Race for the Pure: Blood Cleansing in the Kidneys

Activity 4B

Activity Objectives:

Utilizing a model, students will be able to:

- Explore the structure and function of the kidneys
- Discuss the limitations of the kidney model used in this activity
- Explain why the function of the kidney is so important
- Explain how diabetes and high blood pressure affects kidney function

Activity Description:

Students will race against a simulated kidney in filtering toxins from simulated blood.

Activity Background:

As our bodies carry on all the metabolic activities that sustain life, waste materials, or metabolic byproducts are produced. These waste substances must be regularly eliminated to avoid the accumulation of ***toxic*** levels in the body.

The kidneys remove these waste products by ***filtering*** them from the blood. So they can better do this job (***function***), *the kidneys receive a larger volume of blood flow than any other organ*. The heart receives about 270ml/min. of blood flow, the brain 700ml/min. while the kidney processes around 1000ml of blood per minute. This ***large flow volume*** is responsible for the kidney's dark red color and is necessary for adequately cleansing the blood of waste materials at a sufficient rate.

Flow of blood through the kidneys begins at the ***renal artery***, which transports "unclean" or toxin-rich blood from the body's tissues into the kidney's ***hilus***, the indentation of the kidney that makes it appear bean shaped. From the hilus, the ***renal artery*** branches out into tiny capillaries. These capillaries interact with the kidney's ***nephrons***, the filtering units of the kidney. The nephrons are comprised of a ***glomerulus*** which filters and a ***tubule*** which adjusts water, salt, and waste levels by retaining what is needed and discarding the rest. The waste materials such as drugs, metabolites, salts and excess fluid that together comprise urine are collected from the tubules to the ***renal pelvis*** then to the bladder for excretion. The cleansed blood flows back to the heart via the renal vein. See ***Figure 1 Parts of the Kidney***.

Among the waste materials filtered by the kidneys are the nitrogenous wastes ***creatinine*** and ***urea*** . The kidneys also filter drugs we have ingested. Creatinine and urea are waste molecules from ***protein/purine*** metabolism in the body. The kidneys also remove many of the ***drugs*** we ingest and are very susceptible to damage from misuse of drugs. These three substance types will be the focus of the students' filtering efforts in the activity.

Though this activity focuses on the ***cleansing function*** of the kidney, it is important to note its other crucial functions. In addition to its function as a blood cleanser, the kidney also maintains the body's ***fluid balance***, releases ***hormones*** that regulate our blood pressure (renin) and red blood cell production (erythropoietin), and produces an active form of ***vitamin D*** (calcitrol), another hormone necessary for bone formation and repair.

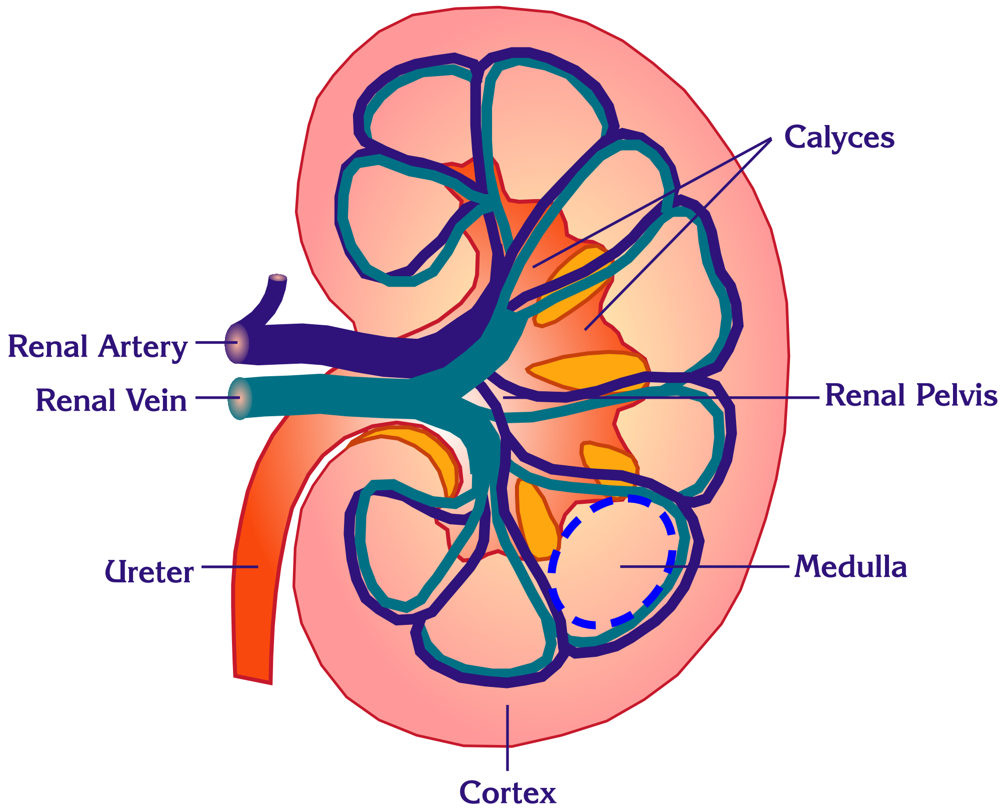


Figure 1 Parts of the Kidney

Teacher note: Utilize this image to assist students in evaluating their concept sketches of the kidney in the processing out process.

Kidney failure is a significant problem in the U.S., where over 100,000 people are diagnosed with the condition annually. When a person is in kidney failure, the kidneys are not able to filter wastes out of their bodies. The most common cause of kidney failure is diabetes.

African Americans, American Indians, and Hispanics/Latinos are more likely to develop diabetes and kidney failure than Caucasians. Researchers do not know why this happens. They do know, however, that high blood pressure and blood glucose levels increase the risk that a diabetic will develop kidney failure.

Diabetic kidney disease takes many years to develop. At first, the kidneys filter more than normal (***hyper filtration***) because of the diabetes. Over the next few years, small amounts of a protein called ***albumin*** leak into the urine; during this time, kidney filtration is normal. The next step involves more albumin leaking into the urine and less filtration taking place. Waste products, such as creatinine are found in the blood because the kidneys are not able to filter them out. As the kidney damage develops, blood pressure usually goes up. ***This is another example of how human organ systems affect each other.*** Usually, it takes 15 to 25 years for complete kidney failure to occur.

In addition to being a result of kidney disease, high blood pressure (***hypertension***) can cause kidney disease. How does high blood pressure harm the kidneys? It makes the heart work harder and can damage blood vessels all over your body. If the vessels leading to the kidneys are damaged, the kidneys may not be able to remove wastes and fluid from the body.

Blood tests can help doctors determine if kidney damage has occurred. If too much ***creatinine is found in the blood***, it indicates that the kidneys are not filtering as they should. Creatinine levels can be used to estimate the main kidney function called GFR (glomerular filtration rate). Another sign of kidney damage is having too much protein in the urine; indicating damaged blood vessels.

People with kidney disease must avoid high protein diets. Reduced amounts of protein may even delay the onset of kidney disease, but a dietician and/or physician must supervise such a diet to ensure adequate nutrition.

Activity Materials: **(per group of 3)**

Kidney Model:

- 1 - 3 minute egg timer with kidney façade
  (paper cut out of kidney, provided at the end of this teacher section, to be taped to face of the timer)
- 1- stopwatch

Filtering Materials:

- 1 - colander with large enough slots to allow "nitrogenous wastes" (rice and birdseed) to pass through but not "blood cells"
- 1 - bar magnet enclosed in a Ziplock® bag
- 1 - 250 ml clear containers (clear plastic cups work well) to hold the filtered toxins
- 1 - large bowl (e.g. cheap plastic salad bowl) to control spillage of the filtering activities. The very thin, inexpensive type works best as it can be flexed to form a lip for pouring the materials.

Blood Model Containing Toxic Materials:*

- 1000 ml graduated cylinder to hold the "blood" mixture. (A 2 liter plastic soda bottle can substitute, just cut off the top then measure and mark 1000 ml level with a permanent marker)
- "Red Blood Cells" = 700 ml volume of red kidney beans
- "White Blood Cells" = 200 ml volume of white lima beans

Note: The ratio of red blood cells to white blood cells in the blood is actually about 700:1. The ratio in the graduated cylinder/kidney model is not accurate but necessary to illustrate the presence of white blood cells visually to the students. See extension activity # 2.

- "Nitrogenous Wastes" (urea and creatinine) = 100 ml volume of white rice (creatinine) and 100ml volume of white millet (urea)
- "Drug" = 20 ml volume iron filings (coarse, unoiled)

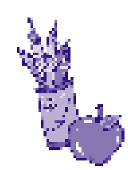
Note: *The "toxin" particles fill in the small spaces between the "blood cells" to make a total volume of 1000ml. You may need to slightly adjust the volumes of the "toxin" particles depending on the size "blood cell" particles you use.*

- 1 Class set ***Student Information Page***
- 1 Copy ***Student Data Page*** per student

*****Note:*** *This activity uses only dry materials, so the blood serum is not represented. This is a limitation of this model and should be discussed with students.*

Activity Management Suggestions:

- Assign tasks to each group member. (One student will measure time with the stopwatch and record while the other two manage the filtering. Have students rotate positions with each successive race).
- Have several extra "Blood with Toxins" set up in the graduated cylinders/soda containers in case a group spills theirs. This allows them to get right back into the game.
- Allow as much student discovery as possible by allowing students to figure out how to use the different tools to filter the substances as quickly as possible.
- Allow enough time for each group to "re-race" so everyone has the opportunity to succeed and have a turn at timekeeping and filtering.



Extensions:

1. The chart below indicates the amount of O2 delivery and blood flow rate to various organs. This illustrates the kidney's predominance in both these categories. The rates are in ml/min per 100 grams of organ. Students can research or be provided with the average masses of the various organs so they can determine/calculate the approximate blood flow/oxygen delivery to their various whole organs. Students can then generate a new data table with the information they have calculated. Students can use the following formula:

$$\text{Blood Flow Rate (ml/min)} = \frac{\text{Mass of the Organ (g) X Blood Flow Rate (ml/min)}}{\text{100 (g)}}$$

Table 1: 0_2 Consumption in the Kidney Compared to Other Organ Systems

Region or Organ	*O2 Delivery ml/min/100 g*	*Blood Flow Rate ml/min/100 g*
Hepatoportal	11.6	58
Kidney	***84.0***	***420***
Renal outer medulla	7.6	190
Brain	10.8	54
Skin	2.6	13
Skeletal muscle	0.5	2.7
Heart	16.8	87

Source: Renal Blood Flow – Glomerular Filtration Rate
George N Coritsidis, MD, Stony Brook University Medical Center
http://www.uhmc.sunysb.edu/internalmed/nephro/webpages/Part_A.htm

2. The ***ratio of red blood cells to white blood cells*** in the blood is actually about 700:1. The ratio in the graduated cylinder/kidney model is not accurate but necessary to illustrate the presence of white blood cells visually to the students. This model does not include the other components of the blood, e.g. plasma and platelets. This is a good opportunity to discuss the ***limitations of scientific models*** utilized to represent the natural world and how the application of a particular model determines what components are emphasized or deemphasized. Canvass students for ideas for alternative ways to model blood with its various components and discuss different applications e.g. a model for teaching medical students vs. one to inform patients with blood disorders. Students can research or be provided with the various components of blood then challenged to create models of same while at the same time identifying and discussing the limitations and possible applications of their own models.

3. Point out that the volumes of the components making up the blood and toxin mixture sum to more than 1000ml (1120 ml) yet when added together the volume is 1000ml. Have students hypothesize how this could happen and use the opportunity to discuss how smaller molecules fit into the spaces between larger molecules just like the seed and rice do with the beans.

4. Data from the data tables can be graphed and variables that affected the students' cleansing time can be discussed and compared to variables that affect the kidney's cleansing time e.g. blood flow constriction due to decreased cardiac output etc.

5. Students can research kidney diseases and apply them to the model and process out their findings.

Activity References Used:

1. National Institutes of Health
   http://www.nlm.nih.gov/medlineplus/ency/imagepages/1101.htm

2. National Kidney Foundation
   http://www.kidney.org/

3. Renal Blood Flow – Glomerular Filtration Rate George N Coritsidis, MD Stony Brook University Medical Center
   http://www.uhmc.sunysb.edu/internalmed/nephro/webpages/Part_A.htm

4. National Institute of Diabetes and Digestive and Kidney Disease
   http://kidney.niddk.nih.gov/kudiseases/pubs/kdd/

5. Nemours Foundation sponsored website "Teen Health", an excellent source for students written in their language at their level
   http://www.kidshealth.org/teen/your_body/body_basics/kidneys.html

6. Comprehensive clinical nephrology / Richard J. Johnson, John Feehally. London ; New York: Mosby, 2000.
   http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/B/Blood.html