

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 NIH Image 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.

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 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?

5. This patient presented with pain in the left lower quadrant of the abdomen. Describe any features

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.

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.

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?

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).

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.

Arrange Chest CT and Radiograph-chest so you can see them both at once.

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.

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

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.

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
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 open images.

Traveling into the third dimension

Open all the images in the Head folder. This folder contains 55 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

Create a stack from the 55 individual images. Look in Image/Stacks.

Animate the stack Image/Stacks/Tools. Animating this stack is like taking a trip through the head from ear to ear.

14. From what perspective (plane of section) are you viewing these images?

Reslicing the stack

NIH Image can reconstruct 3-dimensional image data to view it from different perspectives. Try reslicing this stack to see what frontal, horizontal, and oblique slices look like.

Use the line tool to make a straight line selection in any direction across the head.

Choose Stacks/Reslice and enter 2.2 for Slice Spacing. Click OK and watch carefully.

When NIH Image first draws the resliced image, it appears compressed. The image is then scaled vertically, using the slice spacing you entered, to make the image appear more accurate. The name of the new window comes from the location and angle of the line you selected.

Try reslicing the stack in a different direction. It may be easier to identify the resliced images if you rotate them (Edit/Rotate Right).

15. How might 3-dimensional MRI data and reslicing be used for diagnostic purposes?

Close the stack and reslice images when you are done.

An oblique plane of section is any other than a sagittal, frontal or horizontal section.
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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.

16. 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 false color to the image.

17. 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.

18. 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 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.

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

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

Close all images.

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.

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.

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

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

Close Echocardiogram.

Which imaging technique is appropriate?

Selecting the appropriate imaging technique to diagnose a possible abnormal condition involves consideration of many factors. Perhaps the most important consideration is the effectiveness of the imaging technique at revealing the possible condition. Cost, time, availability and risk to the patient are also important factors to consider.

Open Medical image comparison. This is a stack of images showing each of the techniques covered in this lesson. Use the images in this stack as a reference to answer the following questions.

23. A patient presents with swelling and pain in the forearm after a falling injury. You suspect a broken bone. Which imaging technique would you use to make a diagnosis? Why?

24. A patient presents with a severe headache over the last week or so with recent dizziness and blurred vision. Which imaging technique(s) do you recommend to evaluate this patient’s condition. Why?

25. Which imaging techniques can be used to evaluate physiology (i.e. function). Explain why.

“Functional” MRI

A new technique on the horizon, functional MRI, is also able to evaluate physiology. Functional MRI makes use of the fact that the molecule that carries oxygen in the blood is hemoglobin. The magnetic properties of hemoglobin are affected by the amount of oxygen the molecule is carrying. In 1991, researchers showed that MRI can detect the small magnetic fluctuations that result from changes in blood’s oxygen content caused by changes in blood flow to an organ. For example, brain function can now be studied by evaluating changes in blood flow patterns within the brain as a subject thinks different thoughts. Functional MRI produces a much more detailed image of soft tissues than X-ray or CT, and does not require the injection of a dye or radioactive tracer (as in PET), nor the exposure to X-rays.