Curriculum Units by Fellows of the Yale-New Haven Teachers Institute
1983 Volume VII: Medical Imaging

The Basic Concepts of Diagnostic Ultrasound1

Curriculum Unit 83.07.05
by Beverly Stern

I. Diagnostic Ultrasound

A. Introduction to Ultrasound and Its Use

The human ear can hear sound waves that have a frequency of 20-20,000 hertz. [2] Ultrasound refers to waves that have a frequency higher than 20,000 Hz and are therefore outside our hearing range. Figure 1.

Sound waves cannot travel in a vacuum like light waves; they must have a medium to travel through. In any homogeneous material, sound Will travel at a constant rate. The rate will differ with different media. Carefully read the following table.

1. Section I: Diagnostic Ultrasound and Section II: A Little Math Here and There have been put before the unit purpose, level and objectives in Section III so that they may more easily be copied for classroom sets of text materials.
2. Hz is the symbol for "hertz", the internationally accepted unit for measuring cycles. 1 Hz = 1 cycle per second. MHz is the symbol for megahertz. 1 MHz = 1,000,000 Hz.

Velocity *of Sound in Different Media*

media	feet/second	media	meters/second
air	1,100	air	331
water	4,800	water	1540
		body tissue	1540

Notice that the table uses both the metric unit meter and the English unit feet. Also notice that the approximate speed of sound in water and soft body tissue is the same. [1] Why do you think that is so? The reason is that body tissue contains such a large proportion of water that sound travels through it at approximately the same rate it travels through water.

Before beginning to study the ultrasound medical imaging process, there are two situations I'd like to consider. First, suppose you are standing on an open plane and shout, "HELLO!". What would happen? Your voice would go forth and disappear. Next suppose you were in a canyon and yell, "HELLO!". Now what would happen? Sure, you'd hear an echo. How is an echo produced? It is produced from the sound of your voice going forth and bumping into the side of the canyon wall then being reflected back to you. Figure 2.

If you stand in the canyon and yell, "HELLO!", and in 0.1 seconds an echo comes back to you, how far is it across the canyon? Using the data in the above table and the distance formula you can solve that.

Distance = Rate x Time

d = r x t

d = 1,100 ft/s x 0.1 s

d = 110 ft

Since the sound had to travel 110 ft across the canyon and back, one way, the distance across the canyon, would be half that or 55 ft. Answer: 55 feet

Using the same information, if you see lightning flash 15 seconds before you heard the rumble of thunder, how far away would the lightning be? Answer should be to the nearest mile. We'll get back to this problem in the section on math. Meanwhile, if you are going to try it, remember that 5280 feet = 1 mile.

1. During this unit when reference is made to body tissue it means soft body tissue like liver or kidney rather than hard tissue like bone.

Second situation. Figure 3.

(figure available in print form)

You are on a sailing vessel out at sea and you want to know the depth of the water. Your ultrasound instrument sends out sound waves that hit the bottom and return in 4 seconds. How deep is the water?

d = r x t

d = 4,800 ft/s x 4 s

d = 19,200 ft

Since the sound wave had to travel 19,200 ft round trip, one way, the depth of the water at that point, would be half that or 9,600 ft. If it took 3 seconds to return, how deep would it be? If the water were 15 feet deep, how long would it take for the sound wave to return? These questions will be answered in the section on math.

B. Ultrasound Medical Imaging—The Basic Process Briefly Stated

An ultrasound study in progress is illustrated in Figure 4. The basic ultrasound process goes as follows. The operator, usually a sonographer or radiologist, signals the generator which produces an electrical pulse and sends it to the transducer. [1] The transducer, or probe, changes the electrical pulse into a sound pulse and sends it into the body.

1. An electric current can be produced in a continuous current form or a “pulsed” form where the current is on and then off in a periodic way.

The sound wave will travel through the first body tissue until it hits an interface, where two different tissues are contiguous. Because of this interface, some of the sound wave will be reflected back and some will continue to travel through the next tissue. The part that is reflected back, the echo, is picked up by the transducer and changed into an electric pulse. The electric pulse is then sent to the computer/display. Depending on a) the time it takes an electrical pulse to make the round trip into the body and back and b) its intensity, a computer determines where on the display screen to make a dot and what shade of gray, from light to dark, it should be. The operator reads the information that appears on the screen. Figures 5.

(figure available in print form)

Ultrasound medical imaging produces readable images of inner body structures and motion without surgical entry into the body or radiation. Along with conventional radiography (X-ray), nuclear magnetic resonance (NMR), and computed tomography (CT or CAT scan), ultrasound is one of modern medicines most powerful diagnostic tools.

(figure available in print form)

Figure 3 SAILING VESSEL CHECKING DEPTH

(figure available in print form)

Figure 4 ULTRASOUND STUDY IN PROGRESS

(figure available in print form)

Figure 4 THE BASIC METHOD USED IN ULTRASOUND IMAGING. THE ECHO RETURNS OVER THE SAME PATH.

C. The Basic Process in Greater Depth

Ultrasound is a sound wave. All waves have the following characteristics: frequency, period, wavelength, propagation speed, amplitude and intensity. Frequency, period, amplitude and intensity are determined by the sound source. Propagation speed is determined by the medium, and wavelength is determined by both the source and medium.

The frequency of a wave tells how many cycles occur in a second. Figure 6. Frequency is measured in Hz and MHz. As stated above, the human ear can hear sound waves in the 20-20,000 Hz range and ultrasound refers to sound waves that are above 20,000 Hz. Diagnostic ultra-sound uses frequencies in the 1,000,000-5,000,000 Hz, or 1-5 MHz, range. Figure 1.

(figure available in print form)

Figure 6 FREQUENCY AMPLITUDE

The frequency of a sound wave or pulse is important in image resolution (display) and depth of penetration. The higher the frequency the better the resolution but the less depth of penetration. The lower the frequency the greater the depth of penetration but the poorer the resolution.

Wavelength is the distance or space needed for one cycle to occur. In diagnostic ultrasound wavelength is measured in meters (m) and millimeters (mm). It is important in image resolution. Figure 7.

Sound waves must have a medium to pass through. The speed at which a sound wave travels through a medium is called the propagation speed or velocity. It is equal to the frequency times the wavelength. In ultrasound it is measured in meters per second (m/s) or millimeters per microsecond (mm/µ s). In general, the propagation speed of sound through gases is low, liquids higher and solids highest. The average propagation speed for sound in body tissue is 1540 m/s, or 1.54 mm/µs. Carefully read the following table.

(figure available in print form)

Figure 7 WAVELENGTH

Velocity of Sound in Various Materials

Material	Velocity (m/s)
air	331
fat	1450
water (50°C)	1540
human soft tissue	1540
brain	1541
liver	1549
kidney	1561
blood	1570
muscle	1585
lens of eye	1620
skull-bone	4080
brass	4490
aluminum	6400

From Christensen, E.E. [1]

The period of a wave is the time it takes for one complete cycle to occur. It is the reciprocal of frequency. Period is measured in seconds(s) or microseconds (us). Figure 6.

Amplitude is the maximum height that occurs in a wave minus its normal value. Figure 6. It is measured in watts (W) and microwatts (µ W). Amplitude is important in determining the display and attenuation, the energy loss as sound travels through a tissue.

Intensity is a magnitude, such as energy or a force, divided by a unit of area, volume, etc. For sound it is the power, the amount of energy transferred measured in watts (W) divided by the area of the sound beam measured in square meters, (W/m^2). The sound beam will be discussed later. Amplitude and intensity describe the strength of a sound beam.

So far we have been considering terms that could be used to describe any wave—water, light, sound, radio,etc. Now we will consider ideas more specific to sound waves.

How is sound produced? An electric current, in a pulsed rather than continuous pattern, is sent to the transducer which converts the electrical energy into *mechanical sound* energy. The heart of the transducer is the piezoelectric (pi e zo i lek' trik) crystal. This crystal, which is either natural or man made, has been processed to have the piezoelectric property of changing a mechanical sound to electrical current and vice versa.

(figure available in print form)
Figure 8 THE PROBE

Behind the crystal is backing material which dampens the sound pulse. In front of the crystal is an acoustical lens which helps to focus and cut down on the reflections of returning sound impulses. Figure 8.

Piezoelectric means pressure electricity. The piezoelectric crystal can be thought of as having many small particles called dipoles. Each dipole has a positive and negative charge and is normally positioned as illustrated in Figure 9a.

Plating electrodes are placed on each side of the crystal. A negative charge is induced on one side, a positive charge on the other. This establishes an electric field between the plates, through the crystal. The dipoles are rearranged because of this= the positive charge of the dipole shifts slightly closer to the negative side and the negative charge of the dipole shifts slightly closer to the positive side. Figure 9b. This realignment of the dipoles results in a small decrease in the thickness of the crystal. When the field is turned off, the dipoles return to their original position and the crystal expands.

(figure available in print form)
Figure 9 PEIZOELECTRIC CRYSTAL

It is this contracting and expanding that produces the sound wave. When it expands it pushes the particles in its way and sends them crowding out in all directions. As the crystal becomes narrower there is a space created and the particles rush in to fill the space and return to their former positions. When the crystal pushes out causing a crowding of the particles, it is called compression. Compression represents the maximum in a usual wave illustration or the crowded (dark) part of the line representation of a wave. Figure 10. The space caused by the contraction is called rarefaction; it is represented on the same illustration.

Now let's go back. The generator, or pulser, sent an electric pulse to the transducer which changed it into a sound pulse. It is important next that the sound pulse travel directly from the transducer into the body without any air pockets or bubbles. Air acts as a sound barrier and would result in poorer resolution. To prevent this, a lubricant, such as mineral oil, is always placed on the skin. This provides a good connection between the transducer and the body.

Figure 10 WAVE COMPRESSION AND RAREFACTION

(figure available in print form)
The sound is then sent into the body. Suppose the pulse strikes the top of the liver. Some of the sound energy in the pulse will reflect back and be received by the transducer and some will be transmitted through the liver. When the continuing sound wave strikes the lower boundary of the liver it will again reflect some of the energy back to the transducer and the rest will travel on to possibly repeat the process as it strikes the kidney. Meanwhile, the transducer has been receiving the feedback and what it does with it is very important. The most common options are to display it in A-mode, B-mode, Compounded B-mode, M-mode or Real-Time mode. Later we'll see what the different modes mean.

At this point there are three areas left for which we should take a closer look. One is the sound beam, as compared to the sound wave. Another is the sound's journey into the body and back, and the last is what happens after the transducer receives the reflected sound or echo.

Let’s go to the sound beam first. The sound beam is made up of many sound waves. When the piezoelectric crystal expands, it pushes many particles forward and sets many sound waves into motion. The sound beam with its many sound waves forms two zones. Figure 11.

In the near zone, the sound beam is focused and the waves will be more perpendicular to the tissue. Being perpendicular will give the best reflection which means better resolution, or display, which in turn means more information. If a sound wave hits perpendicular to a tissue, it is called normal incidence. The greater the angle, called the angle of incidence, away from perpendicular that a wave hits a tissue, the less effective it will be. Figure 12.

(figure available in print form)
Figure 11 SOUND BEAM WITH NEAR AND FAR ZONES
(figure available in print form)
Figure 12 ANGLE OF INCIDENCE

Once a beam leaves the near zone and enters the far zone, the less focused and more scattered are the waves. Several variables, like the diameter of the probe, th thickness of the crystal, the lens, and the frequency of waves, go into determining the length of the near zone. For our purpose we only need to know that a sound beam is made up of many waves, that it divides into two zones and that the near zone needs to be long enough to include the structures we want to image.

As sound travels through body tissue its intensity and amplitude will decrease. How much it decreases will depend on the acoustic impedance of the tissue. The acoustic impedance is a property inherent in a medium and differs with different media. Here is a table of acoustic impedance values for various media. Note the smallest and largest.

Acoustic Impedance of Various Materials

Material	Acoustic Impedance (Rayls)
air	0.0004
fat	1.38
water	1.54
brain	1.68
blood	1.61
kidney	1.62
liver	1.65
muscle	1.70
lense of eye	1.84
skull-bone	7.8
aluminum	18.00
mercury	19.7
brass	38.0

From Christensen, E.E. [1]

When a sound wave hits the interface between two tissues, the amount reflected back will depend on 1) the angle of incidence and 2) the difference between the acoustic impedance values of the two tissues. If the difference is great, a large part of the sound will be reflected back. The imaging, therefore, will be poor because too much sound was reflected back and there was not enough left to be able to penetrate further and continue imaging. If the difference is small, a small amount will be reflected back which would allow enough sound left to continue through for further imaging. The percentage of the sound beam reflected back is given by the following formula. It assumes that the wave or beam is perpendicular to the tissue.

(figure available in print form)

R = percent of beam reflected

Z2= acoustic impedance of medium 1

Z1= acoustic impedance of medium 2

Using the equation and table given above, can you determine the percentage of a sonic beam reflected as it crosses the interface between the chest and lung? You can check your answer in the math section.

The liver is often referred to as the window to the abdomen. Do you think you know why? It's because the difference in the acoustic impedances of liver and most other parts of the abdomen is small. This means that a large part of the sound beam will go through the liver to the structures below it allowing them to be viewed (imaged).

Actually what is important here is not that we understand all the mathematics and physics, but that we understand the overall process and get some feeling for the mathematics that the computerized instrumentation performs. The computer component between the transducer and the display makes thousands of calculations per second.

The last area to be considered deals with what happens after the transducer receives the echo. Originally when a sound impulse was received it was processed to appear as a vertical reflection of a point. It looked like spikes of different heights. Figure 13a. The intensity of the returning impulse determined the height of the vertical reflection and the time it took for the impulse to make the round trip would determine the space between verticals. This method of d splay was called A-mode.

Later, instead of the returning electrical impulse making vertical movements as in the A-mode, they were used to produce dots on a screen. This was called B-mode. The "B" comes from "brightness". If the intensity was of a determined intensity, a dot of light was put on the display screen. The first B-mode displays showed all dots the same color or tone. Either a returning pulse was strong enough to cause a dot or it was not. This was called bistable imaging. Figure 13b. Next came the assigning to the returning sound pulses different shades of darkness depending on their intensities. The varying shades of gray reflected variations in the texture of internal organs. This form of display was called gray scale and provided significantly more information. Figure 13c.

Another significant step in improving ultrasound imaging was the development of the Compounded B-mode. Here the images produced at each probe position are stored until the probe has completed its traverse across the body. At that point all the individual scan images are integrated and displayed as a cross section of the body. Figures 13 and 14.

(figure available in print form)

Figure 13

Figure 14

(figure available in print form)

The result of the Compound B-mode is similar to taking a whole loaf of bread and slicing it through the middle. When you do this you cut through the bread in a plane and this would allow you to see the center of the bread—at least in that plane. In a parallel way ultrasound cuts through the body in a plane and allows us to view what's happening inside the body—at least in that plane.

M-mode basically took a B-mode image, turned it vertically and recorded the returning images over time. For example, if the probe was scanning a particular part of the heart it would receive the image in B-mode from that part, but the focus wouldn't move to another part of the heart. Instead it would receive more images from the same part only now there would be different images because of the heart's motion. Over time the returns would look something like Figure 13e. People who understand the functioning of the heart and the principles of ultrasound are able to learn important data from M-mode. The "M" stands for motion.

Real-time mode is the last major display development. This mode allows for visualizing motion of internal structures in a way that is much easier to read. It is important to have the images easier to read because this makes the technique available to more people. Real-time is like a movie of the body's inside functioning It actually is made up of compound B-mode images in frames of about 30 per second.

For real-time the transducer is different than for the A,B or M modes because a larger sound beam is needed. The transducer operates the same way but would have more than one piezoelectric crystal and the crystals would be arranged and fired in different ways.

An ultrasound real-time study was being done when the sonograms in Figure 15 a, b and c were taken. The study was being done to determine the age of the fetus and to see if it looked like a normal pregnancy.

Notice the "+" symbols. They are electronic calipers. The sonographer scans in real-time until she can catch the fetus in the position she wants to take the needed measurements. When she finds a scan she needs, she freezes it, sets the calipers and the computer tells the measurements. The femur in 15a was about 12 ml. The head measurement was about 2.5 cm. With either measurement the sonographer can look on a chart and determine the age.

This is a good place for this ultrasound section to end because what would naturally follow is what is in Lisa Orville's "Imaging the Human Body With Ultrasound."

Figure 15 SONOGRAMS: STILLS FROM A REAL-TIME STUDY

(figure available in print form)
(figure available in print form)
(figure available in print form)

II. A Little Math Here and There

A. Waves . . . Waves . . . Waves

The following six characteristics hold for all waves whether they are water, sound, light or radio waves.

frequency	propagation speed
period	amplitude
wavelength	intensity

1. Using your notes or the text, write a definition of each of the above wave characteristics.
2. Draw and label illustrations of frequency, period, wavelength and amplitude.
3. Complete the following table.

FREQUENCY PERIOD WAVELENGTH PROPAGATION SPEED

a. 5Hz ——— ——— 800 m/s
b. ——— 0.05 s 1200 ft———

B. Distance = Rate x Time (Distance Formula)

Rate is a ratio, a comparison of two numbers. It means so many of something per so many of something else. Look carefully at the following rate examples.

Rate *Example of Meaning*

miles That car is traveling 55 miles per hour. hour

meters

second In air sound travels 331 meters per second.

miles Light travels at 186,300 miles per second. second

For each of these we usually let the second number be 1 of whatever it is: miles per 1 hour, feet per 1 second, meters per 1 second, etc. It doesn't have to be 1, we could say 331 meters per second or 2648 meters per 8 seconds, and mathematically it work out the same. We use the unit rate to make our work easier.

Use the distance formula and solve the following.

Label each answer.

1. A car traveled 60 miles per hour or 3 hours. How far did it travel?
2. At 42 miles hour for 7.5 hours, how far did it travel?
3. At 45 miles hour for 8 hours, how far did it travel?

In air sound travels 1,100 feet per second.

4. How far will it travel in 4 seconds?
5. How far will it travel in 8 seconds?
6. how far will it travel in 0.3 seconds?

In air sound travels 331 meters per second (m/s).

7. How far will it travel in 7 seconds?
8. How far will it travel in 0.1 seconds?
9. How far will it travel in 4.2 seconds?

In water sound travels 4,800 feet per second (ft/s).

10. How far will it travel in 6 seconds?
11. How far will it travel in 0.2 seconds?
12. How far will it travel in 0.01 seconds?

In water sound travels 1540 meters per second (m/s).

13. In 8 seconds, how far will it go?
14. In 0.5 seconds, how far will it go?
15. In 0,03 seconds, how far will it go?

In soft body tissue sound travels 1540 meters per second.

16. How far will it travel in 1 second?
17. How far will it travel in 0.01 seconds?

18. How far will it travel in 0.000001 seconds?

In soft body tissue sound travels 1.54 millimeters per microsecond.

19. How far will it travel in 3 microseconds?
20. How far will it travel in 8 microseconds?
21. How far will it travel in 24.3 microseconds?

C. Special Problems

Use the following data to solve the given problems.

d = r x t
velocity of sound in air
1,100 ft/s
331 m/s
Velocity of sound in water
4,800 ft s
1,540 m s
velocity of sound in soft body tissue 1540 m/s
1.54 mm/ s
1 mile = 5280uft

1. What is the distance across a canyon if it takes 1 second for your echo to return?Use feet.
2. What is the distance across a canyon it it takes 2.4 seconds for your echo to return? Use feet.
3. If you saw lightning flash 15 seconds before you heard the first rumble of thunder, how far away would the lightning be? Round to nearest mile.
4. If you saw the lightning and 10 seconds later heard the first rumblings of thunder, how far away would the lightning be? Round to nearest mile.
5. You are on a sailing vessel and it takes 3 seconds for an ultrasound pulse to reach the bottom and return. How deep is the water? Give answer in feet and meters.
6. Still at sea, it takes 0.5 seconds for your sound pulse to return. How deep is the water? Give answers in both feet and meters.
7. If it took 0.003 seconds for your sound pulse to return , how deep would the water be? Give answer in both feet and meters.
8. How long would it take an ultrasound echo to return to a ship it the water were 75 feet deep? if water were 15ft. deep?

Use 1.54 millimeters/microseconds for #9and #10.

9. How far into the body would sound travel in 4μs?
10. How far into the body would sound travel in 6.47μs?

D. Bet You Can't

Using the data in the table on acoustic impedance, can you use this formula

(figure available in print form)

R=percent of beam reflected

Z1= acoustic impedance of medium 1

Z2= acoustic impedance of medium 2

to find the percentage of beam reflected back at each of these interfaces.

a. chest(soft tissue)—lung(air)

b. kidney—fat

Math Answers

A. Waves . . . Waves . . . Waves

1. use text 2. use text

3a. 5Hz	0.2s	160m	800m/s
3b. 20Hz	0.	1,200ft	24,000ft/s

B. Distance = Rate x Time

1) 180miles	2) 390miles	3) 360 miles	4) 4,400ft
5) 8,800ft	6) 330ft	7) 2317m	8) 33.1ft
9) 1,390.2m	10) 28,800ft	11)960ft	12) 48ft
13) 12,320m	14) 770m	15) 46.2m	16) 1540m
17) 15.4m	18) 0.00154m	19) 4.62mm	20) 12.32m
21) 37.422mm			

C. Special Problems

1) 550 feet	2 1320 feet
3) 3 miles	4 2 miles
5) 7,200 feet	6) 1200 feet, 385 meters
7) 7.2 feet, 2.31 meters	8) 0.015625 seconds; 0.003125 seconds
9) 6.16 millimeters	10) 9.96 millimeters

D. Bet You Can't

1) 99.9% 2) 30%

III. Unit Information

I. Purpose and Level

This unit explains what ultrasound is, how it is produced and why it is useful in medical imaging. A section on mathematics is include

Basic Concepts of Diagnostic Ultrasound was written to be used primarily in a technological mathematics course for 10 th and 11 th grade students with a wide range of ability levels.

II. Specific Objectives: Using about 15 class periods, the student should be able to do the following.

A. Put in writing

1. the ultrasound medical imaging process

2. the sound frequency range audible to humans and the frequency range used in medical imaging

3. how ultrasound is produced

4. why ultrasound is important in diagnostic medicine

B. Sketch illustrations of A-mode, B-mode, Compound B-mode and M-mode

C. Describe in writing the real-time mode

D. Do requested work in math section which includes the following.

1. Define, illustrate and use the following wave characteristics—frequency, periods, wavelength, propagation speed, amplitude and intensity

2. Apply the distance formula in a variety of car and sound situations

III. Overview

A. Section I. Diagnostic Ultrasound

B. Section II. A Little Math Hers and There

C. Section III. Unit Information

D. Section IV. Lesson Plans

E. Section V. Bibliography

IV. Lesson Plans for Ultrasound *

1 st Part

1. Introduce unit using a set of slides and sound
2. Explain project and grading for unit
3. Students are expected to take notes and for homework learn to outline process for a 4 minute quiz

2 nd Part

1. 4 minute quiz

2. Introduce wave theory
3. Read material together
4. Homework do 1-3 in math Wave section

3 rd Part

1. Return quizzes
2. Review overall process and wave theory with slides
3. Discuss transducer and crystal
4. Students expected to carefully illustrate the transducer and label parts
5. Homework—study wave theory and transducer for a 10 minute quiz

4 th Part

1. 10 minute quiz
2. Using slides and text cover the traveling of sound into body tissue and back to transducer
3. Explain computer assisted Distance Formula I practice they are expected to do
4. Students expected to take notes and do assigned problems in the math section

5 th Part

1. Return quizzes
2. Review sound wave traveling into body and back
3. With slides discuss A,B and M modes
4. Students expected to take notes and illustrate concepts
5. Homework—study the process of sound waves entering and returning from body tissues and modes of display

* Plans are divided into ten parts. A highly motivated group of students could possibly cover one part a day, but it is divided into parts instead of days so that conceptual development will have priority over time.

6 th Part

1. 10 minute quiz
2. Discuss real-time, 30 frames per second and how transducer is different
3. Discuss three fetus slides, use charts
4. Using charts, discuss the parts of the anatomy to be seen next class on real-time tape

7 th Part

1. Return quizzes
2. Show and discuss real-time tape

8 th Part

1. Show slides from Lisa Orville's "Imaging the Human Body With Ultrasound"

9 th Part

1. Work with students on their one page summary of diagnostic ultrasound. Complete for homework.

10 th Part

1. Students organize notes, quizzes, summary. Have students fill out form evaluating unit. Make relevant cover designs for their papers. Complete for homework.
Hand in the completed booklets of their work.

V. Bibliography

A. Teachers' Bibliography

1. Christensen, E.E., Curry,T.S., Dowdey, J.E.: *Introduction to the Physics of Diagnostic Radiology: Lea & Febeger, Philadelphia, 2nd Ed.* 1978. Chapter 25, Ultrasound, has clearly presented text and illustrations of the physics of ultrasound.

2. Gosink,B.B.: *Diagnostic Ultrasound, Exercises in Diagnostic Radiology* : W.B. Saunders, Philadelphia 2nd Ed. 1981. Chapter 1 has good illustrations and pictures which are helpful in understanding how ultrasound produces images.

3. Kremkau, Frederick W.: *Diagnostic Ultrasound Principles and Exercises* . Grune & Stratton. New York, 1980. Very clearly states what is happening at each step of the ultrasound imaging process. Has exercises with answers.

B. For Students

1. The Basic Concepts of Diagnostic Ultrasound, Sections I and II. See materials.

2. Distance Formula I. Computer assisted practice in using distance formula with speed of sound in air, water and body tissue. See materials.

C. Materials

1. The Basic Concepts of Diagnostic Ultrasound, Sections I and II. Yale-New Haven Teachers Institute may possibly have a classroom set.

2. Distance Formula I. Computer assisted practice in using the distance formula with speed of sound in air, water and body tissue. In BASIC for Apple II. Floppy disc. Yale-New Haven Teachers Institute. Part of this unit.

3. Slides. Basic Concepts of Diagnostic Ultrasound. Part of this unit. Yale-New Haven Teachers Institute.

4. Speed of Sound. Floppy disc. Computer classroom demonstration which compares the speed of sound in air, water, body tissue and brass. In BASIC for Apple II. Part of this unit. Yale -New Haven Teachers Institute.

5. Video tape. There may be available a video tape on the different types of medical imaging. On it would be real-time ultrasound scanning. Check with Yale-New Haven Teachers Institute.