Biomedical Imaging

Noninvasive visualization of anatomy and physiology

In the late 1800s the practice of medicine was changed forever by the discovery of X-rays by German physicist Wilhelm Roentgen. Until that time, health practioners had to rely on verbal descriptions by patients of their ailment, combined with what could be felt from the surface of the body, to make a diagnosis. X-ray photography was the first imaging technique used to see inside a living body without cutting it open. Since then, many new imaging techniques have enhanced our ability to see inside the body. In this activity, you will evaluate some of these techniques to determine their advantages for imaging different parts of the body.

Physicians who specialize in making diagnoses of illnesses based on the evaluation of medical images are called diagnostic radiologists. Radiography is the science of visualizing internal organs using various forms of radiational energy.

X-rays

💻 Go to https://js9.si.edu to access the online image processer. Then in another window, open the url http://40two.info/barge/ap/images/ip%20images/01%20Biomedical%20Imaging/ . These are both linked on our class webpage. In the X-ray folder, open "Radiograph-chest". This is an X-ray of the chest cavity. Study the image.

Visible light waves do not have enough energy to pass through you. You cast a shadow where your body stops the light. However, X-rays have enough energy to pass through some of the tissues in your body. Dense tissues (like bone) absorb more X-rays than less dense tissue (like fat). When health care professionals take an X-ray image, the patient is positioned between the X-ray machine and the X-ray sensitive film. X-rays easily pass through soft tissues such as skin or fat and expose the film, turning it dark. Dense tissue, such as bone, stops the passage of most X-rays. Bone will appear bright on an X-ray film. X-ray photographs are also called roentgenograms (rent-GEN-0 grams) or radiographs.

X-rays are electromagnetic vibrations of short wavelengths (about 0.01 to 10 nm) that are able to penetrate most substances to some extent. Because X-rays have high energy, they can damage molecules as they pass through tissues. X-ray radiation is known as ionizing radiation because of the damage it can do.

1. What structures do you recognize in this radiograph?

💻 Adjust the brightness and contrast of the image by clicking on the image and dragging horizontally. Use the Zoom, Scale, and Color menus as well as holding down your mouse on the picture and dragging it to adjust the picture so you can see the details. *If the image looks worse after enhancing*, go to the Color menu and click "reset contrast/bias" to return to the original image.

2. What structures are more clearly visible after image processing?

3. This patient presented with left chest pain and shortness of breath. Describe any visible features which might explain his symptoms.

To further increase the visibility of less tissues, hollow organs can be filled with a substance that absorbs X-rays (such as barium) to bring out detail.

💻 Open "Radiograph-colon". In this image, the colon is filled with a barium containing liquid.

4. Which is denser, barium or bone? How can you tell?

5. This patient presented with pain in the left lower quadrant of the abdomen. Describe any features of the colon that might explain her symptoms.

To make blood vessels stand out in an X-ray, a dye that absorbs X-rays is injected into the vessels. X-ray machines are common in clinics and hospitals throughout the developed world. X-ray imaging is relatively inexpensive compared with newer technologies such as MRI and PET.

💻 Open “Radiograph-arteries”. This is an arteriogram of the neck and upper chest region.
6. How do the arteries in this image compare to those in the Radiograph-chest image?

💻 Choose the Rainbow color under the Color menu (under more…) to apply false color to the image.
7. Does false color help you to see any of the structures in the image better? Why or why not?

💻 Open “Radiograph-hip”. This is the hip of a person who has had a hip replacement.
8. Why does the hip prosthesis appear so bright?

9. What might the dark areas in the lower abdomen be and why do they appear darker than other areas? The large intestine is found in the lower abdomen.
💻 Close all images except “Radiograph-Chest.”

Body images as “slices”
In standard X-ray radiographs, objects in the same line of sight are superimposed. For example, this means that the ribs and sternum can get in the way of the examination of the heart. Revolutionary new techniques allow us to visualize the body in thin sections just like slices in a loaf of bread. Slices at any depth within the body can be individually examined without being obstructed by structures above or below them.

X-ray Computed Tomography (CT)
Modern medical imaging began in the 1970’s with the development of a technique called X-ray computed tomography (CT). Tomography is based on the word tomos, which is Greek for slice.

💻 Open “Chest CT” and “Head CT” in the X-ray CT folder.
X-ray computed tomography was developed by South African physicist Allan M. Cormack and British engineer Sir Godfrey Hounsfield. They shared the Nobel Prize in 1979 for their work. X-ray computed tomography, or CT, uses a thin beam of X-rays projected from an X-ray tube that rotates 360 degrees around the body. The X-rays from different angles are absorbed by detectors that surround the patient. The large amount of information generated by the CT scan is constructed into a digital image by a computer. The image shows a slice of the body that shows better detail of soft organs than standard X-ray radiography.

💻 Compare “Chest CT” and “Radiograph-chest” by moving between the two images using the File menu.
10. How does the soft tissue detail in “Chest CT” compare to “Radiograph-chest”?

11. Describe any differences in the appearance of soft tissues in the chest CT.
💻 Close “Radiograph-chest” and “Chest CT”.

Magnetic Resonance Imaging (MRI)
In the 1970’s and 1980’s, magnetic resonance imaging was developed. MRIs are created using a strong magnetic field instead of X-rays. To date, no harm has been shown to be caused by exposure to strong

magnetic fields. Protons in the nuclei of atoms in the body are like tiny magnets. If a person is placed in a strong magnetic field, the protons in their tissues will be aligned with their magnetic poles in the same direction. When the magnetic field is terminated, the protons move back to their original alignment (equilibrium). As the protons return to their original position, they emit radio waves that can be detected by sensors surrounding the body. The strength of the radio signal is proportional to the density of protons in the tissue. A computer uses the detected variances in proton density (and the amount of time it takes protons in different tissues to return to equilibrium) to construct the MRI image.

Open "Head MRI". This is a horizontal "slice" through a human head at about eye level. Use the Zoom, Scale, and Color menus as well as holding down your mouse on the picture and dragging it to adjust the picture so you can see the details. *If the image looks worse after enhancing*, go to the Color menu and click "reset contrast/bias" to return to the original image.

12. Did any of the image processing techniques help you to see the structures better? If so, how?

13. How does the soft tissue detail in "Head MRI" compare to "Head CT"?
Close all images.

Nuclear Medicine
The imaging procedures of nuclear medicine involve the injection of the patient with a mildly radioactive element. The decay products from the radioactive element are detected coming from the body, and are used to construct an image. Because what is being detected comes from out of the body itself, the procedures are classed as autoradiography ("auto" means self) Many different radioactive elements are used, depending on the part of the body being studied and the questions being asked. Positron emission tomography and bone scans are examples of autoradiographic techniques. Radioactive decay products are forms of ionizing radiation.

Positron Emission Tomography (PET)
Positron Emission Tomography, or PET, is an autoradiographic technique used especially to study blood flow in the brain and heart. PET produces a grayscale image which is often false-colorized to aid interpretation. In PET, water or glucose, labeled with a positron-emitting isotope, is injected into the blood. Collision of positrons with electrons results in the formation of gamma rays. The gamma rays are interpreted by a computer to produce an image. Darker areas on the image represent structures containing higher concentrations of the positron-emitting isotope.

Open PET in the Nuclear Medicine folder. This is a horizontal section of the head. Zoom to 2 times. Click on a darker area at the bottom of the image.

A digital image is composed of square picture elements called pixels. Each pixel has a value from 0 to 255 that corresponds to a shade of gray (0=white and 255=black) or color assigned.

14. Place your cursor on a pixel representing an area of high blood concentration (dark) and write down the X and Y corrdinates and the Value of the pixel as shown above the image.

Choose Rainbow under the Color menu, under more…, to apply false color to the image.
15. Find the same pixel and compare its value now to the value you recorded previously. Did the pixel values change when you changed colors?

Return to normal magnification.

16. How does false color help you to evaluate the differences in blood flow in this PET image?

💻 Close PET.

Bone scans

A bone scan is a common procedure used to examine bone growth. The element technetium (^{99m}Tc) is injected into a vein of the patient. The patient’s osteoblasts (cells that make bone) substitute some technetium-tagged phosphate for normal phosphate in newly formed bone. The patient lies on a scanner that detects and records the presence of the radioactive decay product of the technetium. Dark areas correspond to the most rapid uptake of technetium. Bone scans usually take a half a day to complete, unlike CT or MRI scans which take a few minutes.

💻 Open all images in the Bone scans folder. Compare the chest and head-neck images to each other. The images labeled #1 are from one patient and those labeled #2 are from another.

17. Which of these bone scans images appear abnormal? Why?

18. If an area appears dark when it should be light, what kind of condition might be present? What kinds of conditions would promote an abnormally high rate of bone growth?

💻 Close all open images.

Sonograms

Sonography uses sound to make an image called a sonogram. The process is similar to the way bats “echolocate” their prey. High frequency sound waves are directed into the body. Some of the sound waves are reflected back towards the emitter, producing an echo. The high frequency echo is above that of human hearing, but a sensor detects the returning sound. The echo’s strength is proportional to the density of tissue encountered by the sound waves. That is, denser tissue produces a “louder” echo and a computer uses time delay and signal strength to construct an image. This technique applied to the heart is called echocardiography. To date, high frequency sound waves have not been shown to cause harm. Sonography equipment is relatively common in clinics and hospitals.

💻 Open “Ultrasound-b”. This is a 12 week ultrasound of a pregnant woman.

19. Adjust the image. What can you see?

Biomedical Imaging Data Sheet

Name ____

Period _________________

1. What structures do you recognize in this radiograph?

2. What structures are more clearly visible after image processing?

3. This patient presented with left chest pain and shortness of breath. Describe any visible features which might explain his symptoms.

4. Which is denser, barium or bone? How can you tell?

5. Describe any features of the colon that might be abnormal.

6. How do the arteries in this image compare those in the **Radiograph-chest**?

7. Does false color help you to see any of the structures in the image better? Why or why not?

8. Why does the hip prosthesis appear so bright?

9. What might the dark areas in the lower abdomen be and why do they appear darker than other areas?

10. How does the soft tissue detail in **Chest CT** compare to **Radiograph-Chest**?

11. Describe any differences in the appearance of soft tissues in the chest CT.

12. Did any of the image processing techniques help you to see the structures better? If so, how?

13. How does the soft tissue detail in **Head MRI** compare to **Head CT**?

14. Choose a pixel representing an area of high blood concentration (dark) and write down the X and Y coordinates and the Value of the pixel as shown above the image.

15. What is the value of the same pixel you measured above?

16. How does false color help you to evaluate the differences in blood flow in this PET image?

17. Which of these bone scan images appear abnormal? Why?

18. If an area appears dark when it should be light what kind of condition might be present? Why?

19. What can you see?