

# Biomedical Imaging

## Noninvasive visualization of anatomy and physiology



### Teaching Notes

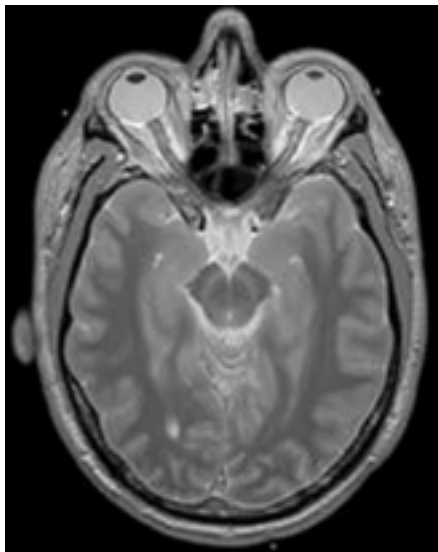
### Overview

Noninvasive medical imaging has revolutionized diagnostic medicine. This lesson gives students of Anatomy and Physiology the opportunity to explore the major biomedical imaging techniques currently used to study the human body and diagnose disease. This lesson is also a good introduction to the basic image processing techniques used throughout the lessons in *A & P Technologist*. Using *NIH Image* to enhance, false colorize and animate medical images, students evaluate each imaging technique for its usefulness in visualizing anatomy and physiology.

The imaging techniques described in this lesson are presented within two contexts: historical and diagnostic. The imaging techniques are presented loosely in the chronology in which they were developed, first introducing conventional X-ray radiography and progressing to the tomographic techniques, autoradiography and sonography. As each imaging technique is introduced, students are asked to manipulate, observe and evaluate each image for its diagnostic value.

Many of the medical images in this lesson show abnormalities. The chest X-ray shows a left upper lobe infiltrate and a possible mass in the left upper lobe; the colon X-ray reveals the presence of diverticulosis; and the hip X-ray shows a hip replacement prosthesis. Students must use careful observation skills and apply basic knowledge of anatomy to hypothesize about possible abnormalities.

MRI of the head in the horizontal plane



Bone scan of the head and neck



### Objectives

The student will:

- use image processing techniques to evaluate the advantages and disadvantages of six different imaging technologies (conventional radiography, X-ray computed tomography, magnetic resonance imaging, positron emission tomography, radionuclide bone scanning, and sonography) for diagnostic value.
- compare and contrast imaging technologies to determine appropriate use in a clinical application.

### Goal

Students will observe and process images from six different medical imaging techniques to determine appropriate use of imaging technology.

### Topics

- Medical Imaging
- Planes of Section
- Introduction to anatomy

### Science Process Skills

- Observation
- Visualization
- Synthesis

### IP Technique Sheets

- Look-Up Tables
- Stacks



## Prerequisites

Prior to this lesson, students should

- be familiar with basic anatomy and anatomical planes of section.

## Acknowledgments

Lesson developed by Paul Johnson, Deborah Alongi, and Sandy Zetlan.

Radiographs and chest CT courtesy of Paul Johnson and the Pima Community College Radiology Department. Head Stack MRI images courtesy of the National Institutes of Health. Digital photographs, proton density MRI, and head X-ray CT images courtesy of the Visible Man Project. PET images courtesy of the Crump Institute, University of California-Los Angeles. Bone scan #1 images courtesy of Louisa Jensen. Bone scan #2 images courtesy of James Ekstrom, Phillips Exeter Academy, Exeter, New Hampshire.

## Answers

1. Answers will vary. The chest X-ray reveals the bright bones of the chest and pectoral girdle. The heart is visible as a bright shadow between the dark areas that represent the lungs. The aortic arch is also visible rising from the top of the heart shadow and curving down across the upper lobe of the left lung (on the right side of the image).
2. Answers will vary. The brightness and contrast enhancement of the image reveals details of the bones, heart shadow and aortic arch but does not reveal the presence of any other organs.
3. Answers may vary. This X-ray shows a serious infiltrate and possible mass in the upper lobe of the left lung. The infiltrate appears as a bright area on the X-ray and is clearly different from the appearance of the right upper lobe.
4. The barium can be concluded to be denser than bone because it appears brighter in the X-ray image.
5. Answers will vary. The colon in the patient's left lower quadrant (in the lower right of the image) shows a large number of circumscribed pouches or sacs (diverticula) extending from the wall of the colon (diverticulosis). There are also a few diverticula present in other areas of the colon.
6. The arteries in the arteriogram are bright and clearly visible in great detail; the standard X-ray does not reveal any arteries that are visible.
7. Answers will vary. Applying a color look-up table can make small differences in pixel values more visible to the human eye than small changes in shades of gray.
8. The hip prosthesis appears so bright because it is made of a very dense material (often titanium).
9. Answers will vary. The dark areas in the lower abdomen represent areas where dense tissue is not present. Often these dark areas in the lower abdomen correspond to gas in the intestine.
10. Answers will vary. The chest CT shows the diaphragm to be visible along with the heart. The lungs still appear as dark spaces beneath the ribs. Other organs in the upper abdomen are also visible although not with much detail. Standard X-ray images show only bone tissue in any detail, with only the densest soft tissues showing up as shadows.
11. Answers will vary. Only the denser soft tissues such as the heart and diaphragm appear bright in the X-ray CT image. Lung tissue, which is mostly filled with air, does not appear bright at all.



12. Answers will vary depending on students' perceptions. Adjusting brightness and contrast can reveal subtle differences in pixel density, such as that present between white and gray matter. Magnification of structures can reveal details; however, too much magnification makes the image appear pixelated. An inverted image is sometimes easier to interpret because the human eye is often trained to observe black objects against a light background. Some color tables (those with a continuous LUT, such as Rainbow or Fire-1) can help the human eye to see subtle differences in pixel values; however, color tables with a discontinuous LUT (such as System) can make a grayscale image appear chaotic and uninterpretable. Shadowing the MRI image gives the impression of three dimensions while sharpening makes edges appear more distinct.
13. Answers will vary. There is much more detail visible in the soft tissues shown in the head MRI image than the head CT. The white and gray matter are seen clearly in the MRI and only slightly in the CT.
14. Each of the head images is a sagittal section.
15. Answers will vary. Three dimensional MRI data and reslicing could be used to determine the exact dimensions and location of abnormal structures within the brain such as a tumor or foreign body.
16. Answers will vary depending upon which pixel students place their cursor on.
17. The pixel value does not change when a color table is applied to an image—only the color assigned to that pixel value changes.
18. Answers will vary. The falsely colored PET image makes small differences in pixel values more visible to the human eye than small changes in shades of gray.
19. Answers will vary. Chest #2 and Head-neck #2 are both abnormal bone scans. They show dark areas within the bone that represent abnormal bone activity due to widespread cancer metastasis.
20. Answers may vary. An area that appears darker than it should be indicates faster than normal bone growth. Conditions that would promote faster than normal bone deposition include bone tumors, arthritis, stress fractures and tumor metastases to bone from other primary cancers.
21. Answers will vary. The chambers of the heart expand and contract as you move through the echocardiogram.
22. Answers will vary. A major advantage of sonography is that it can image movement in real-time, thus allowing a health professional to assess function as well as structure.
23. Answers may vary. The least expensive and most commonly available imaging technique to diagnose a bone fracture would be an X-ray. While there is some risk to the patient due to ionizing radiation, the risk is minimal. If the standard X-ray is negative and the pain and swelling persists, another imaging technique such as an MRI might be used to look for a soft tissue abnormality or a bone scan might be used to detect a stress fracture.
24. Answers will vary. An MRI of the head would be the most appropriate technique because it provides the greatest amount of detail in the soft tissues of the head and brain. An MRI also does not pose any risk to the patient from ionizing radiation. A CT scan of the head might also be used.



25. Answers will vary. Three of the image techniques presented in this lesson can be used to evaluate function: PET, bone scans and sonography. Physiology can be evaluated with the nuclear medicine techniques of PET and bone scanning because these techniques measure uptake of biologically active molecules into the tissues being scanned. An area of increased uptake in a bone scan might indicate a bone tumor, while an area of increased uptake in a PET image of the brain might indicate normal physiologic activity during an information processing task such as reading or listening. Physiology can also be assessed with sonography, in that movement can be tracked in real-time, without harm to the patient. For example, the function of the valves of the heart can be evaluated with echocardiography.

There is a new MRI technique (described in the margin) that will be available soon that will also be able to evaluate physiology. You may want to share this new information with your students as you discuss the answer to this question.

### ***“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.



# Biomedical Imaging

## Noninvasive visualization of anatomy and physiology




### Lesson

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 *NIH Image* to view and manipulate these images. *NIH Image* was developed 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 **H-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-GEN-o grams) or radiographs.

1. What structures do you recognize in this radiograph?

 Adjust the brightness and contrast of this image using the **Brightness** and **Contrast** sliders in the **Map** window.

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.

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.

In addition, *NIH Image* can be used to measure structures in an image for later data analysis.

 **File/Open...**


**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.

 Use the **Brightness** and **Contrast** sliders to adjust brightness and contrast or choose **Process/Enhance Contrast**.


See the **Look-Up Tables IPTechnique Sheet** for tips on adjusting brightness and contrast.




 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.

 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 **Options/Color 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 **H-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**?

 **File/Open...**

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.


 **Options/Grayscale** or **File/Revert to Saved** to go back to the original appearance of the image.




Hint: The large intestine is found in the lower abdomen.

 **File/Close...** or click the  at the upper left corner of an image to close it.

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


 **File/Open.../☒ Open All**

 Click and drag each image by its title bar to arrange them on your monitor.

 Use the  and  sliders in the **Map** window to see the details more clearly.



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


 Close **Radiograph-chest** and **Chest CT**.


 **File/Close...**

## **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).

 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**).

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.



*To do this. . .*

*. . .use this tool and technique*

Adjust brightness or contrast

**Process/Enhance Contrast** or use the  and  sliders in the **Map** window. Click the  to return the **LUT** to its original position.

Magnify structures

Choose the  tool and click on the structure you want to magnify. -click to reverse the magnification.

Invert the image

**Edit/Select All** and then **Edit/Invert**

Apply a color table

**Options/Color Tables▶**

Shadow the image


**Process/Shadow...▶** 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.

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

 **File/Open.../☒ Open All**

See the **Stacks IPTechnique Sheet** for extra help with manipulating stacks.

 **Stacks/Windows to Stack**

 **Stacks/Animate**. Use the 1-9 keys to change the speed of the animation. Click on the image to stop the animation.


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.

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



- ☐ Use the  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.

## 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.

### 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  tool to enlarge the image to a scale of **16:1** (shown in the title bar). 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.

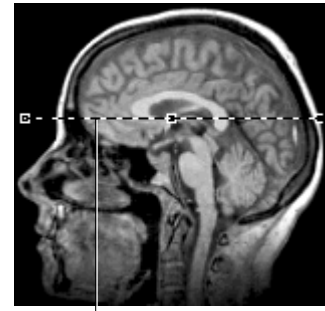
- ☐ Choose **Options/Color Tables/Rainbow** to apply false color to the image.

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.
- ☐ Use the  slider in the **Map** window to 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**.





straight line selection

 **File/Close...**

Radioactive decay products are forms of ionizing radiation.

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.

See the **Look-Up Tables IPTechnique Sheet** for additional information about color tables or manipulating the **LUT**.

- ☐ **(Option)**-click  on the image or double-click the  tool in the toolbar.





## Bone scans

A bone scan is a common procedure used to examine bone growth. The element technetium ( $^{99m}\text{Tc}$ ) 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 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.

- ☐ 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.


 **File/Open.../☒ Open All**

Hint: What kinds of conditions would promote an abnormally high rate of bone growth?

 **File/Close...**

To date, high frequency sound waves have not been shown to cause harm. Sonography equipment is relatively common in clinics and hospitals.

 Use the > and < keys to move forward and backward through the stack.

 Click on the title bar of the **LUT** to make the colors at the bottom visible.



☐ 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.

⏪ Use the > and < keys to move forward and backward through the stack.



# Biomedical Imaging



## Data Sheet

Name(s) \_\_\_\_\_ Class \_\_\_\_\_  
\_\_\_\_\_ Date \_\_\_\_\_

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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?







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?

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