

Biomedical Imaging

Noninvasive visualization of anatomy and physiology

In the late 1800's the practice of medicine was changed forever by the discovery of X-rays by German physicist Wilhelm Roentgen. Until that time, health practitioners 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.

Digital image processing

In addition, you will use a powerful image processing program called ImageJ to view and manipulate these images. ImageJ was developed from the program NIH Image at the National Institutes of Health to investigate and analyze biological and medical images. The advantage of Image J is that you can interact with images rather than just look at them. This program is a genuine research tool that you can use to clarify, colorize, magnify and animate images.

X-rays

In the X-rays 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-GENograms) or radiographs.

1. What structures do you recognize in this radiograph?

Adjust the brightness and contrast of this image. To do this, go up to Image -> Adjust -> Brightness/Contrast. A window will open where you can adjust how the image appears.

2. What structures are more clearly visible after adjusting the brightness & contrast (called 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 dense 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?



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 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.

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.

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. *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?

Choose the Rainbow color table in LookUp Tables to apply false color to the image. Lookup Tables are the different color palettes that can be applied to images. These are found in the Images menu, at the bottom. After you pick a palette you can then use the Adjust brightness/contrast.

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?

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.

Tomography is based on the word tomos, which is Greek for slice.
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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.

Open Head MRI. This is a horizontal “slice” through a human head at about eye level. Try several image processing techniques and evaluate their effects on the image. Don't be afraid to experiment. You can always undo your last change (Edit/Undo) or revert to the saved image (File/Revert to Saved).

To do this use this tool and technique:

- * Adjust brightness or contrast.
- * Magnify structures Choose the magnify tool and click on the structure you want to magnify. Double click on the magnifying glass to reverse the magnification.
- * Invert the image Edit/Select All and then Edit/Invert
- * Apply a color table Image/Lookup Tables
- * Shadow the image Process/Shadow. This will shadow the image in different directions.
- * Sharpen the image Process/Sharpen

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

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

Close all open images.

Traveling into the third dimension

Open all the images in the Human Brain folder. This folder contains 14 MRI images of a human head. Each of the individual slices has only 2 dimensions. However, you can stack the images like a deck of cards, providing depth, a third dimension.

Go to Window in the menu and choose Tile. All your images should be displayed now.

Create a stack from the 14 individual images. Look in Image/Stacks and choose Images to Stack. Then animate the stack Image/Stacks/Tools or Image/Stacks/Animate, whichever you see. Animating this stack is like taking a trip through the head from ear to ear. You can use the Animation Options to slow down or speed up the automatic movement.

12. From what perspective are you viewing these 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-colored to aid interpretation.

Open PET in the Nuclear Medicine folder. This is a horizontal section of the head.

Use the magnify tool to enlarge the image to a 150%. 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 in the LUT.

13. *Place your cursor on 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 in the Info window.*

Choose Image/Lookup Tables/Rainbow to apply a false color to the image.

14. Find the same pixel and compare its value now to the value you recorded previously. Did the pixel values change when you changed color tables?

Return to normal magnification.

Adjust the contrast of the colored image.

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

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.

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 forming 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.

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

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

Close all 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.

Open Echocardiogram. This is a stack of echo images that can be animated to show the action of the heart. An ECG readout is shown at the bottom that correlates with the action of the heart. Move through the slices of the stack to carefully observe what is happening.

Enhance the brightness and contrast to see the outline of the four chambers of the heart better. Find a slice that shows all four chambers well and use the pencil, to outline each chamber. Click on a color at the bottom of the LUT to choose a color.

18. As you move through the echocardiogram, what happens to the chambers of the heart?

19. What is an advantage of the echocardiogram over the other imaging techniques?

Close Echocardiogram.

Close all images.

Image Processing

Many of the examples used in this lesson were from the human body. Image processing is used in many different areas of science, whenever analysis of an image is useful.

20. After working with images and processing them with this image processing software program, what advantage do you see in using image processing to study living things?