CHAPTER NINETEEN

Ultrasound

A. Basic Concepts

1. Ultrasound is sound waves with frequencies greater than 20,000 Hz, which is beyond the range of human hearing.

2. In practice, clinical ultrasound is operated between 1 and 20 MHz.

3. The origin of ultrasound was during World War II, with "sound navigation and ranging" (SONAR).

4. Two factors affect the ***speed of sound*** in a given material.

- ***Compressibility:*** When a material is very compressible, the speed of sound is much slower.
- ***Density:*** As the density of a material increases, the speed of sound decreases if the compressibility coefficient remains the same.
- V = speed of sound in a material
- $V_{GAS} < V_{LIQUID} < V_{SOLID}$
- For example, speed in air = 330 m/sec, speed in water = 1480 m/sec, and speed in bone = 4080 m/sec
- The speed for different body tissues varies slightly around an average speed of 1540 m/sec.
- Speed is *not* dependent on the frequency of the sound wave.

5. Sound is a ***longitudinal wave***. It moves in the same direction in which it interacts with matter. It is a mechanical wave that causes ***compression*** and ***rarefaction*** of the tissue.

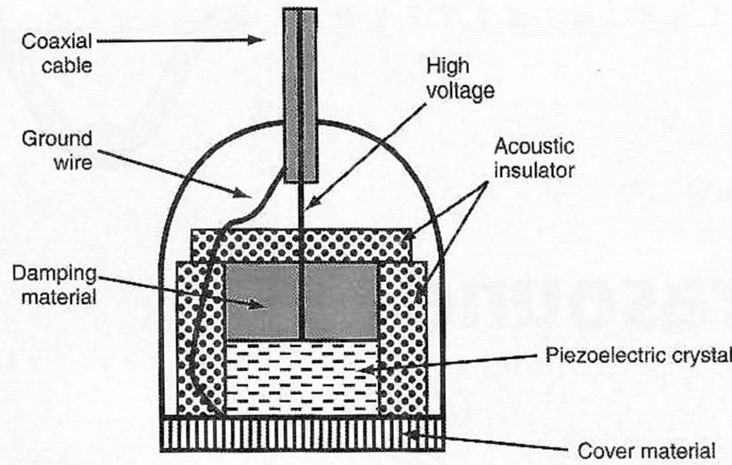
6. A transducer is composed of a piezoelectric crystal. When an electrical voltage is applied to the crystal, it expands. When the voltage is removed, it contracts. Thus, a voltage pulse causes the crystal to vibrate.

- The purpose of the damping material is to stop the vibration as quickly as possible.
- The thickness of the crystal determines the frequency at which it vibrates.

  λ = wavelength = 2T = 2 × thickness of crystal

  v = frequency = (4000 m/sec)/λ

- The piezoelectric crystal is a ceramic material such as lead zirconate titanate (PZT).



- A piezoelectric crystal can use electrical pulses to create vibrations, or mechanical pressure on the crystal can create electrical signals.
- The transducer is used both to send vibrations into tissue and to receive the echoes of the reflected ultrasound waves and convert them to an electrical signal.

7. ***High-Q transducers*** produce sound waves with narrow frequency spreads; however, these crystals take a longer time to stop vibrating after an excitation. This long "ring-down" time results in loss of axial resolution and loss of capability to image near the surface.
8. ***Low-Q transducers*** produce sound waves with wider frequency variations; however, these crystals stop vibration after excitation more rapidly. The short ring-down times result in better axial resolution and better imaging near the surface.
9. The ***basic principle of ultrasound imaging*** is to send a sound wave into a material and listen for an echo when the wave encounters a dissimilar material. The speed of ultrasound in most tissue is around 1540 meters per second. The time between transmission of the sound and the return of the echo (Δt) is related to the depth of the dissimilar surface (X).

   $X = \text{depth} = (1540\ \text{m/sec})(\Delta t)/2$

   - Typically, ultrasound transducers transmit 1% of the time and listen for echoes 99% of the time.

10. The ***acoustic impedance (Z)*** is the characteristic property of the material. Z is the product of density (ρ) and speed of sound in the material (V).

MATERIAL	SPEED (m/sec)	DENSITY (g/cm^3)	Z (RAYLS × 10^{-6})
Air	330	0.001293	0.000427
Water	1480	1.0	1.48
Fat	1460	0.93	1.34
Muscle	1600	1.04	1.66
Bone	4080	1.9	7.75

$Z = \rho \times V$ in Rayls

1 Rayl = (kg/m^2-sec) = (0.1 g/cm^2-sec) or

1 g/cm^2-sec = 10 Rayls

11. The greatest reflection occurs at the interfaces of different materials, where the difference in acoustic impedance (Z) is greatest.

$$\%\ \text{Reflection} = 100\%(Z_1 - Z_2)^2/(Z_1 + Z_2)^2$$

$$\%\ \text{Transmission} = 100\%(4Z_1Z_2)/(Z_1 + Z_2)^2$$

- If the differences in acoustic impedance are large, most of the power of the wave is reflected.
- If the differences in acoustic impedance are small (the impedance values are nearly the same), most of the power of the wave is transmitted.
- In all cases, some of the power is transmitted through the interface and some of the power is reflected.

12. ***Decibel (dB)*** is the unit in which the strength of the reflected echo is measured.

$dB = -10 \times \log_{10}[P_{IN}/P_{ECHO}]$

where P = power in milliwatts/cm^2.

P_{ECHO}	P_{IN}/P_{ECHO}	DECIBELS (dB)
100%	1.0	0
50%	2.0	−3
25%	4.0	−6
12.5%	8.0	−9
10%	10	−10
1%	100	−20
0.1%	1000	−30
0.01%	10,000	−40

- For each factor of 2 reduction in the power of the echo, add −3 dB.
- For each factor of 10 reduction in the power of the echo, add −10 dB.

13. ***Power is removed*** from the sound transmission by scatter, attenuation, reflection, and shear losses.

Attenuation = $\alpha \times \nu \times L$

where α = attenuation coefficient in dB/(MHz-cm), ν = frequency of ultra sound in MHz, and L = total distance traveled = 2 × depth in cm.

MATERIAL	ATTENUATION COEFFICIENT (dB/MHz-cm) AT 1 MHz
Blood	0.18
Fat	0.6
Muscle	1.0–3.3
Liver	0.9
Kidney	1.0

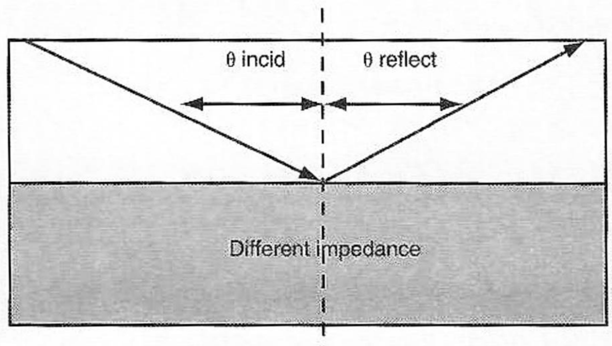
- It is usually assumed that $\alpha \cong 1.0$(dB/MHz-cm) for most tissues.
- Higher frequency ultrasound waves lose power more rapidly than lower frequency waves.
- Because of the rapid power loss at high frequencies, high-frequency transducers cannot penetrate deeply into the body.
- Low-frequency transducers are needed to image deep in the body.
- Because most ultrasound systems cannot image when the power loss is more than −70 to −80 dB, the depth of penetration can be calculated.

FREQUENCY (MHz)	EST. MAXIMUM DEPTH (cm)
1	35
3	12
5	7
10	3.5

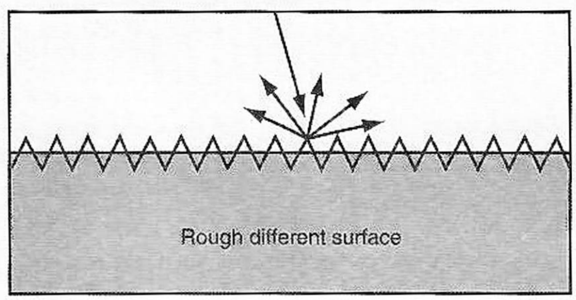
Maximum depth = 70 dB/[$2 \times \alpha \times \nu$]

- Shear is loss of power laterally because of the viscous nature of tissue through which the ultrasound wave travels.
- Scatter sends power out in all directions so that it does not bounce back to the transducer.

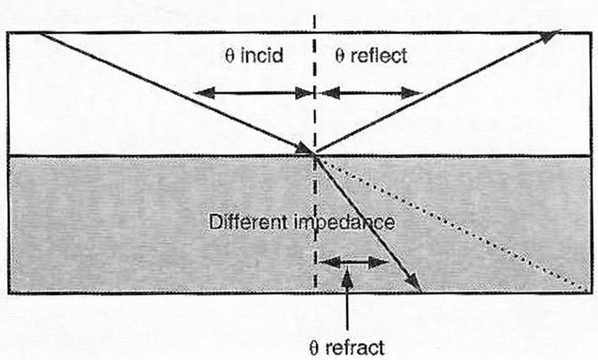
14. ***Reflection*** occurs when an ultrasound signal bounces off a surface with different acoustic impedance values on opposite sides.
    - ***Specular reflection*** involves bouncing the signal from a smooth interface.
    - For specular reflection, the angle of incidence equals the angle of reflection.



- If the incident ultrasound wave is not perpendicular to the interface, the echo reflects away from the transducer. The surface cannot be imaged.
- ***Diffuse reflection*** is a bounce from a rough surface that reflects part of the sound wave in many different directions.



- ***Rayleigh scatter*** occurs when the scattering objects are much smaller than the ultrasound wavelength. The amount of scatter is proportional to frequency to the fourth power. For very small objects, high-frequency ultrasound has a significant amount of Rayleigh scatter.
- ***Refraction*** is the change in direction of an ultrasound wave as it is transmitted across an interface with different impedances.



15. ***Snell's law*** for refraction is the following:

$$\frac{\text{Sin}(\theta\,\text{incidence})}{\text{Sin}(\theta\,\text{refraction})} = \frac{\text{speed incidence media}}{\text{speed refraction media}}$$

16. ***Fresnel zone*** is the depth in which the lateral width of the sound wave does not expand. It is the depth to which the sound wave can provide useful images without a significant loss of lateral resolution. For a circular disc element transducer,

Fresnel zone depth = $d^2/(4\lambda)$

where d = transducer diameter in cm and λ is the wavelength in cm.

FREQUENCY	λ (mm)	FRESNEL ZONE FOR d = 1 cm	FRESNEL ZONE FOR d = 2 cm
1 MHz	1.54	1.6 cm	6.5 cm
3 MHz	0.51	4.9 cm	19.6 cm
5 MHz	0.31	8.1 cm	32.2 cm
10 MHz	0.15	16.7 cm	66.7 cm

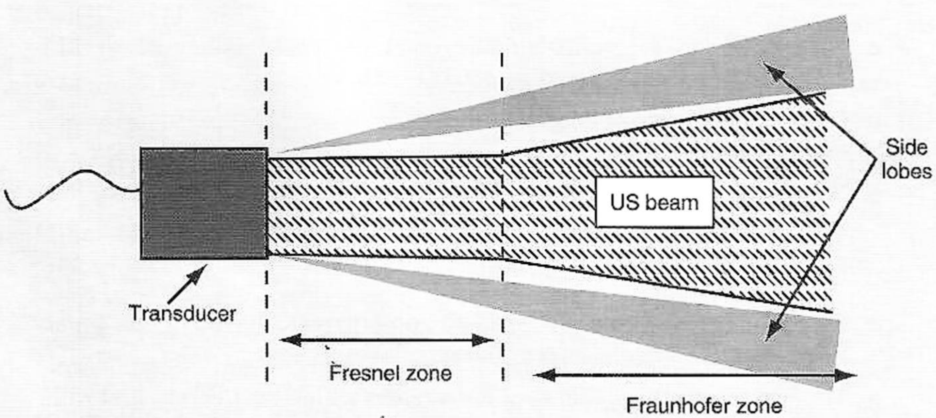
- In general, transducer diameter is usually equal to >10 wavelengths.
- Higher frequency transducers usually have a longer Fresnel zone.
- However, focused transducers exist that use acoustical lenses and electronic focusing to improve lateral resolution at a specified depth (focal length).
- At the focal depth for a single transducer element, the width (W) of the ultrasound beam is

  $W = (1.22\lambda \times F)/d$

  where F = focal distance.
- Higher frequency transducers have shorter wavelengths and narrow widths.
- This is important because lower frequencies have better penetration with shorter Fresnel regions.

17. ***Fraunhofer zone*** is the region in which the ultrasound beam continues to expand in width, which degrades the lateral resolution.

18. ***Side lobes*** are regions of ultrasound power that are outside and to the side of the main beam. Echoes from side lobes are thought to be from the main beams and can be misplaced as artifacts in the image.



19. ***Doppler effect*** is a shift between the transmitted frequency and the received echo related to motion of the object being imaged.

- If the object is moving toward the ultrasound transducer, the frequency increases.

- If the object is moving away from the ultrasound transducer, the frequency decreases.
- This effect is used to measure blood flow. The method is known as "color flow Doppler." Blood flow moving away is displayed as blue and green, and flow toward the transducer is shown as orange and red. The shade and color are related to speed of the blood.
- The measured echo frequency (ν_E) depends on the transmitted frequency (ν_0); the speed of the sound wave in the medium (V); the speed of the object, such as blood (S); and the angle (θ) between the transducer and the moving object, such as the blood vessel.

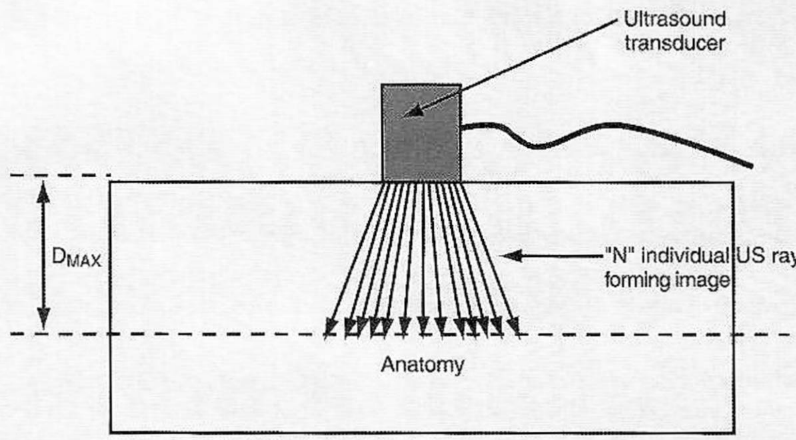
  $\nu_{ECHO} = [2 \times \nu_0 \times S \times \cos(\theta)]/V$

- The ***key features*** are that the Doppler frequency shift increases for faster object speeds and for smaller angles, where the ultrasound beam is aligned nearly parallel to the object's motion.

20. ***Frame rate (or refresh rate)*** is the number of separate ultrasound images that can be shown per second. A fast frame rate is important to show changing or moving objects.

- The time to image one line of an ultrasound image is equal to twice the maximum depth (D_{MAX}) divided by the speed of sound in the medium.

  $t_R = [2 \times D_{MAX}]/V$



- For example, for a 12-cm maximum depth, the time to scan one ray is $[2 \times 12]/[1540 \text{ m/sec} \times 100 \text{ cm/m}] = 0.000156$ sec.
- If there are N rays (or lines) per ultrasound image, the time to form one image is $N \times t_R$.
- The maximum number of ultrasound frames per second (frame rate [FR]) is given below.

  $FR = 1.0/[N \times t_R]$

- For our example with a 12-cm depth and 400 rays, the maximum frame rate is equal to 16 images per second.
- The ***key features*** are that the FR decreases with longer depths and with more rays in the image.

B. Image Quality

1. ***Axial spatial resolution*** is the ability to see small objects in the direction in which the ultrasound beam is moving through the tissue. The smallest separation of ultrasound echoes is about half of three wavelengths, which is the fastest time in which the transducer crystal can stop vibrating after a pulse.

   $\Delta X = 1.5 \times \lambda = (1.5 \times V)/\nu$

   - Because the speed (V) is about 1540 m/sec in most tissue, the axial resolution improves for higher ultrasound frequencies (ν).

2. ***Lateral spatial resolution*** is the ability to see small objects perpendicular to the direction of travel of the ultrasound beam. It depends on the width of the ultrasound beam.
   - Lateral resolution depends on transducer diameter, frequency, type of acoustic lenses, and electronic focusing.
   - Larger diameter transducers and higher frequency transducers have better lateral resolution.

3. ***Ultrasound artifacts*** fall into several different categories.
   - ***Reverberation artifacts*** are the result of the sound wave bouncing several times inside an object, such as a cyst, producing a ghost image of the original structure spaced at intervals behind the real object.
   - ***Shadowing*** is a dark area behind an object that attenuates most of the incident ultrasound signal.
   - ***Mirror image artifact*** occurs when an echo from an object is reflected from a strongly reflecting structure behind the object, producing a mirror image at a different location.
   - ***Side lobe artifacts*** measure echoes outside the main ultrasound beam and falsely place these objects in the main image.
   - ***Slice thickness and width artifacts***, like side lobe artifacts, measure echoes of objects outside the main beam and place them in the image.
   - ***Distortions*** are produced because the speed of sound in the body is different from the assumed average speed of 1540 m/sec.

C. Ultrasound Equipment

1. ***A-mode*** measures the depth of objects along a single ultrasound ray.
2. ***T-M mode*** (or time motion) plots the change in distance with time and has been used to monitor cardiac valve motion.
3. ***Older B-mode mechanical scanners*** used linkages to measure locations as the transducer was moved to many positions to form the image.
4. ***Rotating sector scanners*** have a single-element transducer that either rotates on a wheel or is reflected from an oscillating mirror to produce a triangular image.
5. ***Linear array*** is a series of individual transducers along a line in which each element images one line or ray to form a rectangular image.
6. ***Annular array*** is a series of concentric circular transducers that can shape the beam to different focal depths.
7. ***Phased array*** is a series of transducer elements in a linear or curved array that fire simultaneously with different phase delays to steer the ultrasound beam in various directions to form a trapezoidal image shape.

8. A ***color Doppler flow scanner*** measures blood flow by sensing the Doppler frequency shift.

9. ***Specialized transducers*** include endorectal and cardiac scanners.

10. To offset ***time gain compensation (TGC),*** an amplifier is used that can be adjusted to boost the gain of echoes from deep structures more than those from close structures to compensate for the loss in signal by attenuation of signal by tissue.

D. Potential Bioeffects of Ultrasound

1. The ***main bioeffects*** of ultrasound fall into the following categories, arranged according to the amount of power required (least to most):
    - Central nervous system (CNS) stimulation
    - Tissue heating
    - Cavitation
    - Tissue destruction at very high power
2. ***Thermal index (TI)*** is the ratio of the power required to cause tissue heating to a temperature increase of around 1° C divided by the actual transmitted power. The 1° increase in temperature is usually taken as the safe limit for diagnostic (nondiathermy) ultrasound. A TI of 1.0 or 2.0 is considered safe.
3. Cavitation is tissue tearing, which occurs at high powers.
4. Destruction, such as emulsification of cells, occurs at high power values.
5. The ***mechanical index (MI)*** is used to compare the pressure in the ultrasound wave with pressure that could cause mechanical damage. A pressure of less than 0.3 MPa (300,000 newtons/m^2) is generally considered to be safe.
6. CNS stimulation can occur in some fetal scans of pregnant patients.
7. ***SPTA*** (spatial peak temporal average) is a measure of ultrasound intensity. It is the peak intensity in space averaged over time. Because the transmitting power is turned on only 1% of the time, the SPTA is <1% of the peak intensity.
8. In the United States, it is recommended that the SPTA of a focused diagnostic ultrasound beam should be less than 1.0 watts/cm^2 and that the SPTA of an unfocused beam should be less than 100 mwatts/cm^2. The recommended maximum SPTA depends on the mode being employed.
    - The maximum SPTA for obstetrics and abdominal ultrasound is <100 mwatts/cm^2.
    - Because color Doppler ultrasound employs a high duty cycle and stays in one position for an extended time, its peak intensity and SPTA are nearly the same value.
    - The maximum SPTA for Doppler ultrasonography of peripheral vessels is <700 mwatts/cm^2.

E. Questions

19-1. The speed of sound in body tissue has an average value of about _____ m/sec.

(a) 100 (b) 330 (c) 960 (d) 1540 (e) 4000

19-2. If an echo arrives 100 microseconds (μsec) after the signal is transmitted, the depth of the structure is about _________ cm below the surface.

(a) 4 (b) 6 (c) 8 (d) 10 (e) 12

19-3. The speed of sound in any material is dependent on the characteristics of ________ and ________ of the medium. (i) Density (ii) Strain (iii) Bulk modulus (iv) Frequency (v) Polarity

(a) i and ii (b) ii and iii (c) iii and v (d) i and iii (e) ii and iv

19-4. The frequency of a transducer is primarily determined by the piezoelectric crystal's ________ .

(a) Diameter (b) Thickness (c) Density (d) Conductance (e) Reynold's number

19-5. The material from which the crystal of an ultrasound transducer is composed is called ________.

(a) Gd_2O_2S (b) NaI (c) PZT (d) LiF (e) $CaHPO_4$

19-6. As an ultrasound wave passes from one material to another, the ________ of the ultrasound wave stays constant and the ______ changes.

(a) Amplitude, frequency (b) Period, shear (c) Frequency, wavelength (d) Wavelength, speed (e) Impedance, refractive index

19-7. The acoustic impedance of an ultrasound wave is dependent on the ______ and ________ of the material.

(a) Density, velocity (b) Frequency, elastic modulus (c) Polarity, pH (d) Wavelength, diameter (e) Power, granularity

19-8. If the echo of an ultrasound wave has 0.05% of the initial power, the reduction in intensity is given as ________ dB.

(a) −13 (b) −23 (c) −33 (d) −43 (e) −53

19-9. The percentage of power reflected in the echo of an ultrasound wave primarily depends on ____________ differences of the materials at the interface.

(a) Viscosity (b) Absorption coefficient (c) Acoustic impedance (d) Frequency (e) Refractive index

19-10. The largest reflection of an ultrasound wave would occur at the interface of ________ and ________.

(a) Muscle, bone (b) Muscle, fat (c) Muscle, air (d) Fat, tumor (e) Aluminum, bone

19-11. The Doppler shift is measured in units of ______.

(a) dB/(MHz-cm) (b) Rayls (c) Hz (d) $mwatts/cm^2$ (e) Pascals

19-12. Acoustic impedance is measured in units of ________.

(a) dB/(MHz-cm) (b) Rayls (c) Hz (d) $mwatts/cm^2$ (e) Pascals

19-13. The linear absorption coefficient for ultrasound waves is measured in units of ________.

(a) dB/(MHz-cm) (b) Rayls (c) Hz (d) $mwatts/cm^2$ (e) Pascals

19-14. The intensity of ultrasound waves is measured in units of ________.

(a) dB/(MHz-cm) (b) Rayls (c) Hz (d) $mwatts/cm^2$ (e) Pascals

19-15. The pressure of ultrasound waves is measured in units of ________.

(a) dB/(MHz-cm) (b) Rayls (c) Hz (d) $mwatts/cm^2$ (e) Pascals

19-16. For a 3-MHz ultrasound transducer, the expected axial spatial resolution would be about ________ mm.

(a) 0.4 (b) 0.6 (c) 0.8 (d) 1.0 (e) 1.2

19-17. The maximum depth of penetration of a 3-MHz ultrasound wave would be expected to be about ________ cm, assuming an attenuation coefficient of 1.0 dB/MHz-cm.

(a) 4 (b) 8 (c) 12 (d) 16 (e) 20

19-18. If a 3-MHz sector scanner is used to create an image at a maximum depth of 12 cm with 200 rays of measurement, the maximum expected frame rate is about ________.

(a) 4 (b) 8 (c) 16 (d) 32 (e) 64

19-19. If a 3-MHz ultrasound wave penetrates 5 cm through tissue and then is reflected from a bone surface at that depth, the echo received at the transducer would be expected to be ______ dB.

(a) –10 (b) –20 (c) –30 (d) –40 (e) –50

19-20. The lateral spatial resolution depends on all of the following factors, *except* ___________.

(a) Speed (b) Impedance (c) Transducer diameter (d) Apodization (e) Frequency

19-21. The ultrasound artifact that creates a series of ghost images behind an interface is called ________.

(a) Refraction (b) Reverberation (c) Aliasing (d) Side lobe (e) Shadowing

19-22. The type of ultrasound scanner that fires an array of transducers one at a(n) time to create a rectangular image is called a _________.

(a) Sector scanner (b) Linear array (c) Annular array (d) Phased array (e) T-M mode

19-23. Multidirectional scatter of ultrasound waves from a rough surface is called _________ scatter.

(a) Specular (b) Rayleigh (c) Elastic (d) Diffuse (e) Newtonian

19-24. Quality control testing for ultrasound units should include all of the following, *except* __________.

(a) Distance accuracy (b) Depth of penetration (c) Spatial resolution (d) Uniformity (e) dB linearity

19-25. The type of transducer needed to damp the "ringing" (continued oscillations) of the transducer element as quickly as possible after each excitation is a(n) _______ crystal.

(a) Fraunhofer (b) Low Q (c) Apodization (d) Annular (e) Dynamic aperture

19-26. The Fresnel region is longer for transducer crystals that have _______.

(a) Low frequencies (b) Small diameters (c) Short wavelengths (d) Fractionation (e) Diffraction grating

19-27. To avoid damaging tissue as a result of heating, it is recommended that the SPTA transmit intensity of a focused beam be less than _______ mwatts/cm^2.

(a) 0.5 (b) 10.0 (c) 50.0 (d) 100.0 (e) 1000.0

10-28. The image processing feature that amplifies signal from a deeper depth more than signal from structures closer to the surface is called ________.

(a) ADC (b) TGC (c) MCA (d) RBG (e) FET

19-29. For color Doppler ultrasound imaging, the measurement of flow velocity requires knowledge of all the following parameters, *except* ___________.

(a) Transducer angle (b) Speed in medium (c) Focal length (d) Transmit frequency (e) Frequency shift

19-30. The reason for using an ultrasound gel between the patient's body and the transducer is to _______.

(a) Dissipate heat (b) Provide electrical insulation (c) Provide impedance matching (d) Reduce friction (e) Reduce side lobes

19-31. High-frequency transducers are used primarily to improve ________ .

(a) Spatial resolution (b) Depth penetration (c) Scatter rejection
(d) Radiation dose to the patient (e) Dynamic range

F. Answers

19-1. Answer = (d). Although the speed of sound waves in tissue varies from 1460 m/sec for fat to 1600 m/sec for muscle, the average speed in tissue is 1540 m/sec.

19-2. Answer = (c). The distance is equal to speed times time. However, the depth is traveled twice: once going toward the reflector and once traveling back toward the surface. Thus, depth = $(1.540 \times 10^{+5}$ cm/sec$) \times (100 \times 10^{-6}$ sec$)/2.0 = 7.7$ cm.

19-3. Answer = (d). The speed is dependent on the density and compressibility of the material. Compressibility is inversely related to the bulk modulus. Strain is the change in length divided by the initial length before the application of force. Frequency is determined by the piezoelectric crystal's thickness. Polarity is the electrical charge distribution of the molecular structure of the piezoelectric crystal, which accounts for the property of expanding or contracting linear dimension when a voltage is applied.

19-4. Answer = (b). See note in this chapter (**A6**). Conductance is an electrical property, and Reynold's number refers to flow characteristic of gases and fluids.

19-5. Answer = (c). Gd_2O_2S is the phosphor material of intensifying screens. NaI is a common scintillation material used in nuclear medicine detectors. LiF is the material used in thermoluminescent dosimeters. $CaHPO_4$ is a material used in bone mineral analysis.

19-6. Answer = (c). The frequency is fixed by the transducer design. Both speed and wavelength depend on the properties of the material through which the ultrasound waves travel. Period is equal to one divided by the frequency.

19-7. Answer = (a). The acoustic impedance is the product of density times speed in a material.

19-8. Answer = (c). 0.05% = 0.0005 = 1/2000. Each factor of 10 reduction (1/10) in power adds −10 dB. 1/1000 = (1/10) × (1/10) × (1/10), which adds −30 dB. The extra factor of ½ adds −3 dB, for a total of −33 dB.

19-9. Answer = (c). Viscosity is related to shear loss of power. Absorption coefficient refers to loss in power per linear path length. Frequency differences are related to the Doppler shift and the speed of an object moving toward or away from an ultrasound beam. Refractive index relates to a change in the direction of the ultrasound beam as it crosses boundaries with different sound-wave speeds.

19-10. Answer = (c). The greatest reflection occurs where the acoustic impedance difference is greatest. The acoustic impedances of the various materials in units of Rayls $\times 10^{+6}$ are as follows: air = 0.33 × 0.001293 = 0.000427; fat = 1.46 × 0.93 = 1.34; muscle = 1.60 × 1.04 = 1.66; bone = 4.08 × 1.9 = 7.75; and aluminum = 6.4 × 2.7 = 16.2. The greatest acoustic impedance differences are between air and anything else. For this reason, air interfaces result in almost 100% reflection.

19-11. Answer = (c). Doppler shift is a frequency shift that is measured as a difference in frequencies using units of Hz (or cps).

19-12. Answer = (b). See note in this chapter (**A10**).

19-13. Answer = (a). See note in this chapter (**A13**).

19-14. Answer = (d). See note in this chapter (**D8**).

19-15. Answer = (e). A pascal is equal to 1.0 N/m^2.

19-16. Answer = (c). Resolution = $1.5 \times \lambda = [1.5 \times 1.54 \times 10^{+6}$ mm/sec]/($3 \times 10^{+6}$ Hz) = 0.77 mm. See note in this chapter (**B1**) for equations.

19-17. Answer = (c). Maximum depth equals −70 dB/(2 × (−1) dB/MHz-cm × 3 MHz) = 11.67 cm. See note in this chapter (**A13**) for equations.

19-18. Answer = (d). t_R = (2 × 12 cm maximum depth)/(1.54×10^5 cm/sec) = 0.000156 sec. Frame rate = 1.0/(200 rays × t_R) = 1.0/(200 × 0.000156) = 32 frames/sec.

19-19. Answer = (c). The attenuation of signal power is about −1 dB per MHz per cm through tissue. At 3 MHz, the power loss is −3 dB/cm. The total distance traveled is 10 cm (5 cm in and 5 cm out). The power loss is −3 dB/cm × 10 cm = −30 dB.

19-20. Answer = (b). The lateral width of the beam is related to $d^2/(4\ \lambda)$. The wavelength (λ) is equal to the speed of sound divided by the frequency. Apodization is the use of electronic means to reduce the width of the ultrasound beam.

19-21. Answer = (b). See note in this chapter (**B3**).

19-22. Answer = (b). The description is for a linear transducer array of elements.

19-23. Answer = (d). Specular refers to a single beam with an angle of reflection equal to the angle of incidence. Rayleigh scatter involves very small objects that scatter in various directions. Elastic refer to nuclear collisions that conserve energy. Newtonian is a description of basic mechanical interactions.

19-24. Answer = (e). dB linearity is a nonsensical term that has no meaning.

19-25. Answer = (b). Low-Q piezoelectric crystals stop vibrating more rapidly than high-Q crystals. Fraunhofer refers to a zone where the lateral width of the ultrasound beam does not increase. Apodization is electronic focusing for improved lateral resolution. Annular ring is a type of transducer that can be readily focused by electronic means. A dynamic aperture has a sensor that varies the number of elements involved in receiving aperture size as echoes arrive. A small aperture is used for echoes from a shallow region, and the aperture increases as echoes return from deeper structures. This minimizes the variation in beam width with depth.

19-26. Answer = (c). The lateral width of the beam is related to $d^2/(4\lambda)$. Small diameters and long wavelengths are associated with shorter Fresnel regions. Low frequencies are the same as long wavelengths. Fractionation is related to spreading radiation doses over time to reduce bioeffects. Diffraction grating is related to optical effects.

19-27. Answer = (e). See note in this chapter (**D8**).

19-28. Answer = (b). ADC is analog-to-digital converter, which takes a continuously varying signal and converts it into discrete steps. TGC is time gain compensation amplifier, which selectively boosts deep echoes more than shallow echoes. MCA is multichannel analyzer, which is used in nuclear medicine to measure energy spectra. RBG is the use of the three primary colors (red, blue, and green) to yield all combinations of colors. FET is field effect transistor, which is used in control circuits.

19-29. Answer = (c). See note in this chapter (**A19**) about Doppler ultrasound.

19-30. Answer = (c). If there is any air between the transducer surface and the patient's skin, the difference in acoustic impedance is so large that the sound is 100% reflected. The signal never enters the patient's body.

19-31. Answer = (a). High frequency is associated with better spatial resolution because of the shorter wavelength. Higher frequency loses power faster by attenuation and cannot be used for deep structures. High-frequency ultrasound has more scatter. There is no radiation dose to the patient from ultrasound because it does not create ionizations. Dynamic range is related to the weakest echo that can be measured and the number of bits used in the digitization.