. If these metabolic waste products remain in the body, they rapidly change the body’s homeostasis or steady state. To avoid this change in homeostasis, the body must get rid of (excrete) the waste products quickly and efficiently.

The kidneys are very important organs within the human body because they are essential to maintaining homeostasis within the body. We (human beings) have two bean-shaped kidneys that are found on the back of the abdominal cavity. A kidney is located on each side of the spine is about the size of a fist. All of the blood in the body must pass through the kidneys. The large amount of blood that is passed through the kidneys allows them to do the following:
- Assist in the regulation of blood pressure
- Stimulate red blood cell production
- Maintain calcium levels in the body
- Regulate the composition of the blood by keeping the pH, concentration of various ions, and the volume of water constant. The kidneys filter wastes (urea, ammonia, salts, drugs, water and other toxic substances) from the blood stream in order to keep the blood clean and chemically balanced.

The anatomy of the kidneys provides a greater understanding of the major role they have in maintaining homeostasis within a person’s body. (See Figure 1 on the top of page 2)

The renal artery transports blood from the blood from the body into the kidney, and the renal vein transports filtered blood back into the body. The outer region is known as the cortex, while the inner region is known as the medulla. The renal pelvis is a flat, funnel-shaped
cavity that collects urine in the ureters. Upon closer inspection of these regions of the kidney, thousands of tiny structures, known as nephrons, which is a tube closed at one end and open at the other. (See Figure 2). Nephrons make urine by filtering the blood of its smallest molecules and ions and then reclaiming the needed amounts of useful materials. Surplus or waste molecules and ions are left to flow out as urine.

The process of filtration begins as blood is carried to a tuft of capillaries called the glomerulus. The glomerulus filters the blood by hydrostatic blood pressure, forcing blood through the basement membrane and into the cavity of the glomular capsule, known as the Bowman’s capsule. Blood cells and proteins are too large to be filtered through this membrane in the blood. Water, small molecules, and ions filter through the capillary walls into the Bowman’s capsule, which is located at the closed end of the nephron. The fluid is called nephric filtrate. Here most of the glucose, amino acids, and approximately 60% of the salts are reabsorbed through active transport. As these solutes are removed from the nephritic filtrate, a large volume of water follows through osmosis.

As the remaining filtrate flows into the loop of Henle, it is isotonic to the blood, but while in the loop of Henle, more sodium ions are pumped out into the peritubular capillary network. Since water remains in the loop of Henle, the interstitial fluid in the capillary tubes become very hypertonic and the fluid within the loop of Henle
become hypotonic. In the distal tubes, active transport moves more sodium, but at this point, water also crosses the membrane though osmosis.

After filtrate has passed through the loop of Henle, it enters the collecting tubules, where it then is carried toward a nearby collecting duct. The collecting duct leaves the cortex and descends into the medulla, carrying fluid toward a papillary duct. The filtrate then enters the renal papillae, which are small openings into the renal pelvis. From here, the remaining filtrate, now known as urine, is excreted through the ureters to the bladder, where the urine is stored until it is excreted. The kidneys are able to filter approximately 180 liters of filtrate per day; however, they only excrete 1 to 1.5 liters of urine, conserving the amount of water loss and greatly concentrating the salts and other wastes in the urine.

The function that the kidneys perform is so vital to a human’s survival that total kidney failure can cause a person to die in a very short period of time. Most kidney diseases attack the nephrons, causing them to lose their filtering capacity. Damage to the nephrons may happen quickly, often as a result of injury or poisoning, or, more commonly, most damage occurs slowly and silently. Years may pass before damage from kidney disease becomes apparent. The two most common causes of kidney disease are:

- High blood pressure can damage the small blood vessels in the kidney, not allowing for filtration or poisons from the bloodstream.
- Diabetes keeps a person’s body from using sugar as it should. The sugar then stays in the bloodstream instead of breaking it down. In turn, it acts like a poison that can damage the nephrons.

Kidney disease cannot be cured. However, it may be possible to make the kidneys last longer if kidney disease is detected in the early stages. Precautionary measures that can be taken to help prevent kidney disease include regularly checking blood pressure, avoid pills that can make kidney disease worse, limiting salt, cholesterol, blood sugar and protein levels.

A condition called uremia occurs when a kidney quits working properly. One symptom of uremia is edema, which makes a person’s hands and feet swell. In addition, the body also fills with waste products, which leads to tiredness and weakness because the tissues need to be cleansed to function properly. If this condition is left untreated, a
person may have seizures, enter into a coma or even die. The two methods for treating uremia are dialysis or kidney transplantation.

Medical technology has developed a machine, known as **dialysis**, which can serve as an artificial kidney, filtering out wastes and replenishing the body with "clean" blood. The two major forms of dialysis are **hemodialysis and peritoneal dialysis**. In **hemodialysis**, blood filled with waste products is sent through a machine that filters away waste products and the clean blood is returned to the body. Hemodialysis is usually performed at a dialysis center three times per week for three or four hours. In peritoneal dialysis, a fluid called dialysate, is put in your abdomen. After a few hours, the dialysate containing the wastes is drained from the abdomen and a fresh bag is dripped into the abdomen. On an average a patient learns to do these themselves, about four times a day.

With only a few hours of dialysis a week, a person may live for years without functioning kidneys while waiting for a suitable donor. A donated kidney may come from an anonymous donor who recently died or a living person, usually a relative. It is essential that person receive a kidney that is a good match for their body because then it is less likely that the immune system will reject it. Scientists have developed a special class of drugs to trick the immune system called anti-rejection drugs. These drugs help the body accept a transplanted kidney.

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**Figure 2: Nephron**

[Diagram of a nephron showing key components such as Bowman's capsule, Glomerulus, Afferent arteriole, Efferent arteriole, Proximal convoluted tubule, Distal convoluted tubule, Vascular system connections, and collecting duct.]

Kidney Facts:
- The kidneys represent only 0.5% of the total weight of the body, but receive 20-25% of the total arterial blood pumped by the heart.
- The rate of filtration is approximately 125 ml/min. or 45 gallons (180 liters) per day. Considering you have 7 to 8 liters of blood in your body, this means that your entire blood volume gets filtered approximately 20-25 times a day.
- Each kidney contains over a million nephrons
- The right kidney is slightly lower than the left
- Each kidney weighs about 113-170 grams and is about 11.4 cm long and 6 cm wide and 2.5 cm thick.
- The first workable artificial kidney was developed during World War II in 1944 by Dr. William Kolff who was living in Holland.
- According to the National Kidney Foundation, more than 370,000 Americans are being treated with dialysis or kidney transplantation for kidney failure. Nearly 12 million Americans may be at risk for chronic kidney disease.
- The use of a dialysis machine is suggested when a patient’s blood urea nitrogen value exceeds 100 mg/dl (the normal value is 30 mg/dl)

Objectives
- Construct a model to simulate the action of a kidney
- Relate changes in color, turgor, and salt content to evidence of osmosis
- Evaluate the function of the kidney as an evolutionary adaptation to life on land (This objective is mainly for AP Biology)

Materials needed per group
- Simulated blood
- Dialysis tubing
- Clear cup
- Salt test strip
- Pipet
- Microscope slide
- Coverslip
- Disposable gloves
- Graduated cylinder
- Compound Microscope
Procedure
1. Fill a clear cup with about 200 ml’s of distilled or tap water.
2. Dip the test strip into the water to determine the initial presence of salt in water and remove the strip and wait for 30 seconds.
3. Record the results in the Table 1. A color change of the test pad is an indication of a positive result.
4. Test the simulated blood for the presence of salt by following the same procedure as in Step 2. Record the results in Table 1.
5. Obtain a piece of dialysis tubing and tie a tight knot in one end of the tubing. Open the other end by rubbing the tubing between your fingers. Measure out approximately ______ ml of simulated blood into a graduated cylinder and pour into the tubing. Or, you may pipet in the ______ ml of simulated blood.
6. Tie a knot at the open end of the bag tightly. The bag represents the blood vessels that enter the bag.
7. Rinse off the outside of the dialysis bag in the sink and place it in the cup. Record the initial color of the solution in the dialysis bag and of the water in the cup in Table 1.
8. After 15-20 minutes, remove the bag from the cup. Record the color of the solution in the bag and of the water in the cup.
9. Test for the presence of salt in the water and cut a small hole in the bag to test the simulated blood. Record these results in Table 1.
10. The instructor will place a slide of simulated blood on a microscope slide and place it under a microscope on 100x. Draw a circle and a draw what you see. Next, draw under 400x. Record your observations.
11. The instructor will prepare a slide of the simulated urine and view under 100x and 400x to determine if any blood cells would have passed through the simulated kidney.
12. Dispose of all materials according to your instructor’s directions.
Table 1: Results of Presence of Salt and Color Observations

<table>
<thead>
<tr>
<th>Reading</th>
<th>Presence of Salt</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dialysis Bag</td>
<td>Cup</td>
<td>Dialysis Bag</td>
</tr>
<tr>
<td>Initial</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Assessment

1. Summarize how the model used in this lab demonstrates kidney function. For example, what happened to the bag; the color of the dialysis tubing blood, the color of water in the cup. Did blood cells show up in the urine? Why or why not? By what process did the blood and or water move into and out of the bag?

2. How are the kidneys like a water treatment plant?

3. Aside from filtering the blood, name three or four other functions of the kidneys.
4. Why would certain substances in the urine (e.g., protein, sugars, blood) be an important diagnostic tool for the medical community?

5. Using the following terms create a concept that explains the role of each in the formation urine in the kidneys.

<table>
<thead>
<tr>
<th>Reabsorption</th>
<th>Filtration</th>
<th>Excretion</th>
<th>Bowman’s Capsule</th>
<th>Glomerulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loop of Henle</td>
<td>Proximal convoluted tubule</td>
<td>Distal convoluted tubule</td>
<td>Capillary network</td>
<td>Collecting tubule</td>
</tr>
</tbody>
</table>

And Ureters.

Formation of Urine
In Kidneys
6. You are a molecule of ammonia and your friend in a blood cell. You have both decided to take a tour through the kidneys. A. Describe each of your tours and explain why they would be the same or different.

7. (AP Biology Question) Why is the kidney an evolutionary advancement for land animals. Research this topic and write your answer.