A Kidney Problem?
Teacher information

Summary:
Students analyze simulated urine samples to determine if the patient’s symptoms might be caused by kidney disease. Students model normal kidney function and propose an explanation for the presence of protein and red blood cells in the patient’s urine.

Core concepts:
- To maintain homeostasis the internal environment must be kept stable - within normal limits that are favorable for cell activities.
- The components of the human body interact to maintain a balanced internal environment. To successfully accomplish this, organisms possess a diversity of control mechanisms that detect deviations and make corrective actions.
- If there is a disruption in any human system, there may be a corresponding imbalance in homeostasis.
- The processes of diffusion and active transport are important in the movement of materials into and out of the cell.
- Homeostasis in an organism is constantly threatened. Failure to respond effectively can result in disease or death.
- Disease may be caused by inheritance, toxic substances, poor nutrition, organ malfunction, and some personal behavior. Some effects show up right away; others may not show up for years.
- A failure to take corrective action to restore systems to normal range can result in disease or even death.

Class time required:
Two 40-minute class periods

Teacher preparation:
Each student will need
- 1 copy of A Kidney Problem?
- 1 color copy of the Instructions for Urine Testing (Consider laminating this for reuse)
- 1 color copy of the Circulatory and Excretory System Interaction diagram sheet (Consider laminating this for reuse)
Each team of students will need

- A 2 mL microtube or small test tube filled with pH 12 buffer or a 5% dilution of colorless household ammonia that has been colored with a small amount of yellow food coloring. Label this tube “Patient Urine”

- A small plastic bag that contains 1 strip of EMD pH 0 -14 pH paper (Order from VWR: Catalog # EM-9590-1, Colorpast pH Test strips Universal Range 0-14, EMD Chemicals. Pack of 100 strips is approximately $17.00. http://vwrlabshop.com/colorbphbast-ph-test-strips-emd-chemicals/p/0011566/

- 3 oz. plastic cup labeled “Blood in Renal Artery Entering the Kidney”

- 3 oz. plastic cup labeled “Blood in Renal Vein Leaving the Kidney”

- 10 oz. low form plastic cup or small plastic bowl labeled “Nephron”

- 1 screen, large enough to fit over the “Nephron” (approx 5 X 5 inches) with large openings that allow the small beads, but not the large beads, to pass through freely. Latch hook fabric, mesh anti-slip rug mats, or light weight deer fence work well for this. Test the screen to be certain small beads pass through and large beads do not.

- 3 plastic spoons - green, blue, and white. Label green spoon “Amino Acid Transport Protein”. Label blue spoon “Glucose Transport Protein”. Label white spoon “Salt Transport Protein”.

- 1 small plastic bag labeled “Blood Components” that contains approximately the amounts of these beads. Beads can purchased at a local craft store or ordered from www.consumercrafts.com (see chart below for catalog number).

| Large Beads (will not pass through screen) | 12mm transparent red faceted beads, catalog # 06119-3-T19 (simulates red blood cells) | 3-4 beads |
| - | 15mm white berry beads, catalog # 03906-3-202AB (simulates white blood cells) | 3-4 beads |
| - | 12mm transparent green starflakes, catalog # 06508-7-T12 (simulates protein) | 3-4 beads |
| Small Beads (will pass through screen) | 4mm white faceted bead, catalog # 06122-7-02 (simulates salt) | 15-20 beads |
| - | 4mm green faceted bead, catalog # 06122-7-T12 (simulates amino acids) | 15-20 beads |
| - | 4mm dark sapphire faceted bead, catalog # 06122-7-T24 (simulates glucose) | 15-20 beads |
| - | 4mm yellow faceted bead, catalog # 06122-7-T3 (simulates urine) | 15-20 beads |

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Quick Guide:

Instructions for Urine Testing

1. Dip the test strip (for 1 second) into the tube containing the urine sample.
2. Immediately compare the color of the test strip to the strips shown on the right.
3. Record whether the levels of each substance (Ketones, Blood, Protein, and Glucose) are NORMAL or HIGH.

Kidneys, Nephrons, and the Urinary System

4. Structures in the Urinary System

5. Blood vessels and spaces in the kidney

Blood Components

Patient Urine Sample

Nephron

Blood in Renal Artery

Blood in Renal Vein

Urine Test Strip
During Class:

1. Group students into lab teams of 2-4 students.

2. Distribute to each student: A Kidney Problem, color Instructions for Urine Testing, and color graphics Kidney, Nephrons and the Urinary System.

3. Read The Case and Part 1: Your Task aloud to the entire class.

4. Students work with their team members to complete Part 1. Because reading the information and instructions is very important for this activity, you should suggest that students in a team take turns being “readers” and “doers.”

5. Read The Case and Your Task for Part 2.

6. Students work with their team members to complete Part 2. Because reading the information and instructions is very important for this activity, you should suggest that students in a team take turns being “readers” and “doers.”

7. Optional follow-up: If students have access to computers, consider having them use the interactive animation of kidney function at [http://www.biologymad.com/resources/kidney.swf](http://www.biologymad.com/resources/kidney.swf). This tutorial-animation reviews basic urinary structure and function. Students can click on different types of molecules and watch what happens they go through the kidney nephron.
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Kidneys, Nephrons, and the Urinary System

**Figure 1: A Kidney**

Clean blood leaves through the Renal Vein

Blood containing wastes enters through the Renal Artery

Urine carrying wastes leaves through the ureter

**Figure 4: Structures in the Urinary System**

Renal Artery

Kidney

Renal Vein

Ureter

Bladder

Urethra

**Figures 2 and 3: Blood Vessels and Nephron in the Kidney**

Renal Artery

Glomerulus

Nephron

Renal Vein

Urine
A Kidney Problem?  Teacher Answer Key

The Case:

Ten years ago, your patient was diagnosed with Type 2 diabetes. She has been careless about following the treatment needed to keep her blood glucose levels regulated. Now she is experiencing fatigue, muscle cramps, swollen legs, nausea and back pain. She explains that her urine is sometimes pinkish and cloudy. You suspect that your patient’s kidneys may not be functioning normally.

PART 1:
Are the patient’s kidneys functioning normally?

Your Tasks:
• Conduct a urine test.
• Analyze the information from the urine test to determine if the patient’s kidneys are functioning normally.

Procedure:

1. Test the patient’s urine sample.
   • Use the “Instructions for Urine Testing”, urine test strips, and tube of patient urine.
   • Record the results of the tests on Table 1: Results of Patient’s Urine Test.

Table 1: Results of Patient’s Urine Test

<table>
<thead>
<tr>
<th>Urine Tests</th>
<th>Patients’ Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ketones</td>
<td>Normal</td>
</tr>
<tr>
<td>Blood</td>
<td>High</td>
</tr>
<tr>
<td>Protein</td>
<td>High</td>
</tr>
<tr>
<td>Glucose</td>
<td>Normal</td>
</tr>
</tbody>
</table>
2. Read the information in “Interpreting Urine Test Results.” What substances are present in the patient’s urine that are not present in normal urine?

   **Blood and protein.**

3. Are the patient’s kidneys functioning normally? State two evidences to support your answer.

   **No. The patient’s urine contained protein and blood. Protein and blood is normally not present in urine.**
PART 2:  
How do normal kidneys work?

The Case:

Your patient doesn’t understand how normal, healthy kidneys work to remove wastes and keep blood composition stable—within normal ranges. You would like to show her how the normal kidneys work and what happens when her kidneys are damaged.

Your Task:

Use a model to illustrate how healthy kidneys work to keep the levels of substances in the blood within normal ranges.

**Important Note:** The diagrams in this lab activity are black and white. It is much easier to understand these diagrams if you can look at them in color. Your lab kit contains a sheet of colored diagram. Please set the colored diagram sheet out on your desk so that you can look at it as you work on this lab activity!

A. Kidneys Regulate the Composition of Blood

Your kidneys play a vital role in maintaining homeostasis. They excrete (remove) urea and other wastes, regulate the amount of water in the blood, and adjust the concentration of various substances in the blood. The substances removed from the blood form urine. The cleaned blood then travels to the heart and is pumped to the rest of the body.

As blood travels through the kidney, some blood components need to be:

- **Kept** in the blood because they are essential. Red blood cells, white blood cells, protein, glucose and amino acids should be kept in the blood. These components should not be present in urine.

- **Removed** from the blood and excreted in the urine because they are toxic (poisonous). Urea is a toxic substance that should be removed from the blood.

- ** Balanced** so they are present in the correct concentration in the blood. A certain amount of water and salt is needed by the body and will remain in the blood. If excess water and excess salt are present in the blood, they should be excreted in the urine.
In this lab activity, you will use a model to help you understand how the kidney maintains the proper concentrations of substances in the blood.

1. Remove the bag labeled “Blood Components” from your kit. The beads in this bag represent the blood entering the kidney. The key below indicates what blood components are represented by each type of bead.

2. Blood enters the kidney through the renal artery. Add the contents of the bag labeled “Blood Components” to the cup labeled “Blood in the Renal Artery Entering the Kidney.”

3. Blood also contains water. Add enough water to fill the cup containing the beads about three quarters full of water.

4. What blood component should be completely removed from the blood as it passes through the kidney? What type of bead represents this component?
   
   **Urea—small yellow bead**

5. What five blood components should be kept in the blood as they pass through the kidney? What type of bead represents each of these components?

   **Red blood cells—large red beads**
   **White blood cells—large white beads**
   **Proteins—large green beads**
   **Amino acids—small green beads**
   **Glucose—small blue beads**

6. In addition to water, what blood component should be balanced so that they are present in the correct concentrations in the blood? What type of bead represents this component?

   **Salt—small white beads**

7. What three substances would you expect to find in urine that is excreted by the kidney?

   **Water, salt, and urea**
B. Kidneys Filter Blood

Each kidney contains over 1 million microscopic blood-cleaning units called nephrons. A nephron, shown in the diagram below, is a tiny tube with a cup-shaped structure on the end. The cup-shaped part of the nephron surrounds a tight ball of capillaries called a glomerulus.

**Figure 2: Filtration allows small molecules to enter the nephron**

Blood enters the kidney through renal arteries. The renal arteries branch to supply blood to the tiny balls of capillaries called glomeruli. The walls of the glomerulus capillaries are porous. They act like filters to allow small molecules to move under pressure from the blood into a cup-like part of the nephron. The movement of materials out of the glomerulus capillaries and into the nephron is known as filtration. The fluid that collects in the nephron is called the filtrate.

8. Prepare a model of a glomerulus and a nephron by placing the screen (to represent the glomerulus) over the plastic bowl (to represent the nephron) See diagram on the right.

9. Model the process of filtration that occurs in the glomerulus. Pour the contents of the “Blood Components” cup onto the screen (the glomerulus) to form a single layer.

10. The materials trapped on top of the screen remain in the blood. Pour the materials that stay on top of the screen into the cup labeled “Blood in Renal Vein.” Note: some of the small beads may remain on top of the screen. This is OK. In fact, this actually occurs in the kidneys. Most, but not all, of the substances leave the blood.
11. Write the names of the three blood components that are kept in the blood because they are too large to pass through the pores of the glomerulus. (See key to the right)

**Red blood cells**
**White blood cells**
**Proteins**

<table>
<thead>
<tr>
<th>KEY</th>
</tr>
</thead>
</table>
| Large Beads | Red = red blood cells  
Green = proteins |
| Small Beads | Blue = glucose  
White = salt  
Yellow = urea |

12. The substances that pass through the screen and into the nephron form a fluid called the filtrate. What five substances form the filtrate?

**Amino acids, glucose, water, salt, urea**

13. What determines which blood components remain in the blood and which components end up in the filtrate in the nephron?

*Large components remain in the blood because they cannot go through the pores of the glomerulus. Small components can go through the pores of the glomerulus and form the filtrate. Note: Some small beads may not go through the pores.*

14. Does the process of filtration alone completely separate the wastes from the essential materials? Support your answer with observations of what is present in the nephron cup.

**No. The filtrate in the nephron cup contains waste (urea) and essential materials (glucose, amino acids, and water).**

15. Which of the substances in the filtrate does your body need?

**Glucose, amino acids, salt, and water**
C. Kidneys Reabsorb Needed Substances

Obviously you can’t afford to lose large amounts of water, salt, glucose, and amino acids in your urine! So a second process, called **reabsorption**, moves essential materials from the nephron back into the blood. Reabsorption occurs when transport proteins molecules in the walls of the nephron return essential substances such as glucose, amino acids, water, and salt to the capillaries that surround the nephron.

**Figure 3: Reabsorption returns essential materials to the blood**

![Figure 3: Reabsorption returns essential materials to the blood](image)

**Complete Reabsorption.**

Some essential molecules, such as glucose and amino acids, are kept by being **completely reabsorbed**. These molecules should be completely returned to the blood and should not end up in the urine produced by the kidney. Specific transport proteins in the nephron use energy to move these molecules from the nephron into the capillaries that surround the nephron.

16. What two substances in the filtrate are essential and need to be **completely reabsorbed**?

   *Glucose and amino acids*

17. Model the **complete reabsorption** of these substances. Use the specific “transport proteins” (these are represented by colored spoons that match the color of the beads) to pick up and move **ALL** of the **completely reabsorbed** substances from the “Nephron” cup to the “Blood in Renal Vein” cup.
Selective Reabsorption

Other molecules, such as water and salt, are balanced by being selectively reabsorbed to maintain the proper salt and water balance in the body. Their reabsorption is regulated so that they are returned to the blood if needed but are excreted in the urine if present in excess amounts. Specific transport proteins in the nephron use energy to move these molecules from the nephron into the capillaries that surround the nephron.

18. What two substances should be balanced by being selectively reabsorbed?

*Salt and water*

19. Model how selective reabsorption is used to keep the proper amounts of these substances in the blood.

- The blood needs to contain the proper amount of salt. The “Blood in Renal Vein” cup should contain 5 white beads representing salt. How many white beads will need to be selectively reabsorbed to maintain homeostasis? *Student answers will vary*
- Use the specific “transport protein” (represented by the white spoon) to move salt (white beads) so that the blood in the renal vein contains the proper amount of salt (5 white beads). Leave the remaining (excess) salt in the “Nephron” so it can be excreted.
- The blood needs to contain the proper amount of water. The “Blood in Renal Vein” cup should be about one-half full of water.
- Pour enough of the water from the “Nephron” cup to fill the “Blood in Renal Vein” cup approximately one-half full. Leave the remaining (excess) water in the “Nephron” cup so that it can be excreted.

20. The substances that are reabsorbed did not automatically move from the nephron cup into the renal vein cup. You needed to use lots of energy to make reabsorption happen. Which process do you think the kidney uses to transport these substances from the nephron to the capillaries—active transport or diffusion (passive transport)? Explain your answer.

*Active transport because energy was needed to move the materials from the nephron to the blood.*

21. If you drink a lot of water, you may produce large amounts of urine that has a light yellow color. If you do not drink enough water, you may produce a small amount of urine that has a dark yellow color. How would you explain these observations?

*When you drink excess water, you body maintains homeostasis by excreting the excess water in the urine. When you do not drink enough water (and are dehydrated) your body maintains homeostasis by not excreting as much water in the urine.*
22. The “Blood in the Renal Vein” cup contains “clean” blood. After reabsorption has occurred, what seven substances are present in the “clean” blood in the renal vein?

    Water, red blood cells, white blood cells, protein, glucose, amino acids, and salt. 
    Note: students may also say small amounts of urea.

23. What do you think happens to the “clean” blood in the renal vein?

    It would return to the heart to be circulated to all parts of the body.

**Excreted (Not Reabsorbed)**

24. What substance is NOT reabsorbed from the filtrate? Why is it important that this substance remains in the fluid in the nephron?

    Urea because it is a toxic waste that needs to be excreted.

25. The substances that remain in the nephron (cup) are called urine. What three substances are present in normal urine?

    All of the urea. Some of the water and salt.

26. The urine collects in the hollow center of the kidney and then flows out of the body. List the structures of the urinary system that urine must pass through to exit from the body.

    Kidney – Ureter – Bladder - Urethra
Part 3:
What is wrong with the patient’s kidneys?

So far you have modeled the function of normal kidneys. Now you will consider what might be going wrong in patients with kidney disease. In patients with kidney disease, the kidney structure is damaged and does not function properly. Kidney damage may occur as a result of diabetes, high blood pressure, abnormal kidney development, damage by viruses or bacteria, or by an auto-immune response in which antibodies attach to the kidneys.

1. Your patient’s diabetes has caused kidney disease. What substances in the patient’s urine indicate that her kidneys are not functioning properly. (Refer to Part 1, question 2 on page 2)
   *Red blood cells and protein*

2. Your patient reported pinkish and cloudy urine. What substance might cause her urine to be pink? *Blood* What substance might cause her urine to be cloudy? *Protein*

3. Explain how you could change the beads, screen and cups model that you used to illustrate how kidney damage caused your patient to have blood cells and protein in her urine.
   • What part of the model should be changed?
     *The screen*
   
   • How should you change this part?
     *You would cut holes in the screen to make the pores larger.*

   • What kidney structure was represented by this part of the model?
     *The glomerulus*

4. What process (filtration or reabsorption) was not working properly in your patient? Explain how you know.
   *Filtration because red blood cells and proteins were present in the patient’s urine.*
Part 4: 
Reviewing and Applying What You Learned

1. Label the diagram using the following terms: renal artery, renal vein, nephron, glomerulus, and urine entering the ureter.

2. Draw a labeled arrow on the diagram to represent the process of filtration. In your own words, explain the process of filtration.

   *Filtration allows small molecules to leave the blood but keeps larger molecules and cells in the blood.*

3. Draw a labeled arrow on the diagram to represent the process of reabsorption. In your own words, explain the process of reabsorption.

   *Reabsorption returns essential materials to the blood.*

4. Excretion involves an interaction between the circulatory system and the excretory system. On the diagram above:
   - Put an X in front of the labels for structures that are part of the circulatory system.
   - Put an O in front of the labels for structures that are part of the excretory system.
5. Complete the chart below to indicate what substances should be present in the:
   - clean blood that leaves the kidney through the renal vein
   - urine that leaves the kidney in the ureter

   **Clean blood in renal vein contains:**
   *Water, glucose, red blood cells, white blood cells, proteins, amino acids, and salt*

   **Urine in ureter contains:**
   *Water (excess), salt (excess), and urea*

6. Each day the millions of nephrons in your kidneys produce a total of about 180 liters (47 gallons) of filtrate that flows into your nephron. What would your life be like if your kidneys only carried out filtration (and did not also carry out reabsorption) and all of that fluid became urine?

   *If the kidneys released all of the filtrate as urine: There would be a huge amount of urine. Students may realize this means they would need to drink a huge amount of water to prevent dehydration. The body would lose essential substances such as salt, glucose, amino acids, and water.*

7. Explain why drinking large amounts of water results in the production of large amounts of urine.

   *The amount of water in the blood gets balanced. If you take in too much water, the kidneys will get rid of excess water in the urine.*

8. Explain why eating large amounts of salty foods increases the amount of salt in the urine?

   *The amount of salt in the blood gets balanced. If you take in too much salt, the kidneys will get rid of excess salt in the urine.*

9. In addition to diabetes, what other things may cause kidney disease?

   *High blood pressure, auto-immune disease, or infection by viruses or bacteria.*

10. Why is kidney disease a serious health risk? What would happen to a person if their kidneys did not function properly?

   *Wastes may accumulate in the blood and/or the concentration of substances present in the blood may not be properly balanced.*