THE WEST AFRICA SCHOOL OF HEART AND VASCULAR ULTRASOUND (WASHVU)

ULTRASOUND PHYSICS AND INSTRUMENTATION

Authors: Terry Reynolds BS, RDCS
602-628-9069
reynoldsterry58@gmail.com

Ultrasound Physics – Cardiovascular Credentialing International (CCI) Registry Review

The CCI adult echocardiography board examination consists of 175 multiple choice questions (150 are graded – 25 questions are test questions for future examinations) – 13% are ultrasound physics questions (approximately 22 questions).

Below is the CCI outline for the ultrasound physics portion of the CCI adult echocardiography board examination. Test information including the complete adult echocardiography test outline is available at the CCI website - https://cci-online.org

E. Applying the Physics of Ultrasound **13%**

1. Identify properties of ultrasound waveforms
2. Recognize artifacts
3. Optimize resolution
4. Optimize frame rate
5. Optimize Doppler waveforms
6. Optimize color Doppler
7. Optimize 2D image
8. Optimize 3D image
9. Optimize contrast image

Course Description

The WASHVU ultrasound physics and instrumentation self-instructional course presents the fundamental topics of ultrasound by providing a descriptive presentation of the principles topics of ultrasound physics and instrumentation with questions, answers and explanations following each topic, a sonographer’s point of view for each topic presented, a TOP 5 overview of ultrasound physics is provided, an ultrasound physics and instrumentation in one sentence section is presented and a 100 multiple choice question post-test is provided.

Instructions

- The recommended steps for participating in the WASHVU Ultrasound Physics and Instrumentation course:

1. Read the description for each single topic – e.g.; Nature of Ultrasound

2. Answer the multiple-choice questions which following each topic section – e.g.; Nature of Ultrasound Multiple Choice Questions.

3. Review the answers-explanations after answering the multiple-choice questions assigned to each topic – e.g.; Nature of Ultrasound Multiple Choice Questions Answers-Explanations.

4. Review the TOP 5 summary of the course, answer the TOP 5 questions and review the answers to the TOP 5 questions.

5. Review the ultrasound physics and instrumentation in one sentence in order to review the basic principles.

6. When the course is completed, answer the attached Post-Test 100 multiple choice questions and submit the Post-Test 100 multiple choice questions answer sheet along with the attached course evaluation sheet by mail to: Terry Reynolds 1931 East Mountain View Road, Phoenix, AZ 85020 or by e-mail: reynoldsterry58@gmail.com

7. The answer sheet will be graded and returned within 3 to 5 days after receiving the answer sheet and course evaluation sheet.

8. The graded answer sheet will be returned with answers-explanations attached for review.

Table of Contents

Instructions

Review each individual topic (e.g.; Nature of Ultrasound), answer the multiple-choice questions which follow each presented topic and check answers with the answer-explanations which follow the presented multiple-choice questions. When the course is completed, submit the attached 100 multiple choice questions post-test examination answer sheet and email to reynoldsterry58@gmail.com or mail to Terry Reynolds 1931 East Mountain View Road, Phoenix, Az 85020. Thank you!

Note

Currently there are two types of operating systems-ultrasound machines which operate on different principles: 1. Conventional sonography (e.g.; Pulse-echo; Traditional; Principle 1) and 2. Virtual beam sonography (Synthetic aperture ultrasound; Synthetic aperture method; Principle 2). These two types of systems-machines are fundamentally different. The differences will be presented when pertinent in this course and a comparison of the two different approaches is provided at the end of the course booklet.

Nature of Ultrasound

Sound is a mechanical (e.g.; energy transfer), longitudinal (particles of the medium move (oscillate, vibrate) **PARALLEL** to the direction of sound travel) wave. As sound travels through the medium, sound creates regions of high pressure, high density called compression (condensation) and low-pressure, low-density regions called rarefaction. Sound is **NOT** a transverse wave which is defined as particle motion moving **PERPENDICULAR** to the direction of sound travel (textbooks depict the sound wave as a transverse (e.g.; sine, sinusoidal) wave because it is easier to present the ultrasound physics of sound using a transverse (sine, sinusoidal) wave.

Sound as it travels alters (affects) (but does not permanently change) the medium. Sound transfers energy from one point to another. The four acoustic variables which are altered (affected) but not permanently changed (permanent change would be considered a bioeffect) are:

Pressure – force per unit of area (e.g.; lbs/in^2, Pascals)
Density – mass per unit of volume (e.g.; g/m^3)
Temperature (F, K, C)
Particle motion (Units of distance e.g.; mm, cm)

Sound cannot travel in a vacuum. It requires a medium (particles in which to vibrate). Sound travels in a straight line (but can diverge).

A Sonographer's Summary

- Sound is a longitudinal wave, not a transverse (sine, sinusoidal) wave (may be confusing as a transverse (e.g.; sine wave, sinusoidal) wave is used to explain ultrasound physics in textbooks).
- Longitudinal waves create regions of high pressure and high density (compression) and low pressure, low density (rarefaction) which can be of interest when reviewing bioeffects.
- It is important to note that the peak of the compression portion of the longitudinal wave propagates through soft tissue slightly faster than the peak rarefaction portion. This is termed non-linear propagation of a wave through a medium. The nonlinear propagation of sound through soft tissue is the basis for tissue harmonic imaging. Analysis of this non-linear propagation of the sound wave demonstrates that there are several frequencies besides the fundamental frequency present including multiples of the fundamental frequency which are called the harmonic frequencies.

Nature of Ultrasound – Multiple Choice Questions

1. Sound is a mechanical, ____ wave.
   A. Transverse
   B. Longitudinal
   C. Shear
   D. Sine

2. The particles of a medium move parallel to the direction of sound travel. This is a ___ wave.
   A. Longitudinal
   B. Transverse
   C. Shear
   D. Sine

3. The region of high pressure, high density of a sound wave is called:
   A. Compression
   B. Rarefaction
   C. Refraction
   D. Reverberation

4. The region of low pressure, low density of a sound wave is called:
   A. Refraction
   B. Reverberation
   C. Range ambiguity
   D. Rarefaction

5. Which of the following are considered the four acoustic variables?
   A. Pressure, Density, Temperature, Particle motion
   B. Density, Frequency, Period, Propagation speed
   C. Temperature, Power, Amplitude, Intensity
   D. Particle motion, Attenuation, Reflection, Refraction

6. The units for the acoustic variable pressure are:
   A. Pascal (Pa)
   B. Millimeter (mm)
   C. Meters/second (m/sec)
   D. Microsecond (µsec)
7. Tissue harmonic imaging is based on (the):
   A. Bernoulli principle
   B. Virtual beam sonography
   C. Nonlinear wave propagation
   D. Nyquist limit

Nature of Ultrasound Multiple Choice Questions Answers-Explanations

1. **B.** Sound travels as a longitudinal wave which means the particles of the medium move (e.g. vibrate, oscillate) parallel to the net direction of sound travel. Sound is a vibration and the particles move east to west and west to east, parallel to the direction of sound travel, **NOT** north to south and south to north for this would be called a transverse (sine, sinusoidal) wave.
2. **A.** A longitudinal wave is present when the particles of the medium move (vibrate, oscillate) parallel to the direction of sound travel. A transverse wave means that the particles of the medium move perpendicular to the direction of sound travel (e.g.; sine wave, sinusoidal wave). Sound does not travel as a transverse wave but may be depicted as a sine wave in ultrasound physics textbooks for ease of presentation.
3. **A.** As the particles vibrate in a longitudinal wave, the particles are “squeezed” (pushed) together creating a high-pressure, high-density region called compression. Note that the peak portion of the compression wave moves slightly faster than the rarefaction wave peak. This is referred to as non-linear propagation of sound through the medium and is the basis for tissue harmonic imaging.
4. **D.** In a longitudinal wave, the particles are pushed together (compression) and “pulled apart” creating a low-pressure, low-density region called rarefaction.
5. **A.** As sound travels, pressure, density, temperature and particle motion are varied but not permanently altered. If permanently altered, then this would be considered a bioeffect.
6. **A.** Pressure is force divided by area (e.g.; pounds per square inch (e.g.; lbs/in^2, Newton $(N)/m^2$), Pascal (Newton$(N)/m^2$ - is named after Blaise Pascal in honor for his work hydrodynamics and hydrostatics and experiments with a barometer).
7. **C.** The peak of the compression wave moves faster than the peak of the rarefaction wave. This is nonlinear propagation of a wave through a medium. This causes distortion of the fundamental frequency transmitted and will result in multiple frequencies being created which makes tissue harmonic imaging possible.

Frequency (f)

The definition of frequency is the number of cycles per second. The units for frequency are Hertz (Hz).

One Hertz equals one cycle per second. (Note: In ultrasound physics Hertz (Hz) may indicate what occurs per second. For example, frame rate is the number of frames which occur per second and the units for frame rate are Hertz. Hertz are the units for frequency, frame rate, pulse repetition frequency and the Doppler shift).

The ranges for frequency are:

Infrasound: < 20 Hz
Audible sound: 20 Hz to 20000 Hz (20 kHz)
Ultrasound: > 20 kHz
Medical ultrasound 2 MHz to 15 MHz

As frequency increases, attenuation increases, the depth of penetration decreases, spatial (axial, lateral) resolution improves. As frequency decreases, attenuation decreases, depth of penetration increases, spatial (axial, lateral) resolution degrades.

A Sonographer's Summary

- Spatial resolution (e.g; axial, lateral) is important when trying to acquire high quality images (on which sonographers are evaluated) and so using the maximum transmit frequency is preferable. Increasing the transmit frequency decreases period, pulse duration, wavelength, spatial pulse length which improves axial resolution. Increasing the transmit frequency extends the near field length, reduces the sound beam width in the near field, decreases the sound beam angle of divergence, decreases sound beam divergence in the far field which improves lateral resolution. But increasing the transmit frequency decreases the depth of penetration due to sound attenuation and high frequencies attenuate more rapidly than lower frequencies.
- Transmit frequency is determined by balancing image quality with the depth of the structures being imaged (e.g.; adult echocardiography transmit frequency range: 2 to 4 MHz versus pediatric echocardiography transmit frequency range: ≥ 7.5 MHz)
- For the sonographer, it is always resolution versus depth of penetration.
- Virtual beam sonography improves depth of penetration even while high transmit frequencies are being transmitted because reflections are reconstructed by weighted summation of the returning echoes.

Frequency (f) – Multiple Choice Questions

1. The number of cycles per second is:

A. Frequency
B. Period
C. Wavelength
D. Propagation speed

2. The units for frequency are:
    A. Hertz (Hz)
    B. Millimeters (mm)
    C. Centimeters^2 (cm^2)
    D. Meters/second (m/sec)
3. The range for audible sound is:
    A. < 20 Hz
    B. 20 to 20,000 Hz (20 kHz)
    C. > 20 kHz
    D. 2 MHz to 15 MHz
4. As transmit frequency increases, attenuation:
    A. Increases
    B. Decreases
    C. Remains unchanged
    D. Halves
5. As transmit frequency decreases, attenuation:
    A. Increases
    B. Decreases
    C. Remains unchanged
    D. Cannot be predicted
6. As transmit frequency increases, depth of penetration:
    A. Increases
    B. Decreases
    C. Remains the same
    D. Dependent on the medium
7. As transmit frequency decreases, depth of penetration:
    A. Increases
    B. Decreases
    C. Remains the same
    D. Dependent on the medium
8. The most likely transmit frequency to be used in an adult obese patient is: ____ MHz.
    A. 2
    B. 4
    C. 7.5
    D. 10
9. The useful frequency range for adult echocardiography is:
    A. 2 to 4 MHz
    B. 5 to 7 MHz
    C. 8 to 15 MHz
    D. 18 to 20 MHz

10. The useful transmit frequency range for pediatric echocardiography is:
   A. 2 to 4 MHz
   B. 3 to 5 MHz
   C. 6 to 7 MHz
   D. ≥ 7.5 MHz

11. As transmit frequency increases, spatial (axial, lateral) resolution:
   A. Improves
   B. Degrades
   C. Remains the same
   D. Dependent on the medium

12. As transmit frequency decreases, spatial (axial, lateral) resolution:
   A. Improves
   B. Degrades
   C. Remains the same
   D. Dependent on the medium

13. Which of the following is the primary determinant for the transmit frequency to be used to acquire an ultrasound exam?
   A. Patient preference
   B. Depth of structures to be imaged
   C. Transducer type
   D. Physician preference

14. Which of the following improves on the choice between transmit frequency and depth of penetration?
   A. Traditional pulse-echo system
   B. TDI
   C. Virtual beam sonography
   D. Strain rate imaging

Frequency (f) Multiple Questions Answers-Explanations

1. **A.** Frequency is the number of cycles which occur per second.
2. **A.** The units for frequency are Hertz (Hz). Heinrich Hertz was a German physicist for which the unit for frequency was named in honor of his work with electromagnetic waves.
3. **B.** The human ear has an audible range is 20 Hz to 20000 Hz (20 kHz).
4. **A.** Attenuation is the loss of the amplitude and intensity as sound travels through a medium. As sound travels, it is attenuated (becomes weaker). Higher transmit frequencies are attenuated more rapidly than lower transmit frequencies. Increasing attenuation is the primary reason why high transmit frequency transducers cannot travel deep into soft tissue.
5. **B.** Lower transmit frequencies do not attenuate as rapidly as higher transmit frequencies. Lower transmit frequencies provide for better depth of penetration because of less attenuation.
6. **B.** Higher transmit frequencies attenuate more rapidly resulting in a lower depth of penetration.

7. **A.** Lower transmit frequencies have a lower rate of attenuation providing a greater depth of penetration.
8. **A.** For adult obese patients, a lower transmit frequency transducer is required due to the distance the reflectors lie from the skin surface. A higher transmit frequency may be indicated if examining structures close to the transducer (e.g.; apical thrombus in the apical views).
9. **A.** The adult heart is located deep from the chest wall which means a lower transmit frequency range is required.
10. **D.** The neonate/pediatric heart lies close to the chest wall, so depth of penetration is usually not an issue so the use of higher transmit frequencies is indicated. In addition, the sound waves will usually have less interference due to lung (air) tissue and bone (but not always). These facts usually allow for higher transmit frequencies to be used.
11. **A.** As transmit frequency increases, period decreases, pulse duration decreases, wavelength decreases, spatial pulse length decreases resulting in a shorter pulse and improved axial resolution. As transmit frequency increases, the near zone length increases, sound beam width decreases, sound beam angle of divergence decreases, sound beam divergence decreases in the far field resulting in a narrower sound beam width (diameter) which improves lateral resolution. Axial resolution is determined by spatial pulse length (the shorter the spatial pulse length - the better the axial resolution). The narrower the sound beam width - the better the lateral resolution.
12. **B.** As transmit frequency decreases, period increases, pulse duration increases, wavelength increases, spatial pulse length increases. The longer pulse will degrade axial resolution. The lower transmit frequency will decrease near zone length, increase sound beam width in the near field, increase the sound beam angle of divergence and wider sound beam width in the far field resulting a wider beam width (diameter) overall which will degrade lateral resolution. The shorter the spatial pulse length - the better the axial resolution. The narrower the sound beam width - the better the lateral resolution.
13. **B.** The depth of the structures needed to be examined determine the transmit frequency to be used. Adult echocardiography examinations will use lower transmit frequencies (e.g; 2 to 4 MHz) because the heart lies deep. Pediatric echocardiography examinations may use higher transmit frequencies (e.g.; ≥ 7.5 MHz) because the heart lies closer to the chest wall and there may not be structures which obstruct (e.g.; air, bone). Adult transesophageal echocardiography (TEE) uses higher transmit frequencies (e.g.; 5 to 7 MHz) because the esophagus lies close to the heart posteriorly and there is less air and bone to obstruct.
14. **C.** Virtual beam sonography improves depth of penetration across a range of transmit frequencies because of a process called weighted summation.

Tissue Harmonic Imaging (THI) (Native Tissue Harmonic Imaging) (NTHI)

Tissue harmonic imaging transmits at a low fundamental (center, operating, transmit) frequency (e.g.; 1.8 MHz) and receives and displays twice the fundamental (harmonic) frequency (e.g.; 3.6 MHz). Tissue harmonic imaging is based on the principle of non-linear sound travel through the medium. Sound waves produce regions of compression and rarefaction and the peak of the compression waves move faster than in the rarefaction peaks. This is non-linear propagation of sound through a medium. The fundamental frequency is distorted by this non-linear travel through the medium. There are several frequencies created due to this non-linear sound travel which includes the fundamental frequency and the multiples of the fundamental frequency which are called the tissue harmonic frequencies. The second harmonic (e.g.; twice (double)) the transmit frequency is used to produce the final image. Tissue harmonic imaging has several advantages:

Improves depth of penetration due to the lower transmitted frequency

Improves lateral resolution because the returning frequency is higher (higher frequencies have narrower sound beam widths – lateral resolution is equal to the sound beam width – the narrower the sound beam width – the better the lateral resolution)

Improves the signal-to noise ratio with low level echo amplitudes (e.g.; clutter, reverberations, side lobes, grating lobes, noise, haze) eliminated

Improves contrast resolution because low level signals are ignored

Improves elevational (slice thickness) resolution because the sound beam is “thinner” in the orthogonal plane (e.g.; less tissue volume is returned to the transducer)

Creates a relative auto-focus – harmonic frequencies are generated in the center of the sound beam where acoustic pressure is maximal

High frequency travel time is reduced since it only travels one way (e.g.; back to the transducer) which means less attenuation

Improves the basic ultrasound limitation: Resolution versus Depth of penetration

There are disadvantages associated with tissue harmonic imaging:

- Temporal resolution may not improve because of certain techniques such as pulse inversion which requires two pulses to be transmitted along one line to build one scan line which limits frame rate. Temporal resolution is determined by frame rate – the higher the frame rate - the better the temporal resolution.
- Tissue harmonic imaging may not improve axial resolution because a longer spatial pulse length may be required. Initial experiences with tissue harmonic imaging (THI) reported that cardiac valves appeared thicker than expected though the pulse inversion technique may preserve axial resolution since short pulses can be transmitted with the pulse inversion technique.

A Sonographer's Summary

- Stated simply, the tissue harmonic imaging instrument control key should be turned on at the beginning of each ultrasound examination (and kept on in most cases) because tissue harmonic imaging provides a significant solution to the challenge clinical imaging ultrasound has faced since its beginning: **resolution vs depth of penetration** (especially lateral resolution).
- If uncertain that tissue harmonic imaging is not providing accurate anatomic information (e.g.; obese patient where depth of penetration using tissue harmonic imaging's higher returning frequency is not adequate, valve thickness appears inappropriate for the clinical setting), too low a frame rate, using fundamental imaging (e.g.; tissue harmonics control off) may be useful.

Tissue Harmonic Imaging (THI) – Multiple Choice Questions

1. For tissue harmonic imaging, the fundamental frequency is 2 MHz. The received and displayed frequency will be: ___ MHz
   A. 1
   B. 2
   C. 4
   D. 8
2. Which of the following is **NOT** an advantage of tissue harmonic imaging?
   A. Improves frame rate
   B. Improves lateral resolution
   C. Reduces near field reverberations, grating lobes
   D. Improves depth of penetration

Tissue Harmonic Imaging (THI) Answers-Explanations

1. **C.** Tissue harmonic imaging transmits a fundamental frequency (which is 2.0 MHz in this question) and receives and displays twice the fundamental frequency transmitted (4.0 MHz). The lower transmit frequency (e.g.; 2.0 MHz) improves depth of penetration and the received and displayed higher frequency (e.g.; 4 MHz) improves lateral resolution and eliminates clutter, reverberations, side lobes, grating lobes, noise, haze.
2. **A.** Techniques such as pulse inversion where two pulses are transmitted to create one scan line for tissue harmonic imaging will reduce the frame rate but may preserve tissue harmonic imaging's axial resolution because pulse inversion allows shorts pulses (e.g. spatial pulse length, pulse duration) of ultrasound to be transmitted. Tissue harmonic imaging improves lateral resolution because the higher frequency results in a narrower sound beam width which improves lateral resolution. Clutter, reverberations, side lobes, grating lobes, noise, haze are generated at the fundamental transmitted frequency. Echoes from these sources are also at the fundamental frequency and are suppressed by tissue harmonic imaging. The lower transmitted fundamental frequency and the fact that the higher harmonic frequency only has to travel from the reflector (e.g.; not from the transducer to the reflector and back to the transducer as with fundamental frequency on) improves depth of penetration.

Dynamic Frequency Tuning (Sliding Receive Filters)

Clinical imaging transducers are wide bandwidth transducers meaning the ultrasound transducer produces a wide range of lower frequencies to higher frequencies. These range of frequencies can be subdivided into frequency bands, processed separately and then recombined to form a frequency-averaged image. Higher transmit frequencies near the transducer are “tracked” and the lower transmit frequencies near the transducer are ignored. As depth increases, mid then lower frequencies are tracked and displayed. The reason for dynamic frequency tuning is to improve near field resolution (e.g.; higher frequencies) and improve depth of penetration in the far field (e.g.; lower frequencies).

A Sonographer’s Summary

- Dynamic frequency tuning helps the sonographer with resolution versus depth of penetration.

Dynamic Frequency Imaging in One Sentence

- Verify that the ultrasound machine you are using has dynamic frequency tuning because it improves spatial (axial, lateral) resolution and improves depth of penetration.

Dynamic Frequency Tuning (Sliding Receive Filters) Multiple Choice Questions

1. Which technique may improve depth of penetration and spatial (axial, lateral) resolution by utilizing the wide bandwidth clinical imaging transducers produce?
    A. Power Doppler
    B. Tissue Doppler imaging
    C. Dynamic frequency tuning
    D. Spatial compounding

Dynamic Frequency Tuning (Sliding Receive Filters) Multiple Choice Answers-Explanations

1. **C.** Dynamic frequency tuning imaging allows the “tracking” of the multiple low and high frequencies produced by a wide bandwidth transducer and presenting a frame comprised of those multiple frequencies. Dynamic frequency tuning may improve depth of penetration, spatial (axial, lateral) resolution, contrast resolution, tissue texture and may reduce acoustic speckle. Power Doppler is a color Doppler technique which only presents the amplitude (strength) of the returning Doppler shifts. There is no aliasing, no dependence on incident angle, and is more sensitive to low flow and flow in small or deep vessels. Power Doppler does not provide blood flow direction, velocity or character of blood flow. Tissue Doppler imaging (TDI) is a pulsed-wave (PW) technique which demonstrates tissue velocity over time. It may be presented as a spectral waveform or with color (e.g.; color tissue Doppler). Spatial compounding uses multiple, differing angles

of insonation to create an ultrasound image. Spatial compounding may reduce acoustic speckle and noise.

Period (T)

Period is the time it takes for one cycle to occur. The units for period are units of time: seconds (sec), milliseconds (msec), microseconds (µs). The range for period in clinical imaging is 0.08 to 0.5 µsec. The formula for period is:

T (µsec) = 1/f (MHz)

Period is the reciprocal of frequency (e.g; as frequency increases, period will decrease and as frequency decreases, period increases). Period is not affected by image depth.

A Sonographer's Summary

- Increasing transmit frequency improves axial resolution because period and pulse duration are shorter – the shorter the pulse duration (and spatial pulse length) – the better the axial resolution.
- Use the highest transmit frequency possible for the structures needed to be imaged because a shorter period, pulse duration (as well as a shorter wavelength and spatial pulse length) will improve axial resolution.

Period (T) Multiple Choice Questions

1. The time it takes for one cycle to occur is
    A. Frequency
    B. Period
    C. Wavelength
    D. Propagation speed
2. The sonographer increases the transmit frequency, period will: ___ and spatial (axial, lateral) resolution will: __.
    A. Increase; Improve
    B. Increase; Degrade
    C. Decrease; Improve
    D. Decrease; Degrade
3. The sonographer decreases transmit frequency, period will: _____ and spatial resolution (axial, lateral) will: ________.
    A. Increase; Improve
    B. Increase; Degrade
    C. Decrease; Improve
    D. Decrease; Degrade

Period (T) Multiple Choice Questions Answers-Explanations

1. **B.** The time it takes for one compression and one rarefaction (one cycle) to occur is period
2. **C.** Frequency is the number of cycles which occur per second. As transmit frequency increases, the time it takes for one cycle to occur (period) has to decrease because frequency is cycles per second (finite period of time). Axial resolution improves with a

shorter pulse. Higher frequencies narrow the sound beam width which improves lateral resolution.

3. **B.** As transmit frequency decreases, period increases which results in a longer pulse and poorer axial resolution. Lower transmit frequencies result in wider sound beam widths which degrade lateral resolution.

Wavelength (λ)

Wavelength is the distance or length covered by one cycle. The symbol for wavelength is lambda (λ). The units for wavelength are units of distance (e.g.; millimeter (mm). The range for wavelength in soft tissue is 0.1 to 0.8 mm. The formula for wavelength (mm) is:

Propagation speed (mm/µsec) / f (MHz)

The wavelength equation is called the Wave Equation. It is important because for soft tissue the propagation speed is a constant which then means there is an inverse relationship between wavelength and frequency. For soft tissue, increase transmit frequency - decrease wavelength; decrease transmit frequency – increase wavelength. The higher the transmit frequency, the shorter the wavelength, the shorter the spatial pulse length – the better the axial resolution.

A Sonographer's Summary

- For soft tissue, changing the transmit frequency changes the wavelength and spatial pulse length. Increasing the transmit frequency decreases the wavelength and spatial pulse length which improves axial resolution. The shorter the pulse, the better the axial resolution.
- Image using the highest transmit frequency possible that can adequately image the required structure(s) of interest (e.g.; depth of penetration).

Wavelength (λ) – Multiple Choice Questions

1. The distance or length covered by one cycle is:
   A. Frequency
   B. Period
   C. Wavelength
   D. Propagation speed
2. The propagation speed of sound in of soft tissue is 1.54 mm/µsec. The transmit frequency is
   3 MHz. The wavelength is:
   A. 5
   B. 0.5
   C. 0.5 mm
   D. 0.5 mm/sec
3. The propagation speed of sound in soft tissue is 1.54 mm/µsec. The transmit frequency is 5 MHz. The wavelength is:
   A. 3
   B. 0.3
   C. 0.3 mm

D. 3 mm/sec

4. For a given medium, as transmit frequency increases, wavelength will:
   A. Decrease
   B. Increase
   C. Remain unchanged
   D. Manufacturer dependent
5. For a given medium, as transmit frequency decreases, wavelength will:
   A. Decrease
   B. Increase
   C. Remain unchanged
   D. Halve
6. The propagation speed increases as a sound travels from one medium to a second medium with a different propagation speed. With no change in transmit frequency, wavelength will:
   A. Decrease
   B. Increase
   C. Remain unchanged
   D. Manufacturer dependent

Wavelength (λ) Multiple Choice Questions Answers-Explanations

1. **C.** The distance covered by one compression and one rarefaction (one cycle) is wavelength.
2. **C.** Wavelength (mm) = 1.54 mm/µsec ÷ 3 MHz is 0.51 mm. Note that microsecond (µsec) (one millionth of a second) is “teamed up” with MegaHertz (MHz) (one million cycles per second.)
3. **C.** Wavelength (mm) = 1.54 mm/µsec ÷ 5 MHz = 0.31 mm. It is important to note that in a given medium, as transmit frequency increases, wavelength decreases, spatial pulse length decreases and axial resolution improves.
4. **A.** For a given medium, as transmit frequency increases, wavelength decreases, spatial pulse length decreases and axial resolution improves:

   Axial resolution (mm) = Spatial pulse length (mm) ÷ 2

   The lower the axial resolution number, the better the axial resolution (e.g.; like a golf score).
5. **B.** For a given medium, as transmit frequency decreases, wavelength increases, spatial pulse length increases and axial resolution degrades.

   Axial resolution (mm) = Spatial pulse length (mm) ÷ 2

6. **B.** According to the wave equation, wavelength is determined by propagation speed and transmit frequency.

   Wavelength (mm) = Propagation speed (mm/µsec) ÷ Frequency (MHz)

   Changing the propagation speed will change the wavelength and spatial pulse length. Propagation speed is assumed to be a constant in clinical imaging.

   Since soft tissue’s propagation speed is considered a constant in soft tissue (e.g.; 1.54 mm/µsec), the primary attention is turned to the transmit frequency.

Propagation Speed (c) (Speed of Sound)

Propagation speed is the rate at which sound travels through a medium. The units for propagation speed are units of distance over time (e.g.; meters/second (m/sec); millimeters/microsecond (mm/µsec)

Propagation speed is determined by the medium's density and stiffness. Stiffness has a greater effect on propagation speed than density. Bulk modulus is term representing the non-compressibility (stiffness) of a medium.

Propagation speeds for:

Air: 330 m/sec
Fat: 1450 m/sec
Water: 1480 m/sec
Soft tissue: 1540 m/sec (**AVERAGE**)
Blood: 1570 m/sec
Muscle: 1580 m/sec
Bone: 3500 m/sec

The **AVERAGE** speed of sound in soft tissue can be expressed as: 1.54 mm/µsec, 1540 m/sec, 1.54 km/sec, 154,000 cm/sec.

A Sonographer's Summary

- Propagation speed is important when reviewing refraction. Refraction is the change in the direction of sound as it crosses a boundary. Refraction occurs when there is oblique incidence and the propagation speeds of the two media are not equal. Lateral displacement of structures (duplication of structures – e.g.; two aortic valves seen in the parasternal short axis view of the aortic valve) and edge shadowing are two refraction ultrasound artifacts involving propagation speed. Move the ultrasound transducer if the lateral displacement artifact or edge shadowing artifacts are present.
- Propagation speed is assumed to be a constant when traveling in soft tissue. This is important when reviewing the wave equation and the Doppler equation.
- Propagation speed is assumed a constant by the ultrasound machine. This assumption can lead to the propagation speed error ultrasound artifact. A commonly described propagation speed artifact in adult echocardiography is one associated with the ball and cage Starr-Edwards mechanical valve. The propagation speed of the silastic ball of the Starr-Edwards is 980 msec which means the propagation speed error will place the ball position farther than it actually is from the transducer making the ball appear to be outside the cage. This propagation speed error is well seen in the apical views. The Starr-Edwards valve is no longer being implanted.
- Propagation speed is important to understand because it is the basis for the range equation which calculates the placement of echoes in the correct depth location.

Propagation Speed (c) – Multiple Choice Questions

1. Propagation speed is determined by the:

A. Frequency
B. Period

C. Wavelength
D. Medium

2. The (**AVERAGE**) propagation speed of sound in soft tissue is:
   A. 1.54 mm/µsec (1540 m/sec)
   B. 15.4 msec
   C. 1.54 mm
   D. 1540 cm/sec
3. As stiffness increases, propagation speed:
   A. Increases
   B. Decreases
   C. Remains unchanged
   D. Cannot be predicted
4. Which medium will have the highest propagation speed?
   A. Air
   B. Soft tissue
   C. Bone
   D. All three will be equal

Propagation Speed (c) Multiple Choice Questions Answers–Explanations

1. **D.** The stiffness and density of the medium determines the propagation speed with stiffness (also referred to as bulk modulus) having the greatest effect on propagation speed. In general, the stiffer the medium, the higher the propagation speed.
2. **A.** The figure 1.54 mm/µsec represents the **AVERAGE** of the different structures sound travels through in clinical imaging. This can be expressed as 1540 m/sec, 1.54 km/sec, 154,000 cm/sec.
3. **A.** Propagation speed is determined by a medium's stiffness and density. Stiffness has the greater effect on propagation speed. In general, the stiffer the medium, the higher the propagation speed. Bone is stiffer than air at that is why the propagation speed of bone is 3500 m/sec versus the propagation speed of air (330 m/sec).
4. **C.** Bone is stiffer than air and soft tissue (e.g.; fat, muscle, blood) which means it will have the highest propagation speed as compared to air and soft tissue. For bioeffects, especially in the fetus, it should be noted that bone is a reflector and a significant absorber of sound energy.

Amplitude (A)

Amplitude is the maximum variation of an acoustic variable or voltage. Amplitude is how "loud" sound is. It is a measure of the strength of sound. It is determined by calculating the difference between the maximum value of an acoustic variable and the mean value of an acoustic variable. The units for amplitude are dependent upon the acoustic variable being measured. (e.g., pressure, density, temperature, particle motion) or can be expressed in decibels (dB). The range for amplitude in clinical imaging is 0.1 to 4 MPa.

Amplitude is determined by transmit gain (e.g.; Increase transmit gain - Increase Amplitude - Increase the brightness of the returning signals - Increase mechanical index (MI) - Increase the risk of bioeffects). The greater the returning amplitude (strength) of the reflection, the brighter the reflection seen on the image display.

A Sonographer's Summary

- Transmit gain increases the amplitude (strength) of ultrasound delivered to the patient. This will increase the ultrasound "dose" to the patient. Better to minimize transmit gain using the acronym ALARA (**A**s **L**ow **A**s **R**easonably **A**chievable) and instead use transmit frequency, gain, time gain compensation TGC), lateral gain compensation (LGC), display dynamic range which may reduce the need for transmit gain and reduce the ultrasound "dose."

Amplitude (A) Multiple Choice Questions

1. Amplitude is determined by:
   A. Frequency
   B. Period
   C. Medium
   D. Transmit gain

2. An increase in amplitude will **NOT** result in:
   A. Greater depth of penetration
   B. Brighter reflection displayed
   C. Improved temporal resolution
   D. Increase risk of bioeffects

3. The units for amplitude are:
   A. Hertz
   B. Watts
   C. Decibels
   D. Rayls

Amplitude (A) Multiple Choice Questions Answers-Explanations

1. **D.** As the sonographer increases transmit gain, the electrical voltage delivered to the piezoelectric element(s) by the pulser (transmitter) is increased and a stronger, (e.g.; higher amplitude) signal is transmitted. This may translate into brighter (greater amplitude) signals seen throughout the image display.

2. **C.** Increasing the transmit gain increases the strength of the outgoing signal which will result in a greater depth of penetration, brighter signals throughout the image display, increased sound beam width, poorer contrast resolution and an increase in the risk of bioeffects because of the higher sound energy "dose" being delivered to the patient. Temporal resolution is determined by frame rate. The higher the frame rate, the better the temporal resolution. Frame rate can be increased by decreasing image depth, decreasing the field of view (sector size), decreasing the number of transmit focuses and decreasing the scan line density.

3. **C.** The units for amplitude depend on the acoustic variable being measured. Pressure can be expressed as lbs/in^2, Pascals. Density as g/m^3, kg/m^3. Temperature as Centigrade, Fahrenheit, or Kelvin. Particle motion as units of distance (e.g.; millimeters, meters). Decibels (dB) express a ratio (beginning amplitude and ending amplitude) and is considered a unit for amplitude. Decibels (dB) may also be used as units for transmit gain, time gain compensation (TGC), lateral gain compensation, attenuation, attenuation coefficient (e.g.; dB/cm), total attenuation and dynamic range.
   Hertz (Hz) are the units for frequency, pulse repetition frequency, frame rate and magnitude of the Doppler shift. Watts are the units for power. Rayls are the units for acoustic impedance.

Power (P)

Power is the rate at which sound energy is transferred. The units for power are Watts (W) or milliwatts (mW). The formula for power is:

Power (W or mW) = A^2

Power is determined by transmit gain (Increase transmit gain - Increase power - Increase in the brightness of the returning signals throughout the image display - Increase mechanical index (MI)-Increase risk of bioeffects).

A Sonographer's Summary

- Power is controlled by transmit gain. As with amplitude, minimize transmit gain using the ALARA (**A**s **L**ow **A**s **R**easonably **A**chievable) principle, to lower the ultrasound "dose" to the patient and emphasize using the transmit frequency, display dynamic range, receiver gains such as gain (receiver gain, overall gain), time gain compensation (TGC) and lateral gain compensation (LGC).

Power (P) Multiple Choice Questions

1. The rate at which sound energy is transferred is called:
   A. Frequency
   B. Period
   C. Amplitude
   D. Power
2. Power is determined by:
   A. Gain
   B. Receiver gain
   C. Transmit gain
   D. Overall gain
3. The amplitude is doubled. The new power will be:
   A. Half
   B. Equal to
   C. Double
   D. Quadrupled

Power (P) Multiple Choice Questions Answers-Explanations

1. **D.** The rate at which energy is transferred is power. The rate at which work is done is power.
2. **C.** An increase in transmit gain will result in a stronger electrical pulse being delivered to the piezoelectric elements which will result in a stronger (increased amplitude) pulse emitted which implies that greater sound energy will be transferred to the patient.
3. **D.** Power = Amplitude^2. Doubling the amplitude will quadruple power. Halving the amplitude will result in power (P) being reduced to one fourth.

Intensity (I)

The definition of intensity is the rate of energy transfer to a specified area (Power ÷ area)**.** The units for intensity are Watts per centimeter squared (W/cm^2) or milliwatts per centimeter squared (mW/cm^2). The range for intensity in clinical imaging is 0.01 to 100 mW/cm2 SPTA**.** Intensity is determined by transmit gain (Increase transmit gain - Increase Amplitude - Increase Power - Increase Intensity - Increase brightness of the returning signals throughout the image display - Increase mechanical index (MI) - Increase the risk of bioeffects).

There are several ways to measure intensity including spatial peak, temporal peak (SPTP), spatial average, temporal average (SATP), spatial peak, temporal average (SPTA) and spatial average, temporal average (SATA). Spatial peak, temporal peak (SPTP) is the highest measured intensity. Spatial average temporal average (SATA) is the lowest measured intensity.
There have been no proven biological effects for **UNFOCUSED** sound beams below 100 mW/cm^2 SPTA. There have been no proven biological effects for **FOCUSED** sound beams below 1 W/cm^2 SPTA.

Typical Acoustic Outputs
B-mode: 19 mW/cm^2 SPTA
M-mode: 73 mW/cm^2 SPTA
Color flow Doppler: 234 mW/cm^2 SPTA
Pulsed Doppler: 1140 mW/cm^2 SPTA

A Sonographer's Summary

- Intensity is an important parameter used in evaluating the safety (e.g.; risk of bioeffects). Knowing that spectral Doppler instruments have the highest output intensities, gray scale imaging (e.g.; B-mode, two-dimensional) outputs are the lowest and M-mode and color flow Doppler fall between the two is useful.
- ALARA (**A**s **L**ow **A**s **R**easonably **A**chievable) is a primary guide to imaging safely. De-emphasize the use of transmit gain and instead use instrument controls which limit the ultrasound " dose" such as gain (receiver gain, overall gain), time gain compensation (TGC), lateral gain compensation (LGC), transmit frequency, display dynamic range. Prudent use (e.g.; medically indicated examination only) and reducing the scan time are also important ways to practice ALARA.

Intensity (I) – Multiple Choice Questions

1. The rate at which sound energy is transferred divided by area (Power ÷ Area) is:
   A. Frequency
   B. Amplitude
   C. Power
   D. Intensity

2. Intensity is determined by:
   A. Transmit gain
   B. Gain
   C. Overall gain
   D. Receiver gain

3. The lowest intensity value is:
   A. SPTP
   B. SATP
   C. SPTA
   D. SATA

4. The highest intensity value is:
   A. SPTP
   B. SATP
   C. SPTA
   D. SATA

5. There have been no proven bioeffects for **UNFOCUSED** sound beams below:__ mW/cm^2 SPTA.
   A. 1
   B. 10
   C. 100
   D. 1000

6. There have been no proven bioeffects for **FOCUSED** sound beams below___ mW/cm^2 SPTA.
   A. 1
   B. 10
   C. 100
   D. 1000

Intensity (I) Multiple Choice Questions Answers-Explanations

1. **D.** Intensity is Power ÷ Area (cm^2). Increase transmit gain, increase amplitude, power and intensity. Increase area, decrease intensity, decrease area, increase intensity. Transmit focusing is a way the sonographer can decrease area.
2. **A.** Increase transmit gain, increase amplitude, power and intensity which should result in brighter reflections throughout the image display, a wider sound beam width, poorer contrast resolution, a higher mechanical index (MI) and an increase in the risk of bio effects.

3. **D.** Spatial average, temporal average (SATA) measures the sound intensity across the sound beam (Spatial Peak (SP) and takes into account the "dead" time between pulses and is averaged over the pulse repetition period.
4. **A.** Spatial peak, temporal peak is the highest intensity measured (usually in the center of the sound beam) and is not averaged over time. It is the highest measured intensity value.
5. **C.** The only unfocused sound beam used in clinical imaging is the Pedof (dedicated) CW Doppler probe (and even the Pedof has some internal transmit focusing usually).
6. **D.** Clinical imaging uses focused sound beams and so this value 1000 mW/cm^2 SPTA (spatial peak, temporal average) (also expressed as 1 W/cm^2 SPTA) is important to know.

Acoustic Impedance (Z)

Acoustic impedance is the opposition to sound as it travels through a medium. The symbol for acoustic impedance is Z. The units for acoustic impedance are Rayls. The formula for acoustic impedance is:

Acoustic Impedance (Rayls) = Density (kg/m^3) x Propagation speed (m/sec)

A reflection will occur at the boundary of two media if the media acoustic impedances are different. The greater the difference between the two media acoustic impedances, the greater the reflection and less sound energy transmitted. Acoustic impedance values for the following are:

Air: 0.0004 Mrayl
Fat: 1.35 MRayl
Water: 1.48 MRayl
Soft tissue: 1.25 to 1.75 MRayl (**AVERAGE**)
Blood: 1.65 MRayl
Muscle: 1.70 MRayl
Bone: 6.0 MRayl

The formula used to determine how much sound energy will be reflected at the boundary of two media (Intensity Reflection Coefficient (IRC) for perpendicular incidence is:

Intensity Reflection Coefficient (IRC) = $[(Z_2 - Z_1) \div (Z_2 + Z_1)]^2$

The amount of sound energy transmitted at the boundary of two media can be calculated:

Intensity Transmission Coefficient (ITC) = 1 – IRC

Note: The IRC and the ITC can be expressed as a percentage by multiplying by the IRC or ITC by 100.

A Sonographer's Summary

- The acoustic impedance values as standalone values are not as important as knowing that it is the difference between two media's acoustic impedance values that is important. The greater the acoustic impedance difference between two media, the greater the reflection with less sound energy being transmitted. The more similar the acoustic impedance values, more sound energy will be transmitted than reflected.
- Avoid air (poor acoustic window)- Image fat-muscle (preferred acoustic window).
- Ultrasound gel is required to eliminate the thin layer of air between the transducer - soft tissue which will improve transmission and reception of sound energy.

Acoustic Impedance (Z) Multiple Choice Questions

1. **1.** The acoustic impedance value for soft tissue is approximately 2 MRayls (1.25 to 1.75 MRayls). The acoustic impedance value for air is 0.0004 MRayls. Approximately, how much **REFLECTED** sound energy will occur at a soft tissue – air interface? (Assume perpendicular incidence). _ %
   - A. 1
   - B. 10
   - C. 50
   - D. 99
2. **2.** Approximately how much sound energy would be transmitted at a soft tissue-air interface? (Assume perpendicular incidence). ___%
   - A. 1
   - B. 10
   - C. 50
   - D. 99
3. **3.** Predict the amount of sound energy **TRANSMITTED** at a fat – muscle interface. (Assume perpendicular incidence). ___ %
   - A. 1
   - B. 50
   - C. 75
   - D. 99
4. **4.** Predict the amount of sound energy **REFLECTED** at a fat-muscle interface. (Assume perpendicular incidence). __ %
   - A. 1
   - B. 50
   - C. 75
   - D. 99

Acoustic Impedance (Z) Multiple Choice Questions Answers-Explanations

1. **D.** A reflection will occur at the boundary of two media if the media acoustic impedances are different. The greater the acoustic impedance difference, the greater the reflection with less sound energy transmitted. The acoustic impedance difference between soft tissue and air is significant. Most of the sound energy will be reflected at a soft tissue – air interface (99%) with only a small amount of sound energy being transmitted (1%). Avoid air when scanning.
2. **A.** The acoustic impedance difference between soft tissue and air is significant with 99% of sound being reflected and 1% being transmitted. This is important to know because this fact implies that a soft tissue – air (e.g. soft tissue-lung as in cardiac imaging) has to be avoided. It explains why ultrasound gel must be used to allow for transmission and reception of the sound energy without significant reflection at the surface of the skin.
3. **D.** The difference between fat and muscle is small which infers that very little sound energy will be reflected at a fat-muscle interface (1%) and most sound energy will be

transmitted (99%). This is the goal of imaging ultrasound imaging – avoid air and image fat-muscle interfaces.

4. **A.** Fat and muscle are similar meaning their acoustic impedances are similar which will result in most of the sound energy being transmitted (99%) and very little sound energy being reflected (1%). The fat and muscle interface is the goal of cardiac imaging – it provides for an excellent acoustic imaging window.

Specular Reflectors

Specular reflectors are large (compared to the wavelength), relatively smooth flat surfaced reflectors that are mirror-like. Specular reflectors create strong amplitude reflections. Since specular reflectors act like mirrors, these reflectors are highly incident angle dependent. The best way to image a specular reflector is to strike the specular reflector using a 90-degree (perpendicular) incident angle. Examples of specular reflectors include cardiac valve leaflets, heart walls (e.g.; interventricular septum, interatrial septum), pericardium, vessel walls, diaphragm.

A Sonographer's Summary

- For cardiac imaging, understanding that specular reflectors require perpendicular incidence is important because the heart is composed of these types of reflectors – cardiac valves, vessels, heart walls. The interatrial septum (IAS) is a specular reflector that is associated with an important ultrasound artifact called "echo-dropout". In the apical four chamber view, the middle portion of the interatrial septum may appear to have a defect ("hole"). This may be an artifact due to the fact the sound beam is not striking the interatrial septum, a specular reflector, at a 90-degree (perpendicular) incident angle when using the apical four chamber view. The sound beam is more parallel to the interatrial septum (IAS) than perpendicular in the apical four chamber view. The best view to use when evaluating the interatrial septum (IAS) is the subcostal four chamber view where the interatrial septum can be visualized in this view using perpendicular incidence. The parasternal short axis of the aortic valve improves the incidence angle when examining the interatrial septum (IAS) but the subcostal four chamber is the preferred view.
- The apical four chamber view combined with color flow Doppler may be used to evaluate the potential for shunt flow across the interatrial septum (IAS) because Doppler requires the incident angle be parallel (0 degrees) to blood flow which interatrial septal (IAS) shunt flow may be in the apical four chamber view.
- For specular reflectors a 90-degree (perpendicular) incident angle is preferred – For Doppler, a
0-degrees (parallel to flow) incident angle is preferred. Imaging: 90 degrees; Doppler: 0 degrees.

Specular Reflectors – Multiple Choice Questions

1. Which of the following would **NOT** be considered a specular reflector?
   A. Diaphragm

B. Red blood cell
C. Anterior mitral valve leaflet
D. Common carotid artery

2. The preferred incident angle when imaging a specular reflector is ___degrees.
    A. 0
    B. 1
    C. 60
    D. 90

Specular Reflectors Multiple Choice Questions Answers-Explanations

1. **B.** Specular reflectors are large compared to the wavelength (wavelength is the "yardstick" for clinical imaging ultrasound) and flat, relatively smooth surfaced. Examples of specular reflectors are cardiac valves, heart walls, pericardium, vessel walls and the diaphragm. The red blood cell is considered a scatter reflector (e.g.; Rayleigh scatterer).
2. **D.** Specular reflectors act like mirrors which require perpendicular (90 degree incident angle, normal incidence, direct incidence, orthogonal incidence) in order to maximize the returning sound energy. Doppler requires a 0 degrees (parallel) incident angle in order to maximize the Doppler shift (e.g.; peak velocity).

Scatter Reflectors

Scatter reflectors are small (compared to the wavelength) and/or rough surfaced reflectors which are not angle dependent but are highly frequency dependent (Increase frequency – Increase backscatter). Backscatter is the term used to describe sound energy reflected by a scatter reflector. Scatter reflectors create weak amplitude reflections especially when compared to specular reflectors. Scatter reflectors provide the tissue texture seen in organs such as the liver, kidney, thyroid (e.g.; organ parenchyma). Rayleigh scatter reflectors are a special type of scatter reflector which scatters sound energy equally in all directions - as if dropping a pebble into a still pond. The best example of a Rayleigh scatterer is the red blood cell.

A Sonographer's Summary

- Scatter reflectors can provide tissue texture and can offer important clinical information especially such as in the case of cardiac amyloidosis where the myocardial tissue texture appears different than the normal tissue texture myocardial scatter pattern.
- With two-dimensional imaging, blood appears black because the amplitude of the reflections from blood are too low in amplitude (weak) to be displayed on the B-mode (two-dimensional,
  2-D) image. One exception is when Rouleaux formation (stacks of aggregations of red blood cells) are present in cardiac chambers where blood flow velocity is reduced (e.g.; dilated cardiomyopathy with severe global left ventricular systolic function).
- Scatter reflectors are associated with the image ultrasound artifact called acoustic speckle ("apparent tissue texture").
- Diffuse reflectors are a "hybrid" meaning these reflectors are large compared to the wavelength (e.g.; definition of a specular reflector) but are rough surfaced or have an

irregular surface (e.g.; definition of scatter reflector) and will scatter sound energy and are less angle dependent as compared to specular reflectors.

Scatter Reflectors Multiple Choice Questions

1. Which of the following would **NOT** be considered a scatter reflector?
   A. Abdominal aorta
   B. Tissue parenchyma
   C. Myocardial cells
   D. Endocardial cells
2. Which of the following is considered a Rayleigh scatterer?
   A. Septal tricuspid valve leaflet
   B. Red blood cell
   C. Interatrial septum
   D. Superficial femoral artery
3. Which of the following has the greatest effect on scatter reflectors: Increase____.
   A. Transmit frequency
   B. Image depth
   C. Transmit Gain
   D. Incident angle

Scatter Reflectors Multiple Choice Questions Answers-Explanations

1. **A.** The walls of the abdominal aorta are large (compared to the wavelength) and are relatively smooth surfaced which means the abdominal aorta is considered a specular reflector. The best incident angle to use when imaging the abdominal aorta would be 90 degrees.
2. **B.** The red blood cell is small compared to the wavelength and because it reflects sound energy in a predictable way (e.g.; as if dropping a pebble into still pond), it is considered a Rayleigh scatterer.
3. **A.** As transmit frequency increases, wavelength decreases and backscatter (reflected sound energy from a scatter reflector) increases.

Perpendicular Incidence

Perpendicular incidence (normal incidence, direct incidence, orthogonal incidence) occurs when the ultrasound beam strikes the boundary of two media at a 90 degree incident angle. The amount of sound energy reflected and transmitted at the boundary of two media when there is perpendicular incidence can be predicted:

Intensity reflection coefficient (IRC) = $[(Z_2 - Z_1) \div (Z_2 + Z_1)]^2$

Intensity reflection coefficient (IRC) = 1 – Intensity Transmission Coefficient (ITC)

For perpendicular incidence, a reflection will occur at the boundary of two media if the media acoustic impedances are different (unequal).

For perpendicular incidence, the amount of sound energy transmitted at the boundary of two media can be predicted by the formula:

Intensity Transmission Coefficient (ITC) = 1 – IRC

For perpendicular incidence, the intensity reflection coefficient (IRC) for Soft tissue-Air is approximately 99% (0.99) and the intensity transmission coefficient (ITC) is: 1% (0.01); the IRC Fat-Muscle: 1% (0.01); ITC: 99% (0.99). The IRC for Soft tissue-Bone: 60% (0.60) and the ITC: 40% (0.40). Bone is a reflector and a significant absorber of sound energy.

A Sonographer's Summary

- When scanning specular reflectors – perpendicular (90 degree) incident angle is the goal. When imaging scatter reflectors – altering the transmit frequency is important (increase transmit frequency – increase backscatter)
- For Doppler imaging (e.g.; PW, CW and color flow Doppler), the preferred incident angle to maximize the magnitude of the Doppler shift (e.g.; peak velocity) is 0 degrees (e.g.; parallel to blood flow). Imaging specular reflectors: 90 degrees; Acquiring Doppler: 0 degrees.
- Due the acoustic impedance difference between soft tissue (1.35 to 1.75 MRayls) and air (0.0004 MRayls) avoid air (e.g.; poor acoustic window) and image fat (1.35 MRayls) – muscle (1.70 MRayls) interfaces (good acoustic window). For cardiac imaging, transmitting sound energy is important because the heart lies deep in the chest.

Perpendicular Incidence – Multiple Choice Questions

1. The ultrasound beam strikes the boundary at an incident angle of 90 degrees. A reflection will occur if the

A. Propagation speeds (c) are equal
B. Propagation speeds (c) are unequal
C. Transmit frequencies are different
D. Acoustic impedances (Z) are unequal

2. The IRC (intensity reflection coefficient) for Soft tissue (2 MRayls) - Air (0.0004 MRayls) is approximately ___%. (Assume perpendicular incidence).

A. 1
B. 20
C. 60
D. 99

3. The intensity transmission coefficient (ITC) for soft tissue-air is approximately: ___% (Assume perpendicular incidence.)

A. 1
B. 20
C. 60
D. 99

4. The intensity reflection coefficient (IRC) for fat-muscle is approximately: ___% (Assume perpendicular incidence.)

A. 1
B. 20
C. 60

D. 99

5. The intensity transmission coefficient (ITC) for fat-muscle is approximately:___% (Assume perpendicular incidence.)
    A. 1
    B. 20
    C. 60
    D. 99

Perpendicular Incidence Multiple Choice Questions Answers-Explanations

1. **D.** A reflection will occur at the boundary of two media if the acoustic impedances of the two media are not equal. This statement assumes that the incident angle is perpendicular (90 degrees) to the boundary of the two media.
2. **D.** The greater the acoustic impedance between two media, the greater the amount of reflection with less sound energy transmitted. The difference between soft tissue (1.25 to 1.75 MRayls) and air (0.0004 MRayls) is significant so that 99% is reflected and 1% is transmitted. When imaging, avoid air.
3. **A.** Whatever sound energy is not reflected, it will be transmitted. Since 99% of the sound energy will be reflected back towards the source (i.e.; ultrasound transducer), only 1% will be transmitted. Avoid air when imaging.
4. **A.** The acoustic impedance difference between fat (1.35 MRayls) and muscle (1.70 MRayls) is small which means most sound energy will be transmitted (e.g.; 99%) and only 1% will be reflected. A fat-muscle interface is a goal in clinical ultrasound imaging.
5. **D.** Only 1% of sound energy will be reflected because the acoustic impedance values of fat (1.35 MRayls) and muscle (1.70 MRayls) are very similar. 99% of the sound energy will be transmitted at a fat-muscle interface. Scan fat-muscle interfaces (preferred acoustic window), avoid air.

Oblique Incidence

Oblique incidence is present when the incident angle is **NOT** (less than) 90 degrees. The incident angle always equals the reflected angle. Oblique incidence may result in less information concerning the structure(s) being imaged because less sound energy returns to the sound source – the ultrasound transducer. Refraction is the change in the direction of sound as sound crosses a boundary. Refraction will occur at the boundary of two media if there is oblique incidence and the propagation speeds of the two media are different. This is Snell's law – the law of refraction:

$$\mathbf{Sin_i\,\Theta \div Sin\,\Theta_t = V_1 \div V_2}$$

$$\mathbf{Sin_t = Sin_i \times V_2 \div V_1}$$

Refraction will **NOT** occur if 1: There is perpendicular incidence or 2: There is oblique incidence and the propagation speeds are equal.

Refraction may result in the lateral displacement (duplication of images - e.g.; two left ventricles in the subcostal short axis view of the left ventricle) or cause the artifact referred to as edge shadowing.

A Sonographer's Summary

- If there is a duplication of a structure (e.g.; two left ventricles, two aortic valves), or edge shadowing, move the transducer to improve the incident angle since the artifact may be due to oblique incidence.

Oblique Incidence – Multiple Choice Questions

1. The incident angle for the sound beam is 89.9 degrees. This is___ incidence.
   A. Perpendicular
   B. Normal
   C. Oblique
   D. Direct
2. The incident angle is 56 degrees. The propagation speed in medium one is 1520 m/sec . The propagation speed in medium two is 1570 m/sec. The reflected angle is: ____ degrees.
   A. Less than56
   B. Equal to 56
   C. Greater than 56 degrees
   D. Dependent upon the acoustic impedances of the two media
3. The change in the direction of sound travel as it crosses the boundary of two media is called:
   A. Refraction
   B. Reflection
   C. Reverberation
   D. Range ambiguity
4. Refraction will **NOT** occur if there is 1. Perpendicular incidence or 2. there is oblique incidence and the:
   A. Propagation speeds of the two media are different
   B. Acoustic impedances are different
   C. Propagation speeds are equal
   D. Acoustic impedances are equal

Oblique Incidence Multiple Choice Questions Answers-Explanations

1. **C.** Perpendicular incidence is present when the sound beam strikes the boundary of two media at precisely 90 degrees. A(n) incident angle of less than 90 degrees is oblique incidence.
2. **B.** The incident angle equals the reflected angle. The incident angle may not equal the transmitted angle due to refraction.
3. **A.** Refraction will occur at the boundary of two media if there is oblique incidence and the propagation speeds of the two media are not equal. This is Snell's law – the law of refraction. Refraction will not occur if there is 1. Perpendicular incidence or 2. if there is oblique incidence and the propagation speeds of the two media are equal.
4. **C.** A change in the direction of sound as it crosses a boundary (refraction) will not occur if there is 1. Perpendicular incidence or 2. if there is oblique incidence and the propagation

speeds are equal. Refraction is associated with the duplication of structures (e.g.; lateral displacement) (e.g.; two aortic valves which may appear on the parasternal short axis view of the aortic valve, two left ventricles which may appear in the subcostal short axis view of the left ventricle) and the ultrasound artifact called edge shadowing.

Attenuation

The definition of attenuation is the loss of sound energy's amplitude and intensity as sound travels through the medium. The units for attenuation are decibels (dB). The primary causes of attenuation in soft tissue are: absorption, reflection, and scatter. Absorption (conversion of sound energy into heat) is the primary cause of attenuation in soft tissue.

For soft tissue, a loss of intensity of 3 dB represents a 50% loss in intensity. The chart below is important to understand for test purposes:

3 dB: 50% (1/2)
6 dB: 75% loss (1/4)
9 dB: 88% loss (1/8)
10 dB: 90% loss (1/10)
20 dB: 1/100 of the original intensity remains
30 dB: 1/1000 of the original intensity remains
40 dB: 1/10,000 of the original intensity remains

A Sonographer's Summary

- Knowing that most of the sound energy transmitted to the patient during a clinical imaging ultrasound examination is converted into heat (e.g.; absorption) is useful when related to the risk of bioeffects. The Thermal Indexes (TIS, TIB, TIC) are posted on the image display of the ultrasound machine as a way to measure the temperature increase during an ultrasound examination.

Attenuation – Multiple Choice Questions

1. The primary cause of attenuation in soft tissue is:
  A. Absorption
  B. Reflection
  C. Scatter
  D. Perpendicular incidence

2. The conversion of sound energy into heat is:
  A. Absorption
  B. Reflection
  C. Scatter
  D. Refraction

3. The units for attenuation are:
  A. Hertz
  B. Units of distance (e.g.; m/sec)
  C. Decibels (dB)
  D. Rayls

4. For soft tissue, a loss in intensity of 3 dB represents a ____% loss in intensity.
    A. 100
    B. 50
    C. 75
    D. 88
5. For soft tissue, the original intensity of a sound beam was 100 mW/cm^2 SPTA. As the sound wave traveled through the medium, there was a loss of 6 dB. How much of the original intensity remains: ___ mW/cm^2
    A. 100
    B. 50
    C. 25
    D. 12
6. For soft tissue, there is a 40 dB reduction in the original sound intensity. The amount of the original sound intensity remaining is: ___.
    A. 1/10
    B. 1/100
    C. 1/1000
    D. 1/10,000

Attenuation Multiple Choice Questions Answers-Explanations

1. **A.** The three primary causes of attenuation in soft tissue are absorption, reflection and scatter. Absorption (conversion of sound energy into heat) is the primary cause of attenuation in soft tissue. For bioeffects, it is important to know that most of the sound energy delivered to the patient is converted in heat. The Thermal Index (TI) is a parameter displayed on the ultrasound machine's display screen to indicate temperature increases during the ultrasound examination. Thermal index (TI) is defined as the ratio W ÷ Wdeg, where W is the acoustic power emitted by an ultrasound transducer at any time, and Wdeg is the power required to cause a maximum temperature rise of 1 degree Centigrade (C) anywhere in the sound beam. There are three thermal indexes: Thermal index soft tissue (TIS), thermal index bone (TIB) and thermal index cranial TIC).
2. **A.** Absorption (conversion of sound energy into heat) is the primary cause of attenuation in soft tissue.
3. **C.** Decibels (dB) is a logarithmic unit used to express a ratio such as a beginning amplitude, power or intensity to an ending amplitude, power or intensity.
4. **B.** For soft tissue, every 3 dB loss in intensity (or power) represents a 50% (1/2) loss in intensity. 6 dB is a 75% loss (1/4 will remain). 9 dB is an 88% loss (1/8 will remain). 10 dB is a loss of 90% (1/10 will remain). 20 dB indicates that 1/100 will remain of the original intensity; 30 dB is 1/1000; 40 dB is 1/10,000.
5. **C.** For soft tissue, a 6 dB loss in intensity indicates that there is a loss in intensity of 75% with ¼ (25%) of the original intensity remaining.
6. **D.** For soft tissue, a 40 dB loss in intensity indicates that 1/10000 of the original intensity remains.

Attenuation Coefficient

Attenuation coefficient is the rate at which attenuation occurs in the medium. The units for attenuation coefficient are decibels per centimeter (dB/cm). The attenuation coefficient for soft tissue is:

Attenuation coefficient (dB/cm) = 0.5 dB/cm/MHz

The formula for calculating the attenuation coefficient for soft tissue can be simplified**:**

Attenuation coefficient (dB/cm) = 0.5 x transmit frequency (MHz)

As transmit frequency increases, attenuation coefficient increases, attenuation increases and the depth of penetration decreases.

As path length increases, attenuation coefficient increases. As path length decreases, attenuation coefficient decreases.

A Sonographer's Summary

- The attenuation coefficient indicates that attenuation is dependent on image depth and transmit frequency (dB/cm/MHz).
- The primary goal of the sonographer is to acquire a high-quality diagnostic ultrasound examination. High transmit frequencies improve image quality because spatial (axial, lateral) resolution improves with higher transmit frequencies. High transmit frequencies lack the depth of penetration needed for examinations such as adult echocardiography due to attenuation. Attenuation is the reason sonographers may need to use lower transmit frequencies even though knowing that higher transmit frequencies provide for better spatial (axial, lateral) resolution.
- The transmit frequency used for an ultrasound examination is determined by the structures needed to be imaged. The adult heart lies deep in the chest so lower transmit frequencies
  (e.g.; 2 to 4 MHz) are usually indicated. There may be clinical presentations that may permit the sonographer while imaging an adult heart to use higher transmit frequencies – ruling out ventricular thrombus at the cardiac thrombus while in the apical views.

Attenuation Coefficient Multiple Choice Questions

1. The units for attenuation coefficient are:
   A. Hz
   B. Rayls
   C. dB/cm
   D. mm

2. The attenuation coefficient for soft tissue is:
   A. 0.5
   B. 0.5 dB
   C. 0.5 dB/cm
   D. 0.5 dB/cm/MHz

3. For soft tissue, the attenuation coefficient for 2 MHz is: ____ dB/cm.
   A. 1
   B. 2

C. 3
D. 4

4. For soft tissue, the attenuation coefficient for 4 MHz is: ___ dB/cm.
   A. 1
   B. 2
   C. 3
   D. 4

5. Which of the following does **NOT** increase with an increase in transmit frequency?
   A. Attenuation
   B. Attenuation coefficient
   C. Total attenuation
   D. Depth of penetration

Attenuation Coefficient Multiple Choice Questions Answers-Explanations

1. **C.** Decibels (dB) are the units for amplitude, gain, time gain compensation, lateral gain compensation, attenuation, attenuation coefficient, total attenuation and dynamic range.
2. **D.** For soft tissue, the attenuation coefficient of 0.5 dB/cm/MHz can be simplified to 0.5 × frequency (MHz).
3. **A.** 0.5 × 2 MHz is 1 dB/cm.
4. **B.** 0.5 × 4 MHz = 2 dB/cm
5. **D.** An increase in transmit frequency (e.g.; 2 MHz to 4 MHz) will increase attenuation coefficient and decrease depth of penetration. An increase in transmit frequency will improve spatial (axial, lateral) resolution.

Total Attenuation

Total attenuation is the total (sum) of the attenuation which occurs for a certain path length. The units for total attenuation are decibels (dB). The formula for total attenuation is:

Total attenuation (dB) = Attenuation coefficient (dB/cm) x path length (cm)

As transmit frequency increases, total attenuation will increase. As path length increases, total attenuation will increase.

A Sonographer's Summary

- Total attenuation depends on the transmit frequency and the path length. Deeper structures (e.g.; path length) will require lower transmit frequencies (e.g.; attenuation coefficient) meaning there is a trade-off between resolution and image depth. Pediatric echocardiography generates higher quality images than adult echocardiography due to the shorter path length required imaging neonates and pediatric patients which allows for higher transmit frequencies. Transesophageal echocardiography (TEE) may use higher transmit frequencies in adults (e.g.; 5 to 7 MHz) because the esophagus lies directly posterior to the heart and path length is shorter as compared to transthoracic echocardiography (TTE).

Total Attenuation Multiple Choice Questions

1. The units for total attenuation are:
  A. Decibels (dB)
  B. Decibels/centimeter
  C. Hertz
  D. Rayls

2. The transmit frequency is 2 MHz. The path length is 20 cm. The total attenuation in soft tissue is:
  A. 20
  B. 20 dB
  C. 20 dB/cm
  D. 20 Hz

3. The transmit frequency is 4 MHz. The path length is 20 cm. The total attenuation for soft tissue is:
  A. 40
  B. 40 dB
  C. 40 dB/cm
  D. 40 Hz

4. The transmit frequency is 2 MHz. The path length is 10 cm. The total attenuation is (assume soft tissue): _____ dB.
  A. 2
  B. 5
  C. 10
  D. 20

5. The transmit frequency is 2 MHz. The path length is 20 cm. The total attenuation (assume soft tissue) is: _____ dB.
  A. 2
  B. 5
  C. 10
  D. 20

6. The transmit frequency is increased. Which of the following will **NOT** increase?
  A. Attenuation
  B. Attenuation coefficient
  C. Total attenuation
  D. Depth of penetration

Total Attenuation Multiple Choice Questions Answers and Explanations

1. **A.** Total attenuation is the total amount of attenuation which occurs for a particular path length. The units for total attenuation are decibels (dB).
2. **B.** 0.5 × 2 MHz × 20 cm = 20 dB. For soft tissue, a 20 dB loss in sound intensity means that 1/100th (10 × 10 = 100) of the original intensity remains.
3. **B.** 0.5 × 4 MHz × 20 dB = 40 dB. For soft tissue, a 40 dB loss in sound intensity means that 1/10,000th (10 × 10 × 10 × 10 10,000) of the original intensity remains.
4. **C.** Total attenuation (dB) = 0.5 × 2 MHz × 10 cm = 10 dB.
5. **D.** Total attenuation (dB) = 0.5 × 2 MHz × 20 cm = 20 dB. Comparing this answer to question #3, as image depth increases total attenuation increases even if the transmit frequencies do not change.
6. **D.** As transmit frequency increases, period (T), pulse duration (PD), wavelength (λ), spatial pulse length (SPL) decrease. Spatial (axial, lateral) resolution improves. Attenuation, attenuation coefficient, total attenuation increases as transmit frequency increases. Depth of penetration (due to the increase in attenuation) decreases.

Piezoelectric Effect

The piezoelectric effect is the conversion sound (mechanical) energy into electrical energy and electrical energy into sound (mechanical) energy ("piezo" is pressure – sound is a pressure wave). Ultrasound transducers operate on the piezoelectric effect by converting electrical energy into sound energy (transmission from the ultrasound transducer to the soft tissue) and sound energy into electrical energy (reception from the soft tissue to the transducer). The pulser (transmitter) of the ultrasound machine provides the electrical impulse sent to the piezoelectric elements of the transducer. Applying an electric voltage to the piezoelectric material causes it to expand and contract (e.g.; vibrate) producing a sound wave. Returning sound energy is converted into an electrical signal which can be displayed. The Curie temperature is the temperature is the temperature at which the piezoelectric property is gained (or lost). Ultrasound transducers should never be exposed to high heat (e.g.; autoclaved). Certain natural occurring materials such as quartz, Rochelle salts and tourmaline possess the piezoelectric property. Man-made materials can be given the piezoelectric property by using the polarization process (exposing the man-made material to the Curie temperature). The most common man-made materials converted into piezoelectric elements include lead zirconate titanate (PZT), barium lead zirconate, lead metaniobate, lead magnesium niobite-lead titanate (PMN-PT) and polyvinylidene fluoride (PVDF). Newer ultrasound transducer technology has been introduced called capacitive micromechanical ultrasonic transducers (CMUT). The basic element of the CMUT array includes a membrane which can vibrate upon transmission and reception. The CMUT technology has several advantages including lower cost, large bandwidth and better spatial (axial, lateral) resolution.

A Sonographer's Summary

- Understanding the polarization process and the Curie temperature used for converting man-made materials (e.g.; lead zirconate titanate (PZT) into piezoelectric element(s) is important serving as a reminder that ultrasound transducers cannot be exposed to high temperatures.

Piezoelectric Effect – Multiple Choice Questions

1. The conversion of sound energy into electrical energy (reception) and electrical energy into sound energy (transmission) is the: ___ effect.
    A. Bernoulli
    B. Doppler
    C. Piezoelectric
    D. Continuity

2. Ultrasound transducers operate on the ____ effect.
    A. Piezoelectric
    B. Doppler
    C. Bernoulli
    D. Continuity
3. When should an ultrasound transducer be sterilized by autoclaving?
    A. Daily
    B. Weekly
    C. Monthly
    D. Never
4. Which of the following is a man-made material given the piezoelectric property via the polarization process?
    A. Quartz
    B. Rochelle salts
    C. Tourmaline
    D. PZT
5. Which of the following is a new type of transducer element which produces a wider bandwidth, is cost effective and provides for better spatial (axial, lateral) resolution?
    A. PZT
    B. PVDF
    C. CMUT
    D. Quartz

Piezoelectric Effect Multiple Choice Questions Answers-Explanations

1. **C.** Piezo means pressure. Sound is a pressure wave. Piezoelectric is the conversion of sound energy into electrical energy (occurs during transmission of sound into the patient) and electrical energy into sound energy (occurs during reception of the returning ultrasound from the patient). The conversion of electrical energy into sound energy

occurs first in clinical imaging and this may be referred to as the reverse piezoelectric effect.

2. **A.** The conversion of electrical energy into sound energy during transmission and the conversion of sound energy into electrical energy upon reception is based on the piezoelectric effect. Because the conversion of electrical energy into sound energy occurs first, this may be referred to as the reverse piezoelectric effect. The pulser (transmitter) delivers the electrical impulse to the piezoelectric element(s). The pulser (transmitter) is controlled by the transmit gain instrument control (e.g.; increase transmit gain - increase the amplitude, power, intensity, mechanical index (MI) of the ultrasound pulse emitted by the piezoelectric (transducer) elements).
3. **D.** The piezoelectric characteristic of the man-made ultrasound piezoelectric element(s) (e.g.; lead zirconate titanate (PZT) is achieved by exposing the man-made material to high temperatures (e.g.; Curie temperature) in a magnetic field. If the ultrasound transducer piezoelectric element(s) are exposed to high temperature (e.g.; autoclave) again, piezoelectricity will be lost. The Curie temperature for PZT is 360 degrees Centigrade (680 degrees Fahrenheit). Autoclaving temperatures (e.g.; 120 degrees Centigrade – 250 degrees Fahrenheit) are usually lower than this Curie temperature but exposing an ultrasound transducer to these high temperatures will damage the transducer components.
4. **D.** Tourmaline, Rochelle salts and quartz are natural occurring materials which possess the piezoelectric property. Man-made materials exposed to high temperatures (e.g.; Curie temperature) through the polarization process can be given the piezoelectric property. A common man-made material used is lead zirconate titanate (PZT).
5. **C.** Capacitive micromachined ultrasonic transducers (CMUT) represents a new technology with significant advantages when compared to PZT materials such as wider bandwidths, lower cost, integration with electronic circuits and miniaturization. The CMUT is a capacitor cell that consists of a thin membrane (plate) which can create ultrasonic frequencies when an electrical voltage is applied (e.g.; transmission) and convert sound energy into electrical energy when sound energy is detected (reception).

Transducer Construction

The center (e.g.; transmit, operating, main, fundamental, natural) frequency of an ultrasound transducer is determined by the thickness of the piezoelectric element (primary determinant) and the propagation speed of the piezoelectric material. The thickness is the primary determinant of the center frequency – the thinner the piezoelectric element the higher the center frequency; the thicker the piezoelectric element-the lower the center frequency. The element thickness for a 2 MHz transducer element is 1 mm; for 5 MHz it is 0.4 mm thick; and a 10 MHz transducer element is 0.2 mm.

Transducer center frequency = Propagation speed of the element ÷ 2 x element thickness

For CW (e.g.; Pedof; Therapeutic) ultrasound transducers, the center frequency is determined by the frequency of the driving voltage. The matching layer is placed on the front of the transducer, is thin (e.g.; one-quarter wavelength thick), may be multiple (1 to 3 layers) and have an acoustic impedance mean value of the two acoustic impedances (e.g.; piezoelectric elements and the soft tissue) which reduces the acoustic impedance difference between the piezoelectric element(s) and the skin surface which improves transmission and reception. One disadvantage of the matching layer is that the matching layer(s) may reduce the bandwidth of the transmitted pulse. The CMUT transducers elements do not have as large an acoustic impedance difference between the CMUT elements and the soft tissue which means a wider bandwidth can be transmitted. The damping material is placed behind the piezoelectric element to reduce the ringing of the element allowing short pulses to be produced which will improve axial resolution because it shortens the spatial pulse length (and pulse duration and duty factor). Damping increases the bandwidth and reduces the quality (Q) factor, reduces the amplitude of the outgoing signal reducing efficiency and sensitivity (ability to detect weak amplitude echoes) and decreases the duty factor. Fractional bandwidth increases with damping. Fractional bandwidth:

Bandwidth ÷ Center frequency

A Sonographer's Summary

- High quality diagnostic images are the goal for the sonographer. Axial resolution (mm) = spatial pulse length (mm) ÷ 2. One-half of the pulse length must "fit" between two reflectors which are positioned parallel to the sound beam path to be resolved as two separate reflectors. The shorter the spatial pulse length, the better the axial resolution. Understanding damping shortens the spatial pulse length (and pulse duration) helps in beginning to understand axial resolution. The shorter the spatial pulse length, the better the axial resolution. Increasing transmit frequency (sonographer) and damping (manufacturer) decrease spatial pulse length and improve axial resolution.
- The acoustic impedance levels are: piezoelectric element(s) – matching layer – ultrasound gel – skin surface/soft tissue. The matching layer and ultrasound gel reduce the acoustic impedance differences between the piezoelectric element(s), air and skin surface resulting in improved transmission and reception.

Transducer Construction Multiple Choice Questions

1. Which transducer will have the thickest piezoelectric element?
   - A. 2 MHz
   - B. 4 MHz
   - C. 10 MHz
   - D. 12 MHz

2. Which of the following is **INCORRECT** concerning the matching layer?
   - A. Placed behind the piezoelectric element
   - B. Reduces the acoustic impedance difference between the piezoelectric element and the soft tissue
   - C. May be multiple layers
   - D. Improves transmission and reception

3. Which of the following is **CORRECT** concerning the damping material?
   - A. Placed on the front of the transducer face
   - B. Reduces the ringing of the piezoelectric element(s)
   - C. Increases spatial pulse length (SPL)
   - D. Improves sensitivity

Transducer Construction Multiple Choice Questions Answers-Explanations

1. **A.** The thinner the piezoelectric element(s), the higher the transmit frequency. A 2 MHz ultrasound transducer will have the thickest piezoelectric element(s) when compared to higher frequency transducers greater than 2 MHz.
2. **A.** The matching layer is placed on the front surface of the transducer, may be multiple, is thin (e.g.; ¼ wavelength), has an mean acoustic impedance value between the transducer's piezoelectric element(s) and soft tissue which will reduce the acoustic impedance difference between the ultrasound transducer and soft tissue which improves transmission and reception.
3. **B.** The damping material (damping block) is placed behind the piezoelectric element(s), has a similar acoustic impedance value as the piezoelectric element(s), reduces the ringing of the piezoelectric element(s) which will reduce pulse duration and spatial pulse length which will improve axial resolution (the shorter the spatial pulse length – the better the axial resolution). Damping decreases the amplitude of the emitted sound wave, decreases efficiency, decreases sensitivity (e.g.; ability to detect weak echoes), increases the bandwidth, increases fractional bandwidth and decreases the quality factor (Q factor).

Bandwidth (BW)

Bandwidth is the range of frequencies produced by a damped piezoelectric element. Bandwidth is calculated as the highest frequency produced minus the lowest frequency produced by the piezoelectric element(s):

Bandwidth (BW) = Highest frequency – Lowest frequency

Because imaging transducers are damped, clinical imaging transducers are considered wide bandwidth, high fractional bandwidth, low quality factor (Q factor) transducers. Since there is no or minimal damping for continuous-wave (CW) transducers, CW transducers are considered narrow bandwidth, high quality factor (Q factor), low fractional bandwidth transducers because they are not damped. Fractional bandwidth is how large the bandwidth is compared to the center frequency. An ultrasound transducer with a fractional bandwidth of greater than 80% is considered a broadband transducer. Fractional bandwidth (unitless) is:

Fractional Bandwidth (BW) ÷ Center frequency

A Sonographer's Summary

- Knowing that clinical imaging transducers produce a wide range of transmit frequencies (e.g.; wide bandwidth – broadband transducers) helps in understanding how one ultrasound transducer can be used to emit different transmit frequencies (e.g.; reducing the need to unplug and plug in transducers just to have a new transmit frequency available – "frequency agility", "multi-Hertz"), allows for higher frequencies to create B-mode (two-dimensional) imaging while simultaneously acquiring spectral (e.g.; PW, CW) Doppler and color flow Doppler at lower transmit frequencies, how frequency fusion imaging, frequency tracking ("dynamic frequency tuning) and tissue harmonic imaging can be accomplished.

Bandwidth (BW) – Multiple Choice Questions

1. The range of frequencies produced by a damped piezoelectric element is:
    A. Wavelength
    B. Bandwidth
    C. Quality factor (Q Factor)
    D. Period
2. Which is **CORRECT**?
    A. Imaging transducers are wide bandwidth transducer
    B. Imaging transducers are narrow bandwidth transducers
    C. CW transducers are wide bandwidth transducers
    D. All ultrasound transducers are narrow bandwidth transducers
3. A fractional bandwidth greater than 80% indicates a(n) wide: _____ transducer.
    A. CW
    B. Therapeutic
    C. Broadband
    D. Non-imaging

Bandwidth (BW) Multiple Choice Questions Answers-Explanations

1. **B.** A piezoelectric element is manufactured to produce a specific frequency (e.g.; center frequency, transmit frequency, fundamental frequency, operating frequency) without interruption. Damping disrupts the ringing of the element and this will produce a wide range of frequencies besides the center frequency.
2. **A.** Because clinical imaging transducers are damped in order to produce a shorter spatial pulse length which improves axial resolution, clinical imaging transducers produce a wide bandwidth.
3. **C.** A fractional bandwidth of greater than 80% suggests a wide broadband (e.g.; wide bandwidth transducer.

Quality Factor (Q Factor)

The formula for quality (Q) factor (unitless) is:

Center frequency/Bandwidth (BW)

Imaging transducers are wide bandwidth, low Q factor transducers. CW and therapeutic transducers are narrow bandwidth, high Q factor transducers. Lower quality (Q) factors are associated with better axial resolution. PW Doppler has a higher quality (Q) factor than imaging because the pulse lengths for PW Doppler are longer (5 to 30 cycles for one pulse) than imaging pulse lengths (2 to 3 cycles for one pulse).

A Sonographer's Summary

- Quality factor (Q-factor) provides the same information as fractional bandwidth does about an ultrasound transducer. Quality factor (Q factor) and fractional bandwidth are reciprocals:

Quality factor (QF) = Center frequency ÷ Bandwidth (BW) = 1 ÷ Fractional bandwidth (BW)

Fractional bandwidth = Bandwidth ÷ Center frequency

Quality Factor (Q Factor) – Multiple Choice Questions

1. Clinical imaging transducers are: __________, __________ transducers.
   A. Narrow bandwidth, High Q factor
   B. Narrow bandwidth, Low Q factor
   C. Wide bandwidth, High Q factor
   D. Wide bandwidth, Low Q Factor

Quality Factor (Q Factor) Multiple Choice Questions Answers-Explanations

1. **D.** Clinical imaging transducers are wide bandwidth ultrasound transducers due to damping which will result in a low-quality factor (Q factor), high fractional bandwidth (range for fractional bandwidth is 50 to 100%).

Sound Beam Formation

The sound beam width (diameter) varies with the distance from the transducer. The sound beam is composed of four regions: 1. near field (Near zone) (Fresnel zone), 2. Focus (focal point), 3. Focal zone (focal region), and 4. Far field (Far zone) (Fraunhofer zone). The near field (Near zone) (Fresnel zone) is defined as the distance from the transducer face to the focus – the sound beam narrows as it travels in the near field. The focus (focal point) is the narrowest portion of the sound beam and is where lateral resolution is best and the sound beam intensity is highest. For a single disc CW unfocused transducer, the beam width at one near field length is equal to one-half the transducer diameter. The beam width for a single disc CW unfocused transducer at two near field lengths is equal to the transducer diameter. The focal zone (focal region) can be approximated as: 2x the width of the focal point. The focal region is a part of the near field (distal portion of the near field) and far field (proximal portion of the far field). The lateral resolution is good in the focal zone. The far field (Far zone) (Fraunhofer zone) is the widest portion of the sound beam. In the far field is where the sound beam width widens (diverges) as it travels from the focal point. The lateral resolution is poor in the far field.
The near zone length can be calculated by the formula:

Near zone length (mm) = Transducer diameter^2(mm) ÷ 4 × Wavelength (mm)

For soft tissue: Near Zone Length (mm) = Transducer diameter^2(mm) × Frequency (f) (MHz) ÷ 6

Huygen's principle states that any point on a wave front can be considered a point source producing spherical secondary wavelets. The tangential (tangent – a straight line that touches a curve or curved surface but if extended does not cross it at that point) surface of the secondary wavelets predict the new position of the wave front over time. Sound beam formation is based on Huygen's principle where the wave fronts from each piezoelectric element combine to form a single wave front. Huygen's principle explains the hour-glass shape of the physical sound beam – near field – focus- focal region – far field (wide-narrow-wide).

Virtual beam sonography significantly changes the description of how a clinical imaging sound beam looks like (e.g.; near field-focal point, focal region-far field). There is no longer a “physical” ultrasound beam transmitted but one that is created – a virtual sound beam. An unfocused or weakly focused ultrasound sound beam is transmitted, received and due the new processing techniques produce the results as if the sound beam was a laser – no more describing a near zone, focus, focal region or far field but an image of what a narrow, thin, consistent laser-like sound beam would create. Arguably, this is the most important difference between the two operating systems (conventional sonography versus virtual beam sonography). Thus, the name of the sonography – virtual beam.

A Sonographer’s Summary

- Sound beam width varies as it moves away from the transducer face – this is important for lateral resolution – Lateral resolution is equal to the sound beam width meaning that lateral resolution varies with depth. When reviewing images (and color flow Doppler flow patterns), the reflector-flow pattern depth may be important to consider.
- The sonographer may alter the location of the transmit focus when using phased array transducers. The focus is where the sound beam is narrowest and lateral resolution is best.
- The focus is where the sound intensity is highest-this may be useful to know when acquiring contrast studies. The transmit focus may need to be re-positioned if there is a lack of contrast (e.g.; swirling) in the area of interest (e.g.; cardiac apex when using the apical four chamber view).
- The near zone length formula is important to understand as it teaches that the transducer diameter has the greatest effect on near field length. This fact explains why adult echocardiography ultrasound transducers have a larger transducer diameter as compared to a pediatric echocardiography transducer. Adult hearts are deep in the chest, near zone length needs to be extended, the best way to extend the near zone length is to increase transducer diameter. Large transducer diameters increase the near zone length, decrease the sound beam angle of divergence at the focus, and have less sound beam divergence in the far field which will result in a narrower sound beam width overall- big picture. Large diameter transducers produce narrower sound beam widths overall. Larger transducer diameters are useful when imaging structures located deep in the body (e.g.; adult hearts).

- The smaller pediatric transducer diameter, which is preferred due to patient size, will produce a shorter near zone length, have a wider angle of sound beam divergence at the focus, have greater sound beam width divergence in the far field and produce a wider sound beam width overall – big picture. To offset this, pediatric transducers are high transmit frequency transducers – higher transmit frequencies extend the near zone length, produce narrower sound beams, reduce the sound beam angle of divergence at the focus and have less sound beam divergence in the far field. Smaller transducer diameters produce wider sound beams than large transducer diameters overall. Small diameter transducers are preferred for imaging superficial structures (e.g.; pediatric heart). Large transducer diameters are preferred for deeper imaging (adult heart).

- Adult echocardiography transducers cannot take advantage of the higher frequency portion of the near zone length equation due to attenuation. Higher transmit frequencies attenuate more rapidly than lower transmit frequencies. Adult echocardiography transducer frequencies range from 2 to 4 MHz because of the need for depth of penetration and attenuation.
- The sound beam width is wide and diverging as it moves away from the focus in the far field and lateral resolution is poor. This may be useful to remember to position the transmit focus when examining structures deep from the transducer.
- The learning curve for the small CW Pedof (dedicated CW probe, non-imaging probe, pencil probe) may be reduced knowing that small transducer diameters (and lower transmit frequencies – the Pedof probe is usually a 2.0 MHz transmit frequency transducer) produce wider sound beams.
- Virtual beam sonography produces images that present as if the sound beam was a laser – narrow, thin, uniform throughout, no clutter, reverberations, side lobes, grating lobes, noise, haze). The terms of near field, focus, focal region and far field do not apply. There no longer is a physical sound beam with the characteristics of near field, focus, focal zone, far zone. The sound beam is created by the new powerful processing techniques using GPU (graphics processing unit) and parallel processing which creates a virtual sound beam – narrow, thin, uniform, virtual.

Sound Beam Formation Multiple Choice Questions

1. The region from the transducer face to the focus is called:
   A. Fresnel zone
   B. Focus
   C. Focal region
   D. Fraunhofer zone

2. The narrowest portion of the sound beam where lateral resolution is best and sound beam intensity is highest is called the:
   A. Fresnel zone
   B. Focus
   C. Focal region
   D. Fraunhofer zone

3. The region where the sound beam width diverges beyond the focal point is the:
   A. Fresnel zone
   B. Focus
   C. Focal region
   D. Fraunhofer zone

2. Sound beam formation is based on:
   A. Doppler effect
   B. Bernoulli equation (conservation of energy)
   C. Continuity principle (conservation of mass)
   D. Huygen’s principle

3. For a single disc unfocused CW transducer, the transducer diameter is 20 mm. The beam width at one near zone length is: __ mm.
    A. 40
    B. 20
    C. 10
    D. 5
4. For a single disc unfocused CW transducer, the transducer diameter is 20 mm. The beam width at two near zone lengths is: __ mm.
    A. 40
    B. 20
    C. 10
    D. 5
5. Which of the following transducer diameters will have the longest near field length and the narrowest sound beam width overall? ___ mm.
    A. 5
    B. 8
    C. 10
    D. 15
6. Which of the following ultrasound transducer frequencies will have the longest near field length and the narrowest sound beam width overall? ___ MHz.
    A. 2
    B. 4
    C. 6
    D. 10
7. Which would be the **MOST** accurate term used to describe the displayed results of a virtual beam sonography scan?
    A. Near field
    B. Focus
    C. Far field
    D. Laser

Sound Beam Formation Multiple Choice Questions Answers-Explanations

1. **A.** The sound beam region from the transducer face to the narrowest portion of the sound beam (focus, focal point) is called the near field, near zone or Fresnel zone. The sound beam width (diameter) decreases in the near field and lateral resolution (due to the decreasing sound beam width) is good.
2. **B.** The focus (focal point) is the narrowest portion of the sound beam. Because lateral resolution is determined by sound beam width, (the narrower the sound beam width the better the lateral resolution), lateral resolution is best at the focus. Sound beam intensity is highest at the focus.
3. **D.** The far field (e.g.; Far zone, Fraunhofer zone) is where the sound beam widens (diverges) and where lateral resolution is poorest.

4. **D.** Huygen's principle explains how a uniform sound beam can be created from multiple sound sources (e.g.; multiple piezoelectric elements- an array).
5. **C.** 20 mm ÷ 2 = 10 mm. For a single disc CW unfocused sound beam, the sound beam width is equal to one-half the transducer at one near zone length. Clinical imaging transducers are pulsed-wave (PW) focused ultrasound transducers where the one-half the transducer diameter at one near zone length is an approximation for these clinical imaging transducers.
6. **B.** The sound beam diverges after reaching the focus (focal point). At two near zone lengths, for a single disc CW unfocused transducer, the sound beam width is equal to the transducer diameter.
7. **D.** As the transducer diameter increases, near field length increases and lateral resolution will improve overall. As transmit frequency increases the near field length increases and lateral resolution improves. The near field length formula indicates that transducer diameter has the greatest effect on near field length since the transducer diameter is squared in the near field length equation.

Near zone length (mm) = Transducer diameter^2(mm) ÷ 4 × Wavelength (mm)

For soft tissue: Near Zone Length (mm) = Transducer diameter^2(mm) × Frequency (MHz) ÷ 6

8. **D.** As transmit frequency increases near field length increases and lateral resolution improves.

Near zone length (mm) = Transducer diameter^2(mm) ÷ 4 × Wavelength (mm)

For soft tissue: Near Zone Length (mm) = Transducer diameter^2(mm) × Frequency (MHz) ÷ 6

9. **D.** Virtual beam sonography transmits unfocused sound beams or weakly focused sound beams and by using powerful parallel processing techniques produce images as if the images were acquired with a laser. The terms to describe the traditional (e.g.; 50 years of ultrasound) pulse-echo sound beam characteristics cannot be applied.

Focusing

Focusing reduces the sound beam width (diameter) in the near field which will improve lateral resolution but focusing will decrease the near field length and increase the sound beam width (divergence) (angle of divergence).

There are five focusing methods: 1. Internal, 2. External, 3. Transmit electronic, 4. Dynamic receive,

5. Dynamic aperture (Variable receive). Internal focusing occurs when the piezoelectric element(s) is (are) curved. External focusing is using a curved lens placed on the front of the transducer. The external lens improves elevational resolution. Transmit electronic focusing is achieved by curving the electrical pulses being delivered to the piezoelectric elements and is controlled by the sonographer by using the transmit focus instrument control. Transmit electronic focusing allows for multiple transmit focuses which improves lateral resolution but reduces the frame rate which degrades temporal resolution because each transmit location requires a separate ultrasound pulse be transmitted. Dynamic receive uses delay lines during reception and is required if transmit electronic focusing is being used. Dynamic aperture (variable receive) focusing alters the number of "live" elements receiving the returned echoes. The focal

length (distance from the transducer face to the focal point) can be described as weak, moderate or strong. A strongly focused transducer places the focal point close to the transducer – a weakly focused transducer places the focal point deeper.

A Sonographer's Summary

- Dynamic aperture (variable receive) ("automatic" focusing) is a significant improvement because the sonographer may not have to constantly move the transmit focus when acquiring an ultrasound examination.
- Lateral resolution is determined by the sound beam width. The narrower the sound beam width, the better the lateral resolution. Focusing improves lateral resolution in the near field.
- Two disadvantages of focusing: 1. The near field length is shortened by focusing. 2. The sound beam angle of divergence increases.
- Transmit focusing is the only focusing controlled by the sonographer. If using an ultrasound machine without dynamic aperture (variable focusing) ("automatic") focusing, moving the transmit focus throughout the examination may be required.
- When using transmit focus, the recommendation is for the sonographer to place the focus just distal to the point/region of interest.
- With transmit focusing, multiple focal points (focuses) may be chosen which will improve lateral resolution throughout the display but each focus requires a separate emitted pulse which will reduce frame rate and degrade temporal resolution.
- Transmit focusing is not an integral part of virtual beam sonography. Due to processing of the echoes after being received from an unfocused or weakly focused transmitted sound beam, the displayed reflections represent what a uniform, laser-like sound beam would produce.

Focusing – Multiple Choice Questions

1. _________ reduces the sound beam width in the near field improving lateral resolution but decreases the near field length and increases the angle of divergence.
   - A. Focusing
   - B. Frequency
   - C. Huygen's principle
   - D. Transmit gain

2. The piezoelectric element(s) is (are) curved. This is _____ focusing.
   - A. Internal
   - B. External
   - C. Transmit
   - D. Receive
   - E. Dynamic aperture

3. A curved lens is placed on the surface of the transducer face which will improve elevational (slice thickness) resolution. This is ___ focusing.
   - A. Internal
   - B. External
   - C. Transmit

D. Receive
E. Dynamic aperture

4. The electrical impulses being delivered to the piezoelectric elements are curved. This is ___ focusing.
    A. Internal
    B. External
    C. Transmit
    D. Receive
    E. Dynamic aperture
5. Delay lines are used to "line up" (focus) the returning signals and is used with electronic transmit focus. This is __ focusing.
    A. Internal
    B. External
    C. Transmit
    D. Dynamic receive
    E. Dynamic aperture
6. The number of active piezoelectric elements are altered based on returning depth. This is__ focusing.
    A. Internal
    B. External
    C. Transmit
    D. Receive
    E. Dynamic aperture
7. Which type of focusing is associated with virtual beam sonography?
    A. Internal
    B. External
    C. Transmit focus
    D. Dynamic receive
    E. Dynamic aperture
    F. None of the above

Focusing Multiple Choice Questions Answers-Explanations

1. **A.** Focusing (internal, external, electronic transmit) reduces the sound beam width in the near field zone, improves lateral resolution. Focusing does shorten the near field length and increases the sound beam angle of divergence.
2. **A.** Internal focusing curves the piezoelectric elements.
3. **B.** Placing a curved lens on the transducer face focuses the sound beam by using the principle of refraction and is called external focusing. External focusing improves elevational resolution.
4. **C.** Curving the electrical pulses being delivered to the piezoelectric elements is called electronic transmit focusing. Electronic transmit focusing is the only type of focusing controlled by the sonographer.

5. **D.** If electronic transmit focusing is being used, dynamic receive focusing is required because the piezoelectric elements are being struck at slightly different times, sound will travel out at slightly different times, return back to the transducer at slightly different times which means the returning sound energy is defocused. Using delay lines to "line up" (focus) the returning sound energy is required with electronic transmit focusing and dynamic receive focuses the returning sound energy.
6. **E.** Dynamic aperture (variable aperture) can be described as "automatic" focusing because the number of piezoelectric elements involved upon reception are varied which focuses the sound energy automatically.
7. **F.** The image displayed on the ultrasound machine with virtual beam sonography represents a laser-like sound beam due to processing. The transmitted sound beam in virtual beam sonography is unfocused or, at best, weakly focused. There is no focal point in virtual beam sonography – each pixel is focused. There is no physical sound beam as used in conventional sonography – it is a virtual beam in virtual beam sonography.

Lateral Resolution (LATA – Lateral, Angular, Transverse, Azimuthal, Side by Side)

Lateral resolution is how close two structures may be **PERPENDICULAR** to the sound beam path and still be resolved as two separate reflectors. Lateral resolution is determined by sound beam width (diameter). Sound beam width varies with the distance from the transducer because the sound beam width changes as it travels from the transducer. This fact means that lateral resolution varies with the distance from the transducer. The formula for lateral resolution is:

Lateral resolution (mm) = Sound beam width (mm)

Lateral resolution may be improved by: 1. Increasing the transmit frequency. Higher transmit frequencies produce a narrower sound beam width which improves lateral resolution. 2. Tissue harmonic imaging. The higher returning frequency of harmonic imaging improves lateral resolution because the sound beam width decreases in width as frequency increases. The tissue harmonic sound beam width returning to the transducer will be narrower than the transmitted sound beam width. In addition, side lobes/grating lobes are reduced. 3. Focus. Focusing reduces the sound beam width in the near field but may decrease the near field length and increase the angle of divergence. 4. Increasing line density will improve lateral resolution since each sound beam transmitted is placed closer together without the less use of interpolation. 5. Increase transducer diameter. Larger transducers produce a narrower sound beam width overall.
Virtual beam sonography significantly improves lateral resolution since there is no dependence on the transmitted sound beam to be focused. The reflections returned to the ultrasound machine are processed so that the images seen on the image display represent a sound beam that is laser-like -meaning narrow, thin, uniform throughout.

A Sonographer's Summary

- Lateral resolution varies with the distance from the reflector. The artifact of "point-spreading" (e.g.; beam width artifact) is associated with lateral resolution and can result in structures appearing wider especially in the far field. A good example of this is the width of the color flow Doppler aortic regurgitation jet in the apical five chamber view and apical long axis view may appear wider due to "point-spreading" than the jet width as seen in the parasternal long axis view. Axial resolution is usually better than lateral resolution and is for this reason that axial resolution is preferred when acquiring linear measurements and evaluating blood flow with color flow Doppler on.

- Dynamic aperture (variable focusing) has improved lateral resolution significantly but axial resolution is still preferred.
- The sound beam diverges in the far field and evaluating structures or measuring in the far field should be done knowing this fact. Axial resolution is superior to lateral resolution although both may be similar at the focal point (focus) of a strongly focused sound beam.

Lateral Resolution – Multiple Choice Questions

1. How close two structures **PERPENDICULAR** to the sound beam path may be and still be resolved is ___ resolution.
   A. Axial
   B. Lateral
   C. Temporal
   D. Contrast
   E. Elevational (slice thickness)
2. Which of the following would **NOT** improve lateral resolution?
   A. Increase transmit frequency
   B. Use tissue harmonic imaging
   C. Focus
   D. Decrease transducer diameter width
3. Virtual beam sonography improves:
   A. Lateral resolution
   B. Spatial pulse length
   C. Duty factor
   D. Wavelength

Lateral Resolution Multiple Choice Questions Answers and Explanations

1.B. Lateral resolution is defined as how close two structures may be **PERPENDICULAR** to the sound beam path and still be resolved as two separate reflectors. Lateral resolution is dependent on sound beam width – the narrower the sound beam – the better the lateral resolution. Increasing transmit frequency, tissue harmonic imaging, focusing, and increasing line density all improve lateral resolution. Axial resolution is dependent on spatial pulse length – the shorter the pulse - the better the axial resolution. Temporal resolution is determined by frame rate – the higher the frame rate – the better the temporal resolution. Contrast resolution is determined by the number of gray shades – altering the display dynamic range will alter the number of shades of gray displayed. Elevational (slice thickness) resolution is determined by the thickness of the sound beam – the thinner the sound beam – the better the elevational (slice thickness) resolution.

2. D. Lateral resolution is determined by sound beam width (diameter). The narrower the sound beam width, the better the lateral resolution. Increasing the transducer transmit frequency reduces the sound beam width which improves lateral resolution. Using tissue harmonic imaging allows for higher frequencies to be displayed which effectively reduces the sound beam width improving lateral resolution. Focusing reduces the sound beam width in the near field zone and that will improve lateral resolution. Decreasing the transducer diameter will reduce the near field length which may mean poorer lateral resolution overall. Smaller transducer diameters have shorter near zone lengths, greater angle of divergence and greater sound beam divergence in the far field. Small transducers are best used to evaluate superficial structures.

Near zone length (mm) = Transducer diameter^2(mm) ÷ 4 × Wavelength (mm)

For soft tissue: Near Zone Length (mm) = Transducer diameter^2(mm) × Frequency (f) (MHz) ÷ 6 .

3. A. Virtual beam sonography significantly improves lateral resolution because the displayed image presents the information as if it were acquired from a sound beam which is narrow, thin and uniform throughout unlike the traditional "wide-narrow-wide" sound beam associated with the conventional pulse-echo system.

Axial Resolution (Longitudinal, Range, Radial, Depth)

Axial resolution is how close two structures may be **PARALLEL** to the direction of sound travel and still be resolved as two separate structures. The formula for axial resolution is:

Axial resolution (mm) = Spatial pulse length (mm) ÷ 2

The range for axial resolution in clinical imaging is 0.1 to 1.0 mm. Axial resolution does not vary with depth (lateral resolution does vary with depth). The two primary ways to improve axial resolution are

1. Increase the transmit frequency (higher frequencies produce shorter pulses). For example, the axial resolution for a two-cycle pulse in soft tissue for a 2 MHz is 0.77 mm. The axial resolution for a 5 MHz transducer in soft tissue for a two-cycle pulse is 0.31 mm. 2. Damp. Damping is accomplished by the manufacturer and damping reduces the spatial pulse length. Damping does increase bandwidth and decreases the amplitude of the outgoing signal, efficiency, sensitivity and quality factor (Q factor). Axial resolution and lateral resolution may be referred to as spatial resolution or detail resolution. Axial resolution is generally better than lateral resolution although lateral resolution is similar to axial resolution at the focus (focal point) of a strongly focused ultrasound beam.

A Sonographer's Summary

- Axial resolution is important because it is the resolution used for most basic linear measurements in adult echocardiography (e.g.; wall thickness, chamber dimensions) and the evaluation of color flow jets (e.g.; aortic regurgitation). The best way to improve axial resolution is to increase transmit frequency. Zoom magnification places more pixels to be used in a smaller scan region and may improve axial resolution.
- Axial resolution is superior to lateral resolution.
- Axial resolution is similar when comparing conventional sonography to virtual beam sonography because short pulse lengths are required for axial resolution.

Axial Resolution – Multiple Choice Questions

1. **____ Resolution is how two close two structures may be PARALLEL to the sound beam direction of travel and still be resolved.**
   A. Axial
   B. Lateral
   C. Temporal
   D. Contrast
   E. Elevational (Slice thickness)
2. **The spatial pulse length is 4 mm. Determine the axial resolution. __ mm**
   A. 8
   B. 4
   C. 2
   D. 1
3. **The spatial pulse length for transducer A is 4 mm. The spatial pulse length for transducer B is 6 mm. The spatial pulse length for transducer C is 2 mm. Transducer D has a spatial pulse length of 5. Which transducer has the best axial resolution?**
   A. A
   B. B
   C. C
   D. D
4. **The primary way the sonographer improves axial resolution is:**
   A. Increase transmit frequency
   B. Alter the focus
   C. Decrease the image depth
   D. Narrow the display field of view

Axial Resolution Multiple Choice Questions Answers-Explanations

1. **A.** Axial resolution is dependent upon spatial pulse length to detect structures lying parallel to the sound beam path.
2. **C.** Axial resolution (mm) = 4 mm ÷ 2 = 2 mm.
3. **C.** The shorter the spatial pulse length, the better the axial resolution.

   Axial resolution (mm) = Spatial pulse length (mm) ÷ 2

4. **A.** Increasing the transmit frequency decreases wavelength and spatial pulse length (SPL) which will improve axial resolution.

   Spatial pulse length (mm) = Wavelength (mm) × Number of cycles in a pulse

Note: Wavelength is determined by the transmit frequency and the propagation speed of the media. A change in the media's propagation speed would affect spatial pule length and axial resolution. Propagation speed in soft tissue is considered a constant – a change in transmit frequency would change the wavelength and spatial pulse length.

Wavelength (mm) = Propagation speed (mm/µsec) ÷ Frequency (MHz)

Propagation speed in soft tissue is considered a constant – a change in transmit frequency would change the wavelength and spatial pulse length.

Transducer Types

A sector phased array transducer is a small, square shaped transducer where all the piezoelectric elements are electronically fired but with a slight time delay in order to beam steer and beam focus. The sector phased array creates a "pie-shaped" ("wedge"-shaped, "pizza slice") display. The sector phased array is the most common transducer used in echocardiography. Since the sector phased array transducer transmits from a fixed position, the sound beam travels out similar to spokes on a wheel. To fill in the gaps between the sound beams, the interpolation (averaging) technique is used to fill in the gaps. The **linear phased array** transducer is a relatively large transducer where all of the piezoelectric elements are arranged in a line and fired electronically with time delays in order to beam steer and beam focus. The linear phased array creates a "box-like, rectangular display and a trapezoidal display. Linear phased array is the most common transducer used in vascular ultrasound. The **curved (curvilinear) phased array** is an arc-shaped transducer which operates similar to the sector phased array and linear phased array transducers. The curved phased array creates a blunted sector display. The curved linear array is useful in abdominal applications. The **endocavity** transducer is a small, tightly curved phased array using higher transmit frequencies (e.g.; 4 to 8 MHz) and provides for a wide field of view. The **transesophageal echocardiography** (TEE) transducer is a small high frequency (e,g.; adult echocardiography - 5 to 7 MHz) phased-array transducer attached to a gastroscope. The **Pedof** transducer (dedicated CW, non-imaging CW, pencil probe) is a small, dedicated CW Doppler transducer with two piezoelectric elements (one to transmit and one to receive). It is required for the evaluation in the adult echocardiography laboratory of aortic stenosis from three separate imaging windows: apical, right parasternal and suprasternal.

A Sonographer's Summary

- The sector phased array transducer is the most common type of transducer used in adult echocardiography. It is a described as a "small" transducer and it is compared to the typical linear phased array transducer and curved phased array transducer. Although a "small" transducer, it may be challenging in certain patients to have the transducer "fit" between the rib spaces especially in the older adult. Placing pressure on certain edges of the sector phased array transducer may be useful. For example, while acquiring the parasternal short axis of the left ventricle and parasternal short axis of the mitral valve, placing pressure on the upper part of the sector phased array transducer ("rib hook", pressure point") may improve transmission and image quality. Placing pressure on the lower portion of the phased array transducer when acquiring the apical four chamber may be useful.

Transducer Types Multiple Choice Questions

1. The most common cardiac imaging transducer is the:

A. Sector phased array

B. Linear phased array

C. Curvilinear
D. Pedof

2. All the elements are fired electronically but with a slight time delay in order to beam steer and beam focus. This is a description of a:
   A. Phased array
   B. Linear sequential
   C. Curved linear sequential
   D. Pedof
3. Which transducer is required when acquiring continuous-wave (CW) Doppler information from the right parasternal window in a patient with aortic stenosis?
   A. Sector phased array
   B. Linear phased array
   C. Curvilinear phased array
   D. Pedof

Transducer Types Multiple Choice Questions Answers-Explanations

1. **A.** The sector phased array transducer is a relatively small transducer which allows for imaging the heart between the ribs in the rib spaces. The linear phased array transducer and curved (curvilinear) phased array transducer are relatively large transducers which are not suitable for echocardiography use due to rib and lung interference. The Pedof is a non-imaging probe.
2. **A.** The term "phased" implies a time delay. Array implies more than one piezoelectric element. Phased array transducers are transducers where piezoelectric elements are electronically fired and electronically steered ("swept", moved from one scan line to the next scan line, beam steering) by using slight time delays.
3. **D.** The Pedof (dedicated CW Doppler, non-imaging CW Doppler, pencil probe) transducer is required to be used when evaluating valvular aortic stenosis from these three cardiac windows: apical, right parasternal and suprasternal. The patient will be placed on their left side for the apical Pedof examination, their right side for the right parasternal examination and supine for the suprasternal examination.

Range Equation

The range equation predicts the time it takes for an ultrasound pulses to travel out and back (e.g.; round-trip time) to a reflector. The formula for the range equation is:

Reflector depth (mm) = 0.5 x (propagation speed (mm/µsec) x pulse round-trip time (mm/µs)

For soft tissue: Reflector depth (mm) pulse round-trip time (µsec) ÷ 0.77 mm/µsec

The range equation formula may be simplified for soft tissue. It takes an ultrasound pulse 13 microseconds (µsec) to travel out and back (round-trip) one centimeter in soft tissue:

Reflector depth (mm) Pulse round-trip time (us)/13 µs

The pulse round-trip travel time for reflector depths in soft tissue:

1 cm: 13 µsec
2 cm: 26 µsec
3 cm: 39 µsec

4 cm: 52 µsec
5 cm: 65 µsec
10 cm: 130 µsec
20 cm: 260 µsec

A Sonographer's Summary

- The range equation is useful knowing. Only one pulse can travel in the body at one time. That fact allows the ultrasound machine to place the reflections at the correct depth by noting the round-trip (go-return) time. If another pulse is transmitted while reflections are returning from the previous pulse, the "time clock" of the ultrasound machine will reset and reflections returning from the first pulse will be placed too close to the transducer. This is an example of the range (depth) ambiguity artifact.
- Changing the image depth will directly affect the pulse repetition frequency. Since only one pulse may travel in the body at one time, if the sonographer increases the image depth, the pulse repetition frequency will decrease because the pulser (transmitter) must "wait longer" for the returning pulse because image depth was increased (which increased the pulse round trip time). Decreasing the image depth, increases the pulse repetition frequency because the pulse round-trip time is shorter, the machine has to wait less time, and more pulses can be transmitted at the shallower depth. More pulses (an increase in the pulse repetition frequency) will result in more scan lines leading to more frames (a frame is a collection of 100 to 150 scan lines) created which improves temporal resolution.
- Understanding pulse repetition frequency, that only one pulse may travel in the body at one time and that the range equation is used to accurately place returning reflections at the correct depth is important for understanding how a change in pulse repetition frequency (PRF) affects frame rate (and temporal resolution) and the Doppler Nyquist limit (PRF ÷ 2) which predicts when aliasing will occur.
- Change image depth - change the round-trip (go-return) time - change the pulse repetition frequency - change the frame rate which affects temporal resolution – change the pulse repetition frequency - change the Doppler Nyquist limit – change when aliasing will occur.

Range Equation – Multiple Choice Questions

1. The pulse round trip time in soft tissue is 39 us. The reflector depth is: ___ cm or ___ mm.
   A. 1; 10
   B. 3; 30
   C. 9; 90
   D. 20; 200

2. The distance to a reflector is doubled. The pulse round-trip time will:
   A. Halve
   B. Double
   C. Triple
   D. Quadruple

Range Equation Multiple Choice Questions Answers-Explanations

1. **B.** Reflector depth = 39 µsec ÷ 13 µsec = 3 cm (30 mm). The 13 µsec rule can be used to determine reflector depth in soft tissue:

   Reflector depth (cm) = Pulse round-trip time (µsec) ÷ 13 µsec
2. **B.** Doubling the distance to the reflector will double the pulse round-trip time.

Pulse Repetition Frequency (PRF)

Pulse repetition frequency is the number of pulses created per second. The units for pulse repetition frequency are Hertz (most often in clinical imaging ultrasound pulse repetition frequency is in kilohertz (kHz)). The range for pulse repetition frequency for clinical imaging ultrasound is 1 to 10 kHz (dependent on image depth). Pulse repetition frequency is dependent upon image depth. Since only one pulse may travel in the body at one time, increasing the image depth decreases pulse repetition frequency. Decreasing the image depth increases pulse repetition frequency. Pulse repetition frequency is important to understanding when reviewing frame rate (which determines temporal resolution) and Doppler aliasing:

Nyquist limit = PRF ÷ 2

A Sonographer's Summary

- Pulse repetition frequency is important because it determines frame rate (temporal resolution), when aliasing will occur (Nyquist limit = PRF ÷ 2) and changing the Doppler velocity scale while using PW Doppler or color flow Doppler alters the pulse repetition frequency.
- When a sonographer simply changes the image depth, pulse repetition frequency changes and this change in pulse repetition frequency creates a chain reaction.
- Only one pulse can travel in the body at one time because the machine uses a "time clock" and the range equation to place reflectors at the correct depth. This fact affects the number of pulses transmitted per second (e.g.; PRF). Increase image depth - Increase the pulse round-trip time - Decrease pulse repetition frequency (because the ultrasound machine must wait longer for the returning reflections coming from a deeper depth before transmitting another pulse) - Decrease frame rate - Degrade temporal resolution - Decrease the Nyquist limit-Increase the risk of aliasing.
- To improve temporal resolution (an important resolution in echocardiography), image at the shallowest image depth (Shallower image depths - Increases pulse repetition frequency – Increases the number of scan lines - Increases Frame rate – Improves temporal resolution).
- For PW and color flow Doppler, image at the shallowest image depth (Shallower image depths – Increases pulse repetition frequency – Increases the Nyquist limit (PRF ÷ 2) – Reduces the risk of aliasing).
- If a pulse is transmitted before the previous pulse is received, the returning reflection(s) will be placed too close to the transducer. This placement of a reflector at the incorrect depth is considered an ultrasound artifact called range (depth) ambiguity.
- In virtual beam sonography the pulse repetition frequency is not critical in increasing frame rate because more frames can be created with fewer pulses transmitted.

Pulse Repetition Frequency (PRF) – Multiple Choice Questions

1. The number of pulses created per second is:
    A. Pulse repetition frequency
    B. Pulse repetition period
    C. Pulse duration
    D. Duty factor
2. The sonographer increases the image depth from 10 cm to 20 cm. The pulse repetition frequency will:
    A. Halve
    B. Increase
    C. Decrease
    D. Remain unchanged
3. The sonographer reduces the image depth from 20 cm to 10 cm. The pulse repetition frequency will:
    A. Increase
    B. Halve
    C. Decrease
    D. Remain the same

Pulse Repetition Frequency (PRF) Multiple Choice Questions Answers-Explanations

1. **A.** Pulse repetition frequency (PRF) is the number of **pulses** created per second. Frequency (f) is the number of **cycles** per second.
2. **C.** Only one pulse can travel in the body at one time in order that the ultrasound machine can place the reflector in the correct location using the range equation. As the sonographer increases image depth, the ultrasound machine must wait for that pulse to return before emitting another pulse. Increasing the image depth decreases the pulse repetition frequency, reduces frame rate, degrades temporal resolution, decreases the Nyquist limit and increases the pulse repetition period.
3. **A.** Decreasing the image depth allows more pulses to be emitted since the wait time is reduced for a pulse to travel in the body. Increasing the pulse repetition frequency allows more frames to be created (e.g; higher frame rate) because more pulses allow for more scan lines which means more frames created per second (frame rate) which improves temporal resolution. With PW Doppler on (or color flow Doppler since color flow Doppler is a PW Doppler technique), the Nyquist limit (Nyquist limit predicts when aliasing will occur) is increased when image depth is decreased (Nyquist limit = PRF ÷ 2) which reduces the risk of aliasing. Changing the pulse repetition frequency affects the PW Doppler and color flow Doppler velocity scale.

Pulse Repetition Period (PRP)

The pulse repetition period is the period of time from the onset of one pulse to the onset of the next pulse. It is the pulse “on time” and “off time.” The clinical imaging range for pulse repetition period is 100 μsec to 1 msec (dependent on image depth). Pulse repetition period is the reciprocal of pulse repetition frequency (PRF) which can be expressed by the formula:

Pulse repetition period (msec) = 1 ÷ Pulse repetition frequency (kHz)

As image depth increases, the pulse repetition frequency decreases, pulse repetition period increases; as image depth decreases; pulse repetition frequency increases, pulse repetition period decreases.

A Sonographer's Summary

- The pulse repetition frequency and pulse repetition period are dependent on image depth and propagation speed of the medium sound is traveling in. The propagation speed in soft tissue is assumed a constant (e.g.; 1540 m/sec), meaning pulse repetition frequency and pulse repetition period are determined by image depth in clinical imaging laboratories.
- The maximum pulse repetition frequency (and the minimum pulse repetition period) for an image depth may not always be used. Pulsed-wave (PW) Doppler velocity scales may not always use the maximum pulse repetition frequency and pulse repetition period for a given image depth to avoid range (depth) ambiguity. Less than the maximum pulse repetition frequency and minimum pulse repetition period may be used when imaging superficial structures (e.g.; thyroid) to avoid the ultrasound artifact of range ambiguity.

Pulse Repetition Period (PRP) Multiple Choice Questions

1. The time from the onset of one pulse to the onset of the next pulse is:
   A. Pulse repetition frequency
   B. Pulse repetition period
   C. Pulse duration
   D. Spatial pulse length
   E. Duty factor
2. The sonographer decreases image depth from 20 cm to 10 cm. The pulse repetition frequency will: ____; and pulse repetition period will: ____.
   A. Increase; Increase
   B. Decrease; Decrease
   C. Increase; Decrease
   D. Decrease; Increase
3. The sonographer increases the image depth from 10 cm to 20 cm. The pulse repetition frequency will: ___ pulse repetition period will: ___.
   A. Decrease; Decrease
   B. Increase; Increase
   C. Increase; Decrease
   D. Decrease; Increase

Pulse Repetition Period (PRP) Multiple Choice Questions Answers-Explanations

1. **B.** Pulse repetition period (PRP) is the inverse of pulse repetition frequency.

   Pulse repetition period (msec) = 1 ÷ Pulse repetition frequency (kHz)

2. **C.** As image depth decreases, pulse repetition frequency increases (the ultrasound machine does not have to wait as long before emitting another ultrasound pulse because of the shorter pulse round-trip time) which means the pulse repetition period (the time between pulses) will decrease.

   Pulse repetition period (PRP) (msec) = 1 ÷ Pulse repetition frequency (kHz)

   Decreasing the image depth increases the pulse repetition frequency, decreases the pulse repetition period, increases the frame rate and improves temporal resolution. Temporal resolution is improved by increasing the frame rate. Increasing the pulse repetition frequency, increases the Nyquist limit (Nyquist limit = PRF ÷2) which will reduce the risk of aliasing.
3. **D.** As image depth increases, pulse repetition frequency decreases and pulse repetition period will increase.

   Pulse repetition period (msec) = 1 ÷ Pulse repetition frequency (kHz)

   Increasing the image depth decreases the pulse repetition frequency, decreases frame rate and temporal resolution will be degraded. Increasing image depth results in the Nyquist limit being decreased (Nyquist limit = PRF ÷2) and increases the risk of aliasing.

Pulse Duration (PD)

Pulse duration is the time it takes for one pulse to occur. The units for pulse duration (PD) are time such as microseconds (μsec). The range for pulse duration in imaging ultrasound is 0.3 to 2.0 μsec. The formula for pulse duration is:

Pulse duration (μsec) = Period (μsec) x number of cycles in a pulse (n)

Pulse duration is reduced by increasing the transmit frequency and and/or by damping. Decreasing the pulse duration will improve axial resolution. The shorter the pulse duration and spatial pulse length, the better the axial resolution.

A Sonographer's Summary

- Axial resolution is determined by spatial pulse length. The shorter the spatial pulse length, the better the axial resolution. Pulse duration represents the time it takes for one pulse to occur. A short pulse duration implies that there is short spatial pulse length. The shorter the spatial pulse length, the better the axial resolution. The shorter the pulse duration, the better the axial resolution (assuming the propagation speed is constant and wavelength and spatial pulse length remains unchanged because the propagation speed remains unchanged. In clinical imaging ultrasound, propagation speed is assumed to be a constant).
- Improving axial resolution is important for acquiring high quality images. To shorten the spatial pulse length (and pulse duration), increase transmit frequency (sonographer) or damp (manufacturer).

Pulse Duration (PD) Multiple Choice Questions

1. The time it takes for one pulse to occur is:
   A. Pulse repetition frequency
   B. Pulse repetition period

C. Pulse duration
D. Spatial pulse length
E. Duty factor

2. The sonographer increases the transmit frequency, period will: ____ and pulse duration will: ____.
    A. Increase; Increase
    B. Decrease; Increase
    C. Decrease; Decrease
    D. Increase; Decrease

Pulse Duration (PD) Multiple Choice Questions Answers-Explanations

1. **C.** Pulse duration is the time it takes for one pulse occur. The shorter the pulse duration, the better the axial resolution. Pulse duration does not change when the sonographer changes the image depth. Pulse repetition frequency, pulse repetition period and duty factor will change when the image depth is changed by the sonographer.
2. **C.** As transmit frequency is increased, period, pulse duration, wavelength, spatial pulse length, the axial resolution numerical value (which means better axial resolution), the lateral resolution numerical value (which means better lateral resolution) all decrease.

Spatial Pulse Length (SPL)

Spatial pulse length is the length or distance of a pulse. The units for spatial pulse length are units of distance (e.g.; millimeters (mm). The range for spatial pulse length in clinical imaging is 0.1 to 1.0 mm. The typical number of cycles to produce one pulse in clinical imaging is 2 to 3 cycles. The formula for spatial pulse length is:

Spatial pulse length (mm) = Wavelength (mm) x number of cycles in a pulse
Wavelength (mm) = Propagation speed (mm/µsec) ÷ Frequency (MHz)

Spatial pulse length is reduced by increasing the transmit frequency and/or by damping. Spatial pulse length is important in calculating axial resolution:

Axial resolution (mm) = Spatial pulse length (mm) ÷ 2

A Sonographer's Summary

- Acquiring high quality diagnostic images is the goal. Axial resolution is determined by spatial pulse length – the shorter the spatial pulse length – the better the axial resolution. Increase transmit frequency - decrease wavelength – decrease spatial pulse length – improve axial resolution. Increasing transmit frequency is the primary way a sonographer may improve axial resolution. Image using the highest transmit frequency possible for the image depth required.
- Damping (manufacturer) decreases spatial pulse length and improves axial resolution.

Spatial Pulse Length (SPL) – Multiple Choice Questions

1. The distance or length of a single pulse is:
    A. Pulse repetition frequency

B. Pulse repetition period
C. Pulse duration
D. Spatial pulse length
E. Duty factor

2. For soft tissue, the sonographer increases the transmit frequency, spatial pulse length will:
A. Increases
B. Halve
C. Decrease
D. Remain unchanged

3. For soft tissue, the sonographer alters the image depth, the spatial pulse length will:
A. Increase
B. Decrease
C. Halve
D. Remain unchanged

4. The spatial pulse length is 4 mm. The axial resolution is: ___ mm.
A. 1
B. 2
C. 3
D. 4

5. Spatial pulse length is important in determining ___ resolution.
A. Axial
B. Lateral
C. Temporal
D. Contrast
E. Elevational (Slice thickness)

Spatial Pulse Length (SPL) Multiple Choice Questions Answers-Explanations

1. **D.** The distance covered by a single **pulse** (a collection of cycles) is spatial pulse length. The distance covered by a single **cycle** is wavelength.
2. **C.** As transmit frequency increases, wavelength decreases, spatial pulse length decreases and axial resolution improves. The shorter the spatial pulse length, the better the axial resolution. This assumes the propagation speed is a constant because wavelength is determined by frequency and propagation speed.

   Wavelength (mm) = Propagation speed (mm/µsec) ÷ Frequency (MHz)
   Spatial pulse length (mm) = Wavelength (mm) × number of cycles in a pulse (n)

3. **D.** Spatial pulse length (assuming propagation speed does not change) and pulse duration do not change when the sonographer alters the image depth. Pulse repetition frequency, pulse repetition period and duty factor do change when the sonographer changes image depth.

4. **B.** 4 mm ÷ 2 = 2 mm:

Axial Resolution (mm) = Spatial pulse length (mm) ÷ 2

5. **A.** The shorter the spatial pulse length (SPL), the better the axial resolution:

Axial Resolution (mm) = Spatial pulse length (mm) ÷ 2

Increasing transmit frequency (sonographer controlled) and damping (manufacturer controlled) are two ways spatial pulse length is decreased and axial resolution improved.

Duty Factor (DF)

Duty factor is the time the machine actually spends creating a pulse of ultrasound. Duty factor is unitless since it is a ratio but can be expressed as a percentage. The formula for duty factor is:

Pulse duration (µsec) ÷ Pulse repetition period (µsec)

For continuous-wave (CW) ultrasound, the duty factor is 1 or 100% since the ultrasound machine is always producing a pulse. For pulsed-wave (PW) used in clinical imaging, the duty factor is less than 0.01 (less than 1%).

A Sonographer's Summary

- The duty factor (DF) for imaging (e.g.; B-mode, two-dimensional) ultrasound ranges from 0.1 to 1.0 %. This implies that in clinical imaging, the ultrasound machine spends most of the time listening, not transmitting.
- The PW Doppler duty factor range is slightly higher (0.5 to 5.0 %) than B-mode (two-dimensional) imaging because the pulse duration (PD) used for PW Doppler is longer. The number of cycles for one pulse of Doppler ultrasound is 5 to 30 cycles. For clinical imaging ultrasound, the typical number of cycles in a pulse range from 2 to 3.
- The duty factor in clinical imaging is primarily determined by the pulse repetition frequency. For example, decreasing the image depth – increases the pulse repetition frequency – decreases the pulse repetition period – increases the duty factor.
- Duty factor is important when reviewing bioeffects. Modalities with higher duty factors (e.g.; PW Doppler) will increase the exposure time of the patient to ultrasound energy which increases the risk of bioeffects. Modalities which sweep (scan) through the soft tissue (e.g.; B-mode-two-dimensional) have a lower risk for bioeffects. Modalities which do not sweep the sound beam ("dwell") in one location (e.g.; PW Doppler) have a greater risk of bioeffects.

Duty Factor (DF) Multiple Choice Questions

1. The percentage of time the ultrasound machine spends producing a pulse of ultrasound is:
    A. Pulse repetition frequency
    B. Pulse repetition period
    C. Pulse duration
    D. Spatial pulse length
    E. Duty factor
2. The duty factor for CW ultrasound is: ___%

A. 1
B. 10
C. 50
D. 100

3. The duty factor for imaging ultrasound is: __ %.
    A. 1
    B. 10
    C. 50
    D. 100
4. For soft tissue, the sonographer increases the image depth. Which of the following will be directly affected by the change?
    A. Pulse duration
    B. Axial resolution
    C. Spatial pulse length
    D. Duty factor

Duty Factor (DF) Multiple Choice Questions Answers-Explanations

1. **E.** The formula used to calculate duty factor is:
   Duty Factor = Pulse duration (µsec) ÷ Pulse repetition period (µsec)
2. **D.** Since continuous-wave (CW) ultrasound is always producing a "pulse", the time spent producing that "pulse" is 100% or 1.
3. **A.** The duty factor for clinical imaging ultrasound is very low (less than 1%).
4. **D.** Pulse repetition frequency, pulse repetition period and duty factor change when the sonographer alters the imaged depth. For soft tissue, pulse duration and spatial pulse length are not affected by a change in image depth.

Transmit Gain (Output Power; Power)

Transmit gain determines the amount of sound energy emitted by the transducer to the patient. Transmit gain is controlled by the sonographer. For example, when the sonographer increases the transmit gain, the pulser (transmitter) delivers an increased voltage to the piezoelectric element(s) and a stronger (e.g.; increased amplitude, power, intensity) pulse will be emitted. The units for transmit gain are decibels (dB). Increasing the transmit gain will improve image depth, increase the brightness (amplitude) of the returning signals throughout the image display (e.g.; top to bottom), increases the width of the sound beam which degrades lateral resolution, degrades contrast resolution, may increase the risk of bioeffects and increases the mechanical index (MI). The acronym ALARA (**A**s **L**ow **A**s **R**easonably **A**chievable) is the guide for the amount of transmit gain that should be used during an ultrasound examination. The transmit gain on an ultrasound machine may be labelled in
Decibels (dB):

0 dB = Maximum transmit gain (power)
-3 dB = ½ transmit gain (power)
-6 dB = ¼ transmit gain (power)
-9 dB = 1/8 transmit gain (power

A Sonographer's Summary

- Transmit gain is an important determinant of the ultrasound "dose" delivered to the patient. ALARA (**A**s **L**ow **A**s **R**easonably **A**chievable) is the guiding principle in the use of transmit gain. For ALARA - reduce transmit gain – use transmit frequency, tissue harmonic imaging, gain (receiver gain, overall gain), time gain compensation (TGC), lateral gain compensation (LGC), display dynamic range to manage the reflections demonstrated on the image display. This will reduce the intensity exposure and the ultrasound dose. ALARA is aimed at minimizing the risk of bioeffects overall – reduce transmit gain, reduce scan time and prudent use should be combined to achieve safety through ALARA.

Transmit Gain (Output Power) – Multiple Choice Questions

1. The amount of sound energy emitted by the transducer is determined by:
   A. Transmit gain
   B. Gain
   C. Receiver gain
   D. Overall gain

2. ALARA is the guide for:
   A. Time gain compensation (TGC)
   B. Gain
   C. Transmit gain
   D. Overall gain

3. Which of the following is affected directly by transmit gain?
   A. Mechanical index (MI)
   B. Pulse repetition frequency
   C. Frame rate
   D. Axial resolution

Transmit Gain Multiple Choice Questions Answers-Explanations

1. **A.** The transmit gain control determines the amount of sound energy delivered to the patient. As the sonographer increases transmit gain, the strength (amplitude, power, intensity) of the pulse delivered to the piezoelectric element(s) by the pulser (transmitter) is increased which increases the amount of sound energy emitted by the ultrasound transducer.
2. **C. as Low as R**easonably **A**chievable is the guide used for determining how much transmit gain should be used. Increasing the transmit gain increases the risk of bioeffects. Reducing scan time and prudent use are also important components of the ALARA principle.
3. **A.** The mechanical index (MI) is displayed on the ultrasound machine. It is the parameter used to predict the ultrasound sound beam's ability to cause cavitation-related bioeffects. It is proportional to the ultrasound beam's peak negative pressure and inversely proportional to the square root of the center frequency of the sound beam:
   Mechanical Index (unitless) = Peak negative pressure ÷ √Center frequency (MHz)

In the United States, the Food and Drug Administration (FDA) mandates that the mechanical index (MI) be kept at ≤ 1.9. The mechanical index (MI) can be changed by the sonographer by altering transmit gain and is often required to be altered when acquiring a transpulmonary contrast examination or myocardial perfusion contrast examination.

Gain (Receiver Gain, Overall Gain)

Gain amplifies the strength (amplitude) of all the returning signals regardless of depth. The units for gain are decibels (dB). Gain is controlled by the sonographer. Gain is the preferred gain when attempting to increase the amplitude (strength, brightness) of the signals seen throughout the image display since it does not increase the strength (amplitude, power and intensity) of the outgoing signal. The use of gain while reducing transmit gain reduces the risk of bioeffects.

A Sonographer's Summary

- When trying to increase the brightness (strength, amplitude) of all the signals seen throughout the image display – choose gain – avoid transmit gain. This is a step towards using the ALARA principle.
- Gain affects the overall amplitude (brightness) of all of the echoes seen on the image display.
- The amount of gain is sonographer's choice. One guide to use is that blood pools (e.g.; ventricles, vessels) should not be "filled-in" with extraneous echoes due to increased gain.

Gain (Receiver Gain, Overall Gain) – Multiple Choice Questions

1. Which gain amplifies the returning signal regardless of image depth?
   A. Transmit gain
   B. Output power
   C. Gain
   D. Power
2. Which gain is the preferred gain especially when trying to reduce the risk of bioeffects?
   A. Gain
   B. Transmit gain
   C. Output power
   D. Power

Gain (Receiver gain, Overall gain) Multiple Choice Questions Answers-Explanations

1. **C.** Gain (receiver gain, overall gain) amplifies all returning reflections regardless of depth. Changing the gain will affect the amplitude (strength) (brightness) of all the echoes being

displayed but does not increase the amplitude, power, intensity and decreases the risk of bioeffects.

2. **A.** Gain (receiver gain, overall gain) amplifies the returning signals, which means that the strength of the signals returning to the ultrasound transducer are increased without delivering an increase in sound energy to the patient. Gain, as compared to transmit gain, is considered safer and is preferred because gain reduces the ultrasound dose delivered to the patient.

Time Gain Compensation (TGC) (Depth Gain Compensation (DGC)

Time gain compensation (TGC) compensates for attenuation by allowing the sonographer to adjust the brightness (amplitude, strength) of the returning signals at particular depths. Reflections from tissue close to the transducer will have a greater amplitude (and brightness) as compared to similar (or the same) soft tissue distal to the transducer. The echoes from the distal soft structures will be weaker (and less bright) only due to attenuation. Time gain compensation allows the sonographer to amplify those returning deep reflections so that the echoes appear equal to the echoes returning from similar soft tissue structures close to the ultrasound transducer. The units for time gain compensation are decibels (dB). Time gain compensation is controlled by the sonographer by using slide pods which are increased as depth from the transducer increases. Adaptive ("automatic") time gain compensation is performed in real-time with sonographer input.

A Sonographer's Summary

- The goal for using time gain compensation is to have tissues which have similar reflective properties be displayed with similar amplitudes.
- For adult echocardiography, one way to set up the time gain compensation slide pods is to arrange the slide pods as a "reverse C" although with adaptive time gain compensation this may not be optimal.
- A change in transmit frequency may require a change in gain settings including time gain compensation.
- If one section of the image display is demonstrating the echoes are too bright or too weak, use time gain compensation instead of transmit gain or gain.

Time Gain Compensation (TGC) Depth Gain Compensation (DGC) – Multiple Choice Questions

1. Which gain allows the sonographer to control the amplitude of the returning signals at particular depths?
    A. Gain

B. Transmit gain
C. Overall gain
D. Time gain compensation

2. The sonographer notes that one section of the display is too bright. To adjust this particular depth, the sonographer should choose:
    A. Time gain compensation
    B. Gain
    C. Transmit gain
    D. Power

Time Gain Compensation (TGC) (DGC) Multiple Choice Questions Answers-Explanations

1. **D.** Time gain compensation allows the sonographer to control the amplitude (strength) of echoes at certain depths as compared to transmit gain and gain (receiver gain, overall gain) which affect echo amplitude throughout the image display.
2. **A.** If a region of the image display is too bright or too dark, the time gain compensation (TGC) control is the preferred instrument control to choose to improve that specific region. A change in transmit frequency may require a change in gain settings including time gain compensation.

Display Dynamic Range

The general definition of dynamic range is that dynamic range is the ratio of the largest to smallest amplitude that a system can handle. There are several different types of dynamic range: input, output, gain, display. Display dynamic range is the instrument control which affects the number of shades (e.g.; range of echo amplitudes) of gray displayed. The units for dynamic range are decibels (dB). Increasing the display dynamic range increases the range of reflections displayed which will include weaker amplitude echoes. Increasing the dynamic range (e.g.; wide, high) will increase the number of gray shades displayed. There will be a decrease in contrast. Decreasing the display dynamic range (e.g; narrow, low) eliminates weaker amplitude reflections which reduces the number of gray shades displayed. There will be an increase in contrast and may even result in a bistable (black and white) display of returning signals. Display dynamic range is an important instrument control in determining contrast resolution.

A Sonographer's Summary

- A narrow (low) display dynamic range produces a high image contrast (black and white) image. A narrow dynamic range enhances strong amplitude reflections, eliminates weak echoes and noise. A narrow display dynamic range may be useful in technically difficult studies. It is important to remember that when choosing a narrow display range, information from low amplitude signals (e.g.; vegetation, thrombus) may be reduced or eliminated.
- A wide (high) display dynamic range produces a low image contrast (more shades of gray; less black and white). Choosing a wide dynamic range may soften (e.g.; less contrast – less black and white) the displayed image and adds more information to the image.

- Choosing a narrow (low) display dynamic range setting eliminates low level amplitude signals. It may be useful to alter (e.g.; increase, wide, high) the display dynamic range when ruling out low amplitude echoes/ structures such as thrombus, cardiac valve vegetations.
- Choosing a display dynamic range of between 60 to 70 dB is a good starting range.

Display Dynamic Range Multiple Choice Questions

1. The ratio of the largest to smallest amplitude or power that a system can handle is:
   A. Edge enhancement
   B. Dynamic range
   C. Scan conversion
   D. Threshold
2. The sonographer increases the display dynamic range (e.g.; wide dynamic range). What will occur?
   A. Image depth increases
   B. Number of shades of gray displayed increases
   C. Increase in amplitude of returning echoes from a certain depth only
   D. Improved temporal resolution
3. The sonographer reduces the dynamic range (e.g.; narrow dynamic range). What will occur?
   A. Image depth increases
   B. Number of shades of gray displayed decreases
   C. Increase in amplitude of returning echoes from a certain depth only
   D. Improved temporal resolution
4. Which of the following does **NOT** have decibels (dB) as the units?
   A. Transmit gain
   B. Overall gain
   C. Time gain compensation
   D. Dynamic range
   E. Frequency

Dynamic Range Multiple Choice Questions Answers-Explanations

1. **B.** Dynamic range may be defined as the range of echo amplitudes that may be handled and displayed by the ultrasound machine. Dynamic range affects the gray scale and contrast resolution.
2. **B.** Increasing the display dynamic range allows more echoes to be displayed (wider range of echo amplitudes) which will change (increase) the number of shades of gray displayed.
3. **B.** Decreasing the display dynamic range will reduce the number of echo amplitudes displayed (narrower range of echo amplitudes) which will change the number of shades gray displayed that can result in a more black and white (more contrast) (bistable display). Reducing the display dynamic range may eliminate important low level amplitude echoes (e.g.; thrombus, vegetation).
4. **E.** The units for frequency are Hertz (Hz). Hertz is per second. Pulse repetition frequency, frame rate and Doppler shift are also expressed in Hertz (Hz).

Rejection (Threshold)

Rejection (threshold) reduces or eliminates low level amplitude signals and/or electronic noise. The units for rejection (threshold) are decibels (dB). An ultrasound machine may not have a reject instrument control key – the manufacturer may use a high pass filter which allows high amplitude signals to be displayed while rejecting all low amplitude echoes that do not meet a minimum threshold. Reject can alter the display dynamic range and contrast resolution as it eliminates low amplitude signals.

A Sonographer's Summary

- Most ultrasound machines, the manufacturer will use a high pass filter for reject (threshold) and the sonographer may not have input.

Rejection (Threshold) – Multiple Choice Questions

1. Which of the following ultrasound instrument controls eliminates low level amplitude signals and/or electronic noise?
   A. Transmit gain
   B. Gain
   C. Time gain compensation
   D. Rejection (Threshold)

Rejection (Threshold) Multiple Choice Questions Answers-Explanations

1. **D.** Rejection (threshold) can be controlled/determined by the sonographer or the manufacturer of the ultrasound machine.

Write Zoom and Read Zoom

There are two types of zoom: write zoom and read zoom. Write zoom is a preprocessing magnification technique. The sonographer chooses an area of the image display to be magnified. The expanded (zoomed) region is much smaller than the original field of view which allows more pixels to represent the reflections within the expanded area. This may improve spatial (lateral, axial) resolution.

Read zoom is a postprocessing magnification technique which displays pixels in a larger format on the image display. Pixel-to-pixel variation are seen more easily but spatial (axial, lateral) resolution) is not improved.

A Sonographer's Summary

- Write zoom can be helpful especially when trying to evaluate for small structures such as vegetations. Write zoom may also be useful in acquiring measurements. The American Society of Echocardiography (ASE) recommends using write zoom when measuring the right ventricular wall thickness in the recommended view for the measurement – the subcostal four chamber view. The ASE recommends using write zoom when measuring the left ventricular outflow tract diameter in the parasternal long axis of the left ventricle. Atrial volume measurements may be easier to acquire when using the write zoom feature.

- Axial resolution may be improved with write zoom because more pixels are used to represent reflected structures.
- Lateral resolution may be improved because line density may be increased with write zoom on.
- Temporal resolution may be improved with write zoom as the frame rate may be increased with write zoom on.

Write Zoom (Regional Expansion) – Read Zoom Multiple Choice Questions

1. Which of the following will most likely improve spatial (axial, lateral) resolution?
    A. Write zoom
    B. Read zoom
    C. Increased transmit gain
    D. Decreased transmit frequency

Write Zoom – Read Zoom Multiple Choice Questions Answers/Explanations

1. **A.** Write zoom may be a way to improve spatial (axial, lateral) resolution. Write zoom applies more pixels to the zoomed region of interest which should improve axial resolution. Write zoom may increase line density which should improve lateral resolution. The frame rate may increase with write zoom improving temporal resolution. Read zoom increases the size of each pixel in the zoomed region which will not improve resolution.

Contrast Resolution

Contrast resolution is the ability to differentiate reflectors that have different acoustic properties. It is the ability of a gray-scale display to distinguish between echoes of slightly different amplitudes. There are two types of contrast resolution: 1. Intrinsic contrast resolution which depends directly on the digital scan converter (e.g; number of bits per pixel); 2. Recording contrast resolution which depends on the instrument settings and controls the sonographer chooses to use. The sonographer choices include using tissue harmonic imaging, display dynamic range, gain settings (e.g.; transmit gain, time gain compensation (TGC), lateral gain compensation (LGC), post-processing curves, B-color, display monitor controls (e.g.; brightness, contrast). The brightness control on the display monitor controls the overall range of brightness levels seen on the display monitor. Contrast control affects the shades of gray that will be seen on the display monitor.

A Sonographer's Summary

- The sonographer does have significant influence on the gray scale seen on the display. It can be often dependent on the sonographer's opinion.
- Guiding principles include blood cavities should not be filled in, the image should not appear "overgained".
- Increasing the gain settings may actually result in degrading contrast resolution.

- It is important to realize information can be excluded by the sonographer by choosing a narrow dynamic range setting or a bistable post-processing curve.
- Tissue harmonic imaging improves contrast resolution because harmonic imaging improves the signal-to noise ratio with low level echo amplitudes (e.g.; clutter, reverberations, sound beam side lobes, grating lobes, noise, haze) being eliminated.
- The ultrasound machine display monitor and display monitor used for interpretation of ultrasound examinations have controls (e.g.; contrast, brightness) which may affect gray scale presentation and, especially the display monitor being used for interpretation, may not match up to what was visualized during the acquisition of the ultrasound examination.

Contrast Resolution Multiple Choice Questions

1. The ability of the ultrasound machine to differentiate between subtle differences in amplitude and display those differences accurately is:
    A. Axial
    B. Lateral
    C. Temporal
    D. Contrast
    E. Elevational (slice thickness)
2. Which of the following would **NOT** affect contrast resolution?
    A. Tissue harmonic imaging
    B. Frame rate
    C. Post-processing curve(s)
    D. Display dynamic range

Contrast Resolution Multiple Choice Questions Answers-Explanations

1. **D.** Contrast resolution is the ability to identify differences in echogenicity between adjacent soft tissue regions.
2. **B.** The sonographer has many choices for determining gray shade presentation on the display. Tissue harmonic imaging, post-processing curves, transmit gain, gain, time gain compensation (TGC), lateral gain compensation (LGC) and display dynamic range all have input on how reflectors are displayed. B-color is useful because the eye can differentiate more color tints than gray shades (the human eye can only differentiate 64 gray levels simultaneously). Additionally, the ultrasound machine display monitor (and review monitors used for interpretation) have a brightness and contrast control which may affect gray scale presentation.

Amplitude mode (A-mode)

Amplitude mode (A-mode) is the original method of medical imaging. Returning reflections were displayed as spikes - the taller the spike - the greater the amplitude (strength) of the returning echo. The x axis demonstrated reflector depth; the y axis demonstrated the amplitude (strength of the returning reflections). For echocardiography, the spikes would be moving along the x axis demonstrating motion such as the motion of the cardiac valves and ventricular walls.

A Sonographer's Summary

- Amplitude mode (A-mode) provided limited information about cardiac structure and function. The spikes of the A-mode were turned on their side so that one could see the peak of each spike that presented the reflections as dots – which came to be known as brightness-mode (B-mode).

Amplitude mode (A-mode) Multiple Choice Questions

1. Which imaging modality demonstrates returning reflections as spikes?
    - **A.** Amplitude mode (A-mode)
    - **B.** Brightness mode (B-mode)
    - **C.** Constant-depth mode (C-mode)
    - **D.** Doppler mode (D-mode)

Amplitude mode (A-mode) Multiple Choice Questions Answers-Explanations

1. **A.** Amplitude mode (A-mode) demonstrates returning reflections as spikes – the taller the spike, the greater the amplitude of the returning echo. A-mode also demonstrates depth and motion. It is the fundamental building block for B-mode (brightness mode). A-mode has been used in ophthalmic ultrasound and cardiac ultrasound. B-mode (brightness mode) demonstrates returning reflections as bright dots – the brighter the dot – the greater the amplitude of the returning echo. C-mode (constant-depth mode) operates similar to PW Doppler – a certain image depth is set by the sonographer – only the reflections from the chosen depth is displayed. D-mode is the Doppler mode – PW, CW and color flow Doppler.

Brightness (B-mode)

Brightness (B) mode displays returning reflections as bright dots - the brighter the dot the greater the amplitude of the returning signal. B-mode is the basis for the scanning modalities - M-mode, Two-dimensional (2-D), Three-dimensional (3-D).

A Sonographer's Summary

- The term two-dimensional (2-D) imaging means that there are two axis presented – x axis (width) and y axis (depth, length).
- Three-dimensional (3-D) imaging presents length, width and height.
- Four dimensional (4-D) is the combination of three-dimensional (3-D) with time (temporal) being the fourth dimension (e.g.; motion).

Brightness Mode (B-Mode) Multiple Choice Questions

1. Which mode displays returning signals as bright dots with the brighter the dot the greater the amplitude (strength, brightness) of the returning signal?
    - **A.** A-Mode

B. B-Mode
C. C-Mode
D. M-Mode

2. Which of the following will **NOT** be displayed using brightness mode (B-mode)?
   A. Distance
   B. Width
   C. Amplitude
   D. Pressure

Brightness Mode (B-mode) Multiple Choice Questions Answers-Explanations

1. **B.** Brightness mode (B-mode) is the fundamental way reflectors are displayed in clinical imaging. The brighter the dot, the greater the amplitude of the returning signal.
2. **D.** Pressure is an acoustic variable. Amplitude is displayed on B-mode as shades of gray.

M-mode (Time-Motion mode; TM-mode)

Time-Motion mode (M-mode) is a B-mode operation which displays reflector motion and depth over time. The display is "swept" at a standard speed of 50 mm/sec to demonstrate structure motion (e.g.; cardiac valve motion, ventricular wall motion). The x -axis of the M-mode demonstrates time, the y axis is depth (distance) and the z axis is the amplitude (strength) of the returning reflection. The primary advantage of M-mode is excellent temporal resolution (e.g.; timing or duration of cardiac events). The disadvantage of M-mode is the "icepick" view of the anatomy. The combination of M-mode with color flow Doppler (CMM) is an excellent method for timing certain cardiac events such as cardiac valve regurgitation. Curved anatomical M- Mode (CAMM) presents an M-mode color display format in which functional information of strain and strain rate is presented. The M-mode cursor is "curved" to follow the myocardial walls such as in the apical four chamber view.

A Sonographer's Summary

- M-mode has virtually been replaced with two-dimensional imaging including the acquisition of linear measurements of the heart walls and chambers. Because M-mode has excellent temporal resolution, it may still be indicated when trying to sort out the timing of cardiac events – duration of systolic anterior motion (SAM) of the mitral valve, differentiating mid-to-late mitral valve prolapse from holosystolic prolapse. Color M-mode (CMM) can be useful in determining the duration of valve regurgitation and the duration of regurgitant flow is an important indicator of severity. Color M-mode may also be useful in the evaluation of ventricular diastolic function.

M-mode (Time-Motion mode; TM mode) Multiple Choice Questions

1. The primary advantage of M-mode is: ____ resolution.
   A. Axial
   B. Lateral
   C. Temporal

D. Contrast
E. Elevational (slice thickness)

2. M-mode combined with color flow Doppler is referred to as:
   - **A.** Three-dimensional (3-D)
   - **B.** CMM
   - **C.** B-mode
   - **D.** TDI

M-mode (Time-Motion mode, TM mode) Multiple Choice Questions Answers-Explanations

1. **C.** M-mode sends 3000 to 5000 pulses down one line of sight. This allows for excellent temporal resolution which can be useful when determining the timing of events.
2. **B.** CMM is the combination of color flow Doppler (C) with M-mode mode. This combination can be useful in determining the timing and duration of flow such as mitral regurgitation and in the evaluation of ventricular diastolic function.

Two-Dimensional (2-D) (Two-D)

Two dimensional (2-D) (two-D) (distance and width) is a B-mode operation which uses bright dots to demonstrate reflector depth and motion. The amplitude of the returning reflection is demonstrated by brightness – the brighter the dot – the greater the amplitude (strength) of the returning reflection. This is referred to as the gray scale. The y axis represents depth (distance), the x axis is width and the z axis the gray scale (brightness of the B-mode dot). Two-dimensional is the fundamental imaging modality of clinical imaging ultrasound.

A Sonographer's Summary

- Two-dimensional (2-D) (two-D) has virtually replaced M-mode in adult echocardiography. Linear measurements are now acquired using two-dimensional imaging. Two-dimensional imaging allows for better estimation of the heart's volume measurements such as atrial volumes ventricular volumes (e.g.; ejection fraction).
- It is important to remember that two-dimensional imaging represents a "thin" slice of a three-dimensional structure (e.g.; the heart). Multiple slices, on-axis (and occasionally off-axis) is required.
- Time is required to "build" the frames of two-dimensional imaging. M-mode has better temporal resolution when compared to two-dimensional imaging. Virtual beam sonography two-dimensional imaging has much higher frame rates (>1000 Hz) than conventional two-dimensional imaging (60 Hz).
- All five resolutions (axial, lateral, temporal, contrast, elevational) need to be maximized by the sonographer when acquiring a two-dimensional examination.

Two-dimensional (2-D) (Two-D) Multiple Choice Questions Answers-Explanations

1. Which imaging mode provides information concerning a structures depth (distance), width and motion?

A. A-mode
B. D-mode
C. C-mode
D. 2-D

Two-dimensional (Two-D) (2-D) Multiple Choice Questions Answers-Explanations

1. **D.** For two-dimensional imaging, the y axis represents depth (distance). The x axis represents width. The z axis represents amplitude (strength, brightness) of the returning reflections. Motion of structures are demonstrated by two-dimensional imaging.

Three-Dimensional (3-D) and Four-Dimensional (4-D)

Three-dimensional ultrasound is acquired using a matrix transducer which is composed of nearly 3000 piezoelectric elements which allows insonation of a volume of soft tissue versus a single, “thin” two-dimensional slice. Multiple pyramidal data sets are acquired or multiple acquisition of narrow volumes of data are acquired and then “stitched” together. Advantages of three-dimensional imaging include volume rendering, surface rendering and tomographic slicing. Spatial resolution (axial, lateral) resolution and temporal resolution may not equal two-dimensional imaging. Color flow Doppler may be acquired during a three-dimensional examination, but M-Mode and conventional Doppler (e.g.; PW, CW) may not be acquired. Four-dimensional (4-D) is the addition of time (temporal) to three-dimensional imaging and is often implies motion is being presented.

A Sonographer’s Summary

- The advantage of three-dimensional imaging is obvious because it enables the sonographer to acquire and present full volume data of complex three-dimensional objects (e.g.; heart).
- The widespread use of three-dimensional imaging in the echocardiography laboratory has yet to be fulfilled. Cost of equipment, spatial (axial, lateral) resolution, temporal resolution, inability to provide all of the cardiac modalities may be factors hampering its use in the day-to-day work of the echocardiography laboratory.

Three-Dimensional (3-D) and Four-Dimensional (4-D) Multiple Choice Questions

1. Which of the following may **NOT** be acquired during a three-dimensional examination?
    - **A.** Volume rendering
    - **B.** Surface rendering
    - **C.** Tomographic slicing
    - **D.** CW Doppler

Three-Dimensional (3-D) and Four-Dimensional (4-D) Multiple Choice Questions Answers-**Explanations**

1. **D.** CW Doppler may not be acquired during a three-dimensional ultrasound examination. Spatial resolution (e.g.; axial, lateral) and temporal resolution may not equal to two-dimensional imaging.

Temporal Resolution

Temporal resolution is the ability to resolve fast moving structures accurately. Temporal resolution is determined by frame rate. A frame is a collection of transmitted ultrasound pulses with one ultrasound pulse equal to one scan line. Approximately 100 to 150 scan lines make up one frame. Frame rate is the number of frames displayed per second. The units for frame rate are Hertz (Hz). The standard frame rate for conventional sonography is 60 Hz. The frame rate for virtual beam sonography is 1000 Hz (or greater).

Temporal resolution is improved by increasing the frame rate. Reducing image depth, reducing field of view, reducing the number of focuses, decreasing scan line density may increase the frame rate and improve temporal resolution. Reducing the scan line density may affect spatial (axial, lateral) resolution.

Frame rate (Hz) = Pulse repetition frequency (Hz) ÷ Number of scan lines per frame (N)

Parallel processing is a technique used by the manufacturer to increase frame rate. Slightly wider sound beams are transmitted which allows creation of two (or more) scan lines for each sound beam transmitted. Parallel processing produces more scan lines per transmitted pulse – which allows more frames to be created - which improves temporal resolution.

A Sonographer's Summary

- The goal is to acquire a high-quality diagnostic ultrasound examination. All five resolutions are important to optimize: axial, lateral, temporal, contrast, elevational (slice thickness). Temporal resolution is important in echocardiography, as compared to general ultrasound and vascular ultrasound scanning because the heart moves.
- To maximize temporal resolution image at the shallowest depth using the narrowest field of view (e.g.; sector width) with the minimum number of focuses (usually one transmit focus for echocardiography) and reduce scan line density when indicated. Additionally, using the zoom (e.g.; write zoom) feature may increase the frame rate. Single transmit focus, narrow sector and low line density increases the frame rate and improves temporal resolution.
- M-mode has the best temporal resolution followed by two-dimensional imaging with color flow Doppler provide having the worst temporal resolution.
- Virtual beam sonography has very high frame rates (>1000 Hz) which means temporal resolution is excellent. High frame rates are achieved in virtual beam sonography because there is no dependence on the pulse-echo system (one pulse is transmitted – the machine waits for the reflections to return to the transducer- one scan line is created-the process is repeated).

Temporal Resolution – Multiple Choice Questions

1. Which resolution is determined by frame rate (the higher the frame rate the better this resolution)?
    A. Axial
    B. Lateral
    C. Temporal
    D. Contrast
    E. Elevational (Slice thickness)
2. Which of the following will **NOT** improve frame rate and improve temporal resolution decrease:
    A. Image depth
    B. Field of view (e.g; sector width)
    C. Number of focuses
    D. Transmit Gain
    E. Scan line density
3. Which imaging modality has the best temporal resolution?
    A. A-Mode
    B. B-Mode
    C. M-Mode
    D. Three-dimensional (3-D)
4. Which type of focusing directly affects the frame rate and temporal resolution?
    A. Internal
    B. External
    C. Transmit focus
    D. Dynamic receive
    E. Dynamic aperture
5. Which manufacturer technique improves temporal resolution?
    A. Parallel processing
    B. Damping
    C. Sub-dicing
    D. Apodization
6. Which operating system has higher frame rates and better temporal resolution?
    A. Conventional sonography
    B. Virtual beam sonography

Temporal Resolution Multiple Choice Questions Answers-Explanations

1. **C.** Temporal resolution is determined by frame rate. The higher the frame rate the better the temporal resolution. Axial resolution is determined by spatial pulse length. The shorter the pulse length, the better the axial resolution. Lateral resolution is determined by beam width (diameter). The narrower the sound beam width, the better the lateral resolution. Contrast resolution is determined by the number of shades of gray displayed. Increasing the display dynamic range alters the contrast resolution. Elevational (slice thickness) resolution is determined by the thickness of the sound beam.
2. **D.** Decreasing image depth, field of view (sector width), the number of focuses and/or scan line density will increase the frame rate and improve temporal resolution. The zoom feature (e.g.; write zoom) may increase frame rate which improves temporal resolution.
3. **C.** M-mode samples along one line of site ("icepick" view of the heart, single line of sight) with 3000 to 5000 pulses sent along that one line which provides excellent temporal resolution.
4. **C.** Transmit focus allows the sonographer to choose more than one focus. Each focus requires a pulse to build one scan line which will decrease the frame rate and degrade temporal resolution. Adult echocardiography generally uses only one transmit focus in order to preserve frame rate.
5. **A.** Parallel processing transmits a slightly wider sound beam which allows for more than one scan line to be produced for each transmitted pulse. Parallel processing increases the number of scan lines which will increase the number of frames created which improves temporal resolution. The higher the frame rate, the better the temporal resolution. Damping shortens spatial pulse length (and pulse duration) which improves axial resolution. Sub-dicing and apodization are ways the manufacturer uses to reduce side lobes and grating lobes.
6. **B.** The frame rates for virtual beam sonography is 1000 Hz (or higher). The higher the frame rate the better the temporal resolution. Virtual beam sonography does not depend on the time requirement of the pulse-echo operating system to produce scan lines-frames-frame rate.

Doppler

The **Doppler effect** (principle) is defined as that there will be a change in the frequency of sound relative to the motion of the source and/or the observer. The amount of decrease or increase in the change in frequency depends on the frequency emitted by the source (e.g. ultrasound transducer), the speed of the reflector (e.g.; blood velocity) and the angle between the source and receiver (e.g.; Doppler incident angle). The change in the frequency caused by the motion is the called the Doppler shift frequency or simply the **Doppler shift.** The Doppler shift is the difference between the transmit frequency and the received frequency. The magnitude of the Doppler shift can be expressed in the Doppler equation:

Doppler shift (Fd) (kHz) = 2 × Transmit frequency (f_0) (kHz) × Blood velocity (V) (cm/sec) × Cosine Ɵ of the incident angle ÷ propagation speed (c) (cm/sec)

If the Doppler transmit frequency **(f_0)** is changed, the magnitude of the Doppler shift will be altered (e.g.; an increase in the Doppler transmit frequency will result in an increase in the magnitude of the Doppler shift. (e.g.; changing the Doppler transmit frequency from 2.5 MHz to 5.0 MHz will increase (double) the magnitude of the Doppler shift). A change in the blood velocity **(V)** will result in a change in the magnitude of the Doppler shift (e.g.; an increase in red blood cell velocity will increase the magnitude of the Doppler shift).
The **cosine** of 0 degrees is 1 which infers that the preferred Doppler incident angle is 0 degrees (parallel) to blood flow. The cosine of 20 degrees is 0.94. The cosine of 60 degrees is 0.5. The cosine of 90 degrees is 0. Knowing these cosines suggests that as the Doppler incident angle increases (e.g.; 0 degrees towards 90 degrees), the magnitude of the Doppler shift will decrease (because the cosine of the Doppler incident angle decreases) and the peak velocity observed on the Doppler display will be lower than the true peak velocity.
The propagation speed in soft tissue is assumed to be a constant (c).

Summary of the Doppler shift equation:

1. A change in the transmit frequency (f_0) will change the magnitude of the Doppler shift.
2. A change in blood velocity (V) will change the magnitude of the Doppler shift.
3. To maximize the magnitude of the Doppler shift (e.g.; peak velocity), the Doppler incident (intercept) angle should be zero degrees because the cosine of zero degrees is 1.

The Doppler equation may be re-arranged to determine velocity:

$$\textbf{Velocity} = F(d) \times c \div 2 \times f_0 \times \text{Cosine } \Theta$$

F(d) is the Doppler shift; **c** is the propagation speed (a constant); **f_0** is the transmit frequency; **cosine theta (ϴ)** of the Doppler incident angle

The **Fast Fourier transform (FFT)** is the method used to display the returning Doppler signals for PW, CW, and high PRF Doppler ultrasound. The FFT display x (horizontal) axis depicts time (e.g.; flow duration). The y (vertical) axis represents the Doppler frequency shift (e.g.; velocity) and the z axis represents the amplitude (gray shade) of the returning Doppler signal. By convention, blood flow moving towards the transducer (e.g.; positive Doppler shift) is placed above the Doppler zero baseline. Blood flow moving away from the transducer (e.g.; negative Doppler shift) is placed below the Doppler zero baseline. The sonographer can invert this presentation. Spectral broadening is defined as the vertical thickening of a Doppler spectral waveform (tracing) which results in window fill-in. Spectral broadening indicates disturbed/turbulent flow for PW and high PRF but not CW Doppler.
The **Doppler wall filter** is a high pass wall filter eliminating high (strong) amplitude signals (e.g.; wall motion, valve motion), low Doppler frequency shifts (e.g.; low velocity flow). For normal flow, the Doppler wall filter should be set low (e.g.; 200 to 400 Hz); for high velocity flow (e.g.; valve regurgitation, valve stenosis) the Doppler wall filter should be set higher (400 to 800 Hz) for this will allow the sonographer to “hear” the higher velocity flow.
Aliasing is an artifact of PW (and color flow Doppler since color flow Doppler is a PW Doppler technique). If the Doppler shift exceeds the Nyquist limit (PRF ÷ 2), aliasing will occur. This is referred to as wrap-around or apparent flow reversal.
It is important to know the Nyquist Limit equation:

Pulse repetition frequency (kHz) ÷ 2

The Nyquist limit predicts when aliasing will occur.

Pulsed-wave (PW) Doppler requires one piezoelectric element to transmit and receive and uses a sampling gate (sample volume) to detect blood flow direction, Doppler frequency shift (velocity) and character of blood (e.g.; laminar flow vs turbulent flow) and duration of flow at a certain depth. The primary advantage of PW Doppler is range resolution (range discrimination). Range (depth) resolution means that PW Doppler can determine the blood flow direction, velocity, character and duration of blood flow at a specific depth. The primary disadvantage of PW Doppler is the artifact called aliasing – PW Doppler cannot resolve high velocity flow.

Tissue Doppler imaging (TDI) is a form of PW Doppler. Tissue Doppler imaging demonstrates the direction and velocity of the heart walls. Tissue Doppler imaging may be used to provide information concerning cardiac systolic and diastolic function. Tissue Doppler imaging may be used to acquire cardiac strain imaging. Tissue Doppler imaging uses a low-pass filter which eliminates low amplitude, high Doppler frequency shifts (high velocity).

Continuous-wave (CW) Doppler uses two piezoelectric elements – one to transmit and one to receive and detects blood flow direction, velocity and flow duration throughout the Doppler sound beam. The primary advantage of CW Doppler is that there is no inherent sampling rate which means no aliasing regardless of the peak velocity. For CW Doppler, there is no Nyquist limit. The primary disadvantage of CW Doppler is range ambiguity. Range ambiguity means that there is no depth information concerning blood flow. CW Doppler provides information concerning blood flow direction, velocity and flow duration but cannot be used to determine the character of blood flow (laminar flow vs turbulent flow).

Aliasing appears as "wrap-around" on the Doppler spectral image display. Aliasing may be avoided when using PW Doppler by the following methods: **1.** Increase the Doppler velocity scale because increasing the Doppler velocity will increase the Doppler pulse repetition frequency (PRF) which means the Nyquist limit (PRF÷2) will be increased; **2.** Decrease the image depth because this will increase the Doppler PRF which will increase the Nyquist limit; **3.** Decrease the Doppler transmit frequency (f_0) because reducing the Doppler transmit frequency will reduce the magnitude of the Doppler shift to possibly below the Nyquist limit; **4.** Shift the Doppler baseline which will allow the machine to "paste" the aliasing flow onto the flow moving in the correct direction; **5.** Use CW Doppler – CW Doppler does not alias because there is no inherent sampling rate – which means no Nyquist limit. **6.** Increase the Doppler incident angle (e.g.; 0 degrees to 20 degrees to 60 degrees to 90 degrees). Increasing the Doppler incident angle decreases the cosine of the Doppler incident angle which will reduce the magnitude of the Doppler shift. This is usually not clinically useful because as the Doppler incident angle increases, the magnitude of the Doppler shift decreases and the acquired peak velocity will be lower than the actual true peak velocity.

A Sonographer's Summary

- The one ultrasound physics formula useful to know is the Doppler equation. There are three fundamental keys which can affect how the sonographer acquires a Doppler examination: 1. the transmit frequency affects the magnitude of the Doppler shift – image with the lowest Doppler transmit frequency to avoid aliasing and improve depth of penetration. 2. The higher the blood velocity, the higher the Doppler shift and the higher the peak velocity that will be displayed on the Doppler display screen. 3. To maximize the Doppler shift (and peak velocity) the Doppler incident angle should be 0 degrees (parallel). If not parallel to flow, the magnitude of the Doppler shift (peak velocity) will be lower than it is resulting in an underestimation of the peak velocity and pressure gradients.

- To review: Use the lowest Doppler transmit frequency, high velocity blood flow creates high Doppler shifts which may result in aliasing, be parallel (0 degrees) to flow.
- The Doppler wall filter can be useful when trying to detect the maximum peak velocity because it eliminates the high amplitude, low Doppler frequency shifts (low velocity) flow signals allowing the sonographer to "hear" the high velocity flow.
- For cardiac imaging never angle correct. Angle correction may lead to an overestimation of the Doppler shift (and peak velocity) which may result in an incorrect diagnosis.
- **For all cardiac Doppler (PW, CW, TDI, Color flow) - Be parallel!**

Doppler – Multiple Choice Questions

1. There will be a change in the frequency of sound relative to the motion of the source and/or the observer is the:
   A. Doppler effect (principle)
   B. Doppler shift
   C. Bernoulli principle
   D. Poiseuille's law

2. A train whistle is moving towards the observer. There will be an increase in sound:
   A. Frequency
   B. Period
   C. Velocity
   D. Propagation speed

3. A train whistle is moving away from the observer. There will be a decrease in sound:
   A. Frequency
   B. Velocity
   C. Propagation speed-
   D. Direction

4. The difference between the transmit frequency and the returning frequency is the:
   A. Doppler shift
   B. Doppler effect (principle
   C. Bernoulli principle
   D. Poiseuille's law

5. The transmit frequency is 2,000,000 Hz. The returning frequency shift detected from moving red blood cells is 2, 001,000 Hz. Which is **INCORRECT**?
   A. Blood flow is moving towards the transducer
   B. Blood flow information will be placed above the zero baseline
   C. The frequency shift is in the audible range
   D. The Doppler shift is negative

6. There is an increase in blood velocity. The magnitude of the Doppler shift will:
   A. Increase

B. Remain unchanged
C. Decrease
D. Oscillate

7. The sonographer increases the Doppler transmit frequency from 2.5 MHz to 5.0 MHz. The magnitude of the Doppler shift will:
A. Alias
B. Double
C. Halve
D. Quadruple

8. To maximize the Doppler shift (velocity), the Doppler incident angle should be: ___ degrees.
A. 0 (parallel)
B. 20
C. 60
D. 90 (perpendicular)

9. ____ performs spectral analysis for conventional (PW, CW, high PRF) Doppler.
A. Autocorrelation
B. Fast Fourier transform (FFT)
C. B-mode
D. Three dimensional

10. The x (horizontal) axis of the FFT spectral display demonstrates:
A. Time (duration) of blood flow
B. Magnitude of the Doppler shift (velocity)
C. Amplitude (gray shades)
D. Direction

11. The y (vertical) axis of the FFT spectral display demonstrates:
A. Time (duration) of blood flow
B. Magnitude of the Doppler shift (velocity)
C. Amplitude (gray shades)
D. Direction

12. The z axis of the FFT spectral display demonstrates:
A. Amplitude (strength) of the returning signals
B. Velocity
C. Direction
D. Duration of blood flow

13. Vertical thickening of a spectrum with window fill-in suggests:
A. Laminar flow
B. Parabolic flow
C. Inlet (plug) flow
D. Turbulent flow

14. The Doppler wall filter is a ____ pass wall filter because it eliminates high amplitude, low velocity signals.
A. High
B. Medium

C. Low
D. Zero

15. The primary advantage of PW Doppler is:
A. Range ambiguity
B. Range resolution
C. Aliasing
D. Dynamic range

16. The primary disadvantage of PW Doppler is:
A. Aliasing
B. Range resolution
C. Range discrimination
D. Range ambiguity

17. The primary advantage of CW Doppler is:
A. Range ambiguity
B. Range discrimination
C. Range resolution
D. No inherent Nyquist limit

18. The primary disadvantage of CW Doppler is:
A. Range discrimination
B. Range resolution
C. Range ambiguity
D. Nyquist limit

19. The formula for the Nyquist limit which predicts when aliasing will occur is:
A. SPL (mm) ÷ 2
B. PRF (kHz)÷ 2
C. Number of cycles in a pulse × period (T) (µsec)
D. 1 ÷ PRF (kHz)

20. For a PW Doppler examination, the Doppler PRF is 4000 Hz. The detected Doppler shift is 3000 Hz.
A. Aliasing will not occur
B. Aliasing will occur
C. The returning signals will be placed entirely above the baseline
D. The returning signals will be placed entirely below the baseline

21. The Doppler PRF is 10 kHz. The returning Doppler shift from a stenotic valve is 4 kHz.
A. Aliasing will not occur
B. Aliasing will occur
C. CW Doppler will be required to resolve the peak velocity
D. The Doppler shift is not audible

22. Which of the following will **NOT** help avoid the Doppler artifact called aliasing?
A. Increase the Doppler velocity scale
B. Decrease image depth
C. Decrease the Doppler transmit frequency
D. Shift the zero baseline
E. Decrease the Doppler incident angle

Doppler Multiple Choice Questions Answers-Explanations

1. **A.** The **Doppler effect (principle)** is there will be a change in the frequency of sound relative to the motion of the source and/or the observer. The **Doppler shift** is the difference between the transmitted frequency and the received frequency. The magnitude of the Doppler shift is dependent on the transmit frequency (f_0), the velocity (speed) of blood flow (V) and the cosine of the Doppler incident (intercept) angle.
2. **A.** According to the Doppler principle, the moving train whistle that is moving towards the observer will "compress" the train whistle's sound waves which means a higher frequency will be heard by the observer.
3. **A.** As the train whistle moves away from the observer, the sound waves are "pulled apart" resulting in a lower frequency heard by the observer.
4. **A.** The **Doppler shift** is the difference between the transmitted frequency and the received frequency. (Doppler shift (kHz) = Frequency received (f_r) – Frequency transmitted (f_t).
5. **D.** 2,100,000 Hz - 2,000,000 Hz = 1000 Hz. This is considered a positive Doppler shift which means blood flow is moving towards the transducer. The audible range for sound is 20 Hz to 20000 Hz (20 kHz) so 1000 Hz (1 kHz) is in the audible range. By convention, positive Doppler shifts are placed above the Doppler zero baseline.
6. **A.** The Doppler equation is:

   Doppler shift (kHz) = 2 x transmitted frequency (f_0) x blood velocity (V) x cosine ϴ ÷ c

   According to the Doppler equation, the magnitude of the Doppler shift will increase as red blood cell velocity (V) increases. The relationship is directly proportional.
7. **B.** The Doppler equation is:

   Doppler shift (kHz) = 2 x transmitted frequency (f_0) x blood velocity (V) x cosine ϴ ÷ c

   According to the Doppler equation, the magnitude of the Doppler shift will increase as the transmit frequency (f_0) increases. The relationship is directly proportional.
8. **A.** The Doppler equation is:

   Doppler shift (kHz) = 2 x transmitted frequency (f_0) x blood velocity (V) x cosine Ø ÷ c

   The cosine of 0 degrees (parallel) is 1. The cosine of 20 degrees is 0.94. The cosine of 60 degrees is 0.5. The cosine of 90 degrees is 0. To maximize the magnitude of the Doppler shift according to the Doppler equation, the best Doppler incident angle is 0 degrees (parallel) because the cosine of 0 degrees is 1.
9. **B.** Fast Fourier Transform (FFT) creates the Doppler spectral display using spectral analysis.
10. **A.** The x axis of the Fast Fourier Transform (FFT) (PW, CW, high PRF Doppler spectral display is the horizontal axis representing time or duration.
11. **B.** The vertical axis of the Fast Fourier Transform (FFT) (PW, CW, high PRF Doppler) spectral display represents the magnitude of the Doppler shift which can be converted into velocity by re-arranging the Doppler equation.

    Velocity = F(d) × c ÷ 2 × f_0 × Cosine ϴ

    F(d) is the Doppler shift; c is the propagation speed (a constant); f_0 is the transmit frequency; cosine theta of the Doppler incident angle

12. A. The amplitude (strength) of the returning Doppler signal is called the z axis of the Fast Fourier Transform (FFT) PW, CW, high PRF Doppler spectral display. The z axis can be useful when evaluating the severity of valve regurgitation. A lightly stained (z axis) spectral display may indicate mild valve regurgitation. A darkly stained (z axis) spectral display may suggest a more significant valve regurgitation is present.

13. D. Vertical thickening of a Doppler spectral display will result in spectral window fill-in and is called spectral broadening. Spectral broadening (vertical thickening of a Doppler spectrum with window fill-in) is associated with blood flow that is not laminar (e.g ; disturbed flow, turbulent flow). The interpretation of whether there is laminar flow or disturbed flow or turbulent flow using spectral broadening is not possible using CW Doppler.

14. A. The Doppler wall filter is called a high pass filter because it filters out (eliminates) high (strong, bright) amplitude signals (i.e.; wall motion, valve motion) and low Doppler frequency shift (e.g.; low velocity) flow. Tissue Doppler imaging uses a low pass filter which filters out (eliminates) low amplitude signals and high Doppler frequency shifts.

15. B. The primary advantage of PW Doppler is that because PW Doppler uses a sample gate (e.g; sample volume), blood flow direction, velocity, character (e.g.; laminar vs disturbed vs turbulent flow) and flow duration can be evaluated at a precise depth. This is called range (depth) resolution or range (depth) discrimination.

16. A. Because PW Doppler is a sampling technique, it is limited in resolving high velocity flow. The Nyquist limit (PRF ÷ 2) predicts when aliasing will occur. If the Doppler shift (e.g.; velocity) exceeds the Nyquist limit, aliasing will occur.

17. D. CW Doppler continuously sends and receives. There is no inherent sampling rate. Since there is no inherent sampling rate for CW Doppler, there is no Nyquist limit and higher velocity flows can be detected and displayed without aliasing.

18. C. CW Doppler does not use a sample gate (e.g.; sample volume) so the depth at which the blood flow velocity information is being detected cannot be precisely determined. This is referred to as range (depth) ambiguity.

19. B. The Nyquist limit predicts when aliasing will occur. The formula for the Nyquist limit is:

Nyquist limit = Pulse repetition frequency (PRF) ÷ 2

If the magnitude of the Doppler shift exceeds the Nyquist limit, aliasing will occur.

20. B. 4000 Hz ÷ 2 = 2000 Hz. The Nyquist limit is 2000 Hz in this example. The Doppler shift is 3000 Hz. Aliasing will occur because the Nyquist limit has been exceeded. This question requires the use of the Nyquist limit equation of:

Nyquist limit = Pulse repetition frequency (PRF) ÷ 2

21. A. 10000 Hz ÷ 2 = 5000 Hz. The Nyquist limit in this example is 5000 Hz. The Doppler shift is 4000 Hz. The magnitude of the Doppler shift is less than the Nyquist limit so aliasing will not occur.

Nyquist limit = Pulse repetition frequency (PRF) ÷ 2

22. E. Increasing the Doppler velocity scale will increase the pulse repetition frequency which will increase the Nyquist limit. Decreasing the image depth increases the pulse repetition frequency (PRF) which will increase the Nyquist limit. Decreasing the Doppler transmit frequency will decrease the magnitude of the Doppler shift:

Doppler shift (kHz) = 2 x transmitted frequency (f_0) x blood velocity (V) x cosine Θ ÷ c

Shifting the Doppler zero baseline will allow the ultrasound machine to "paste" the aliasing flow onto the non-aliasing flow. Decreasing the Doppler incident angle (e.g.; 60 degree Doppler incident angle to 20 degree Doppler incident angle) should increase the magnitude of the Doppler shift which may mean aliasing will most likely still be present. If the Doppler incident angle is moved to 90 degrees (e.g.; increased from 0 degrees to 90 degrees), the cosine of 90 degrees is 0, and aliasing would be eliminated but this would not be clinically useful. Aliasing will not occur when using CW Doppler.

Color Flow Doppler

Color flow Doppler is a PW Doppler technique using multiple sample gates (multigate – 200 to 500 sample gates per scan line) along each scan line of color to detect blood flow direction, mean velocity and character (e.g.; laminar, disturbed, turbulent) of blood flow.

Autocorrelation is the rapid technique used by color flow Doppler to convert Doppler shift information into color. Packet size is the number of ultrasound pulses sent down one line of color to detect Doppler shift information. A minimum of three pulses (e.g; minimum packet size of three – packet size ranges from 3 to 32 pulses per scan line with 200 to 500 sample gates) must be sent down one scan line for color because autocorrelation is an averaging technique. Increasing the packet size will improve the estimation of the mean velocity but will decrease the frame rate. It is important to note that because color flow Doppler requires that one pulse be sent for imaging and at least 3 pulses for creating one scan line of color – the frame rate with color flow Doppler on will be lower than with color flow Doppler off. Color flow Doppler depicts the mean velocity not the peak velocity of blood flow.

There are a wide variety of color maps. The three most common color flow Doppler maps are: 1. Directional map which uses only the colors blue, red and black. Blue and red provide the direction of blood flow only. Black is the color flow Doppler zero baseline for all three color maps. The width of the black baseline may indicate the degree of filtering. A thin (narrow) black zero baseline may indicate the amount of filtering is minimal. The thicker the black zero baseline, the greater the degree of filtering and less low velocity flow will be demonstrated. By convention, the color blue is displayed for blood flow moving away from the transducer while red is used to demonstrate blood flow towards the transducer. Black indicates no Doppler shift detected or a change in the direction of blood flow.

The enhanced (hue) map uses shades of blue and shades of red which provides for the direction, mean velocity and character of blood flow. A mosaic of color suggests turbulent flow. The brighter the color, the higher the mean velocity. The color black indicates no Doppler shift detected or a reversal of blood flow direction. The variance map uses green folded onto an enhanced map to depict turbulent flow. The color green indicates turbulent flow when the variance map is on. The power Doppler map displays only the amplitude of the returning signal; and is **NOT** angle dependent.

Color flow Doppler has lower frame rates compared to two-dimensional imaging because of the requirement of the packet size be at least three for each line of color; two-dimensional imaging requires only one pulse per scan line. To improve the color flow Doppler frame rate reduce the field of view (e.g.; sector width), reduce the image depth, reduce scan line density and/or decrease the packet size. Color gain affects the amount of color flow displayed. Increasing the color gain until speckling occurs then reducing the color gain until the speckling is eliminated is how the appropriate color gain setting is chosen. The color velocity scale (PRF) controls the pulse repetition frequency which can influence the amount of color displayed. The color velocity scale acts as filter. Increasing the color velocity scale increases the pulse repetition frequency and reduces the amount of color flow displayed. The recommended color flow Doppler velocity scale range for echocardiography is 50 to 70 cm/sec. Decreasing the color flow velocity scale decreases the pulse repetition frequency which adds more color to the display and may be useful when evaluating low flow states such as pulmonary vein flow or hepatic vein flow.

Color flow Doppler aliases and is described as apparent flow reversal. Color flow Doppler will alias at lower velocities compared to PW Doppler because of lower pulse repetition frequencies.

Flash artifact is the application of color on moving tissue. Decreasing the color gain or increasing the color flow Doppler velocity may help reduce flash artifact.

Power Doppler is a color flow Doppler technique which displays the returning amplitude (strength) from the blood. Power Doppler does not provide information concerning the blood flow direction and velocity – only the amplitude of the returning signals. The advantages of power Doppler include that aliasing will not occur, it is independent of the Doppler incident angle and has a higher sensitivity of detecting low velocity flow.

A Sonographer's Summary

- The color flow Doppler velocity scale affects the pulse repetition frequency and acts as a filter. Increasing the color velocity scale increases the pulse repetition frequency and reduces the amount of color displayed. Decreasing the color flow Doppler velocity scale decreases the pulse repetition frequency and more color will be displayed. This is important to realize in echocardiography because severity of regurgitation (especially mitral regurgitation, tricuspid regurgitation) is determined by jet size (the amount of color displayed). The American Society of Echocardiography recommends that the color flow Doppler velocity scale be set between 50 to 70 cm/sec. This is depth dependent because pulse repetition frequency is dependent on depth.
- Changing the color flow velocity scale outside the recommended 50 to 70 cm/sec may be necessary in certain clinical situations. When examining potential low flow velocity (e.g.; patent foramen ovale (PFO), atrial septal defect, pulmonary vein flow, hepatic vein flow, superior vena cava flow) reducing the color flow velocity scale below the recommended setting will be required.
- The color flow Doppler velocity scale determines the amount of color flow Doppler displayed. Color flow Doppler gain also affects the amount of color displayed. Increase the color gain until color speckle appears on the screen and then reduce color gain until the speckle is eliminated is how to set the color gain at its appropriate level
- The frame rate when color flow Doppler is on is lower than when only scanning with two-dimensional (2-D) imaging. To preserve color flow Doppler frame rate (and improve temporal resolution), image at the shallowest image depth, use a narrow color flow Doppler field of view (sector width), decrease scan line density and/or reduce packet size.

- Turbulent flow is displayed as a mosaic with color flow Doppler on.
- Aliasing is common in color flow Doppler imaging, appears as apparent flow reversal and does not necessarily indicate a significant high mean velocity flow is present. The pulse repetition frequency with color flow Doppler on is low, the Nyquist limit is lower and aliasing will occur at a lower (mean) velocity. Aliasing may be useful especially when sampling with PW or CW Doppler because the aliasing area denotes where the highest mean velocity is located.
- As with conventional (PW, CW) Doppler, being parallel (0 degrees) to blood flow is critically important.
- Virtual beam sonography color flow Doppler frame rates are much higher than those in conventional sonography color flow Doppler.
- Virtual beam sonography allows for real-time triplex imaging (two-dimensional + PW Doppler + color flow Doppler).
- Virtual beam sonography allows for vector velocity flow imaging using arrows to demonstrate blood flow – the length of the arrow represents velocity; the arrow indicating the direction of blood flow.
- Virtual beam sonography eliminates the flash artifact color flow Doppler artifact.

Color Flow Doppler – Multiple Choice Questions

1. Which of the following is **INCORRECT** concerning color flow Doppler?
   A. CW Doppler technique
   B. Multigate
   C. Aliasing can occur
   D. Lower frame rates than two-dimensional imaging
   E. Depicts the mean velocity of blood flow
2. The rapid technique which converts Doppler shift information into color is:
   A. Fast Fourier Transform (FFT)
   B. Autocorrelation
   C. Time interval histogram
   D. TDI
3. The number of pulses transmitted to create one line of color flow Doppler (minimum of three pulses per scan line) is called:
   A. Sample volume
   B. Sample gate
   C. Packet size
   D. TDI
4. Which of the following is **INCORRECT** concerning how to increase the color flow Doppler frame rate reduce:
   A. Field of view (e.g.; sector width)
   B. Image depth
   C. Packet size
   D. Color gain
5. Which of the following would increase the amount of color flow Doppler displayed?
   A. Increase two-dimensional transmit gain

B. Reduce color flow Doppler gain
C. Decrease the color flow Doppler velocity scale
D. Increase the field of view width

6. **6.** Which color flow Doppler map uses green to depict turbulent flow?
    A. Intensity
    B. Directional
    C. Enhanced (hue)
    D. Variance
7. Which of the following acronyms is used to explain how the direction of blood flow is shown with color flow Doppler?
    A. ASH
    B. SAM
    C. BART
    D. IHSS
8. Which of the following is best to use when examining for the presence of low velocity blood flow?
    A. Transmit gain
    B. Power Doppler
    C. Increase the color flow Doppler velocity scale
    D. Change color flow Doppler maps
9. Which of the following provides for high color flow Doppler frame rates (in the hundreds), real-time triplex imaging, vector velocity imaging and minimizes color flow Doppler artifacts such as the flash artifact?
    A. Conventional sonography
    B. Virtual beam sonography

Color Flow Doppler Multiple Choice Questions Answers-Explanations

1. **A.** Color flow Doppler is a PW Doppler technique using hundreds of sample gates (sample volumes) along each scan line. CW Doppler is not a feasible color flow Doppler technique due to range ambiguity.
2. **B.** Autocorrelation is a rapid averaging technique and is much faster than Fast Fourier Transform (FFT). Since it is an averaging technique, a minimum of three samples must be acquired in order to depict the mean velocity (average velocity) of blood flow in color.
3. **C.** Packet size (e.g.; dwell time) is the number of pulses emitted to create one scan line of color flow Doppler. In order to determine a mean velocity, the minimum packet size is three pulses per scan line. This does not include the one pulse minimum for tissue information. Increasing the packet size improves the estimation of the mean velocity but reduces the frame rate.
4. **D.** Decreasing the color gain will allow the application of less color on the image display but would not affect frame rate.
5. **C.** The color flow velocity scale affects the color flow Doppler pulse repetition frequency and also acts as a color flow Doppler filter. Increasing the color flow velocity scale

increases the pulse repetition frequency and will reduce the amount of color flow displayed. Decreasing the color flow Doppler velocity scale will decrease the pulse repetition frequency and will result in more color flow Doppler displayed.

6. **D.** The intensity color flow Doppler map uses red and blue to depict blood flow direction and black as the color flow Doppler zero baseline. The enhanced (hue) color flow Doppler map uses shades of red and blue with black as the zero baseline. The variance map uses the enhanced map and "folds" the color green onto the enhanced map to aid in demonstrating turbulent flow. A mosaic of color with either the enhanced (hue) map or variance map on suggests the presence of turbulent flow.
7. **C.** By convention, red is used to demonstrate a positive Doppler shift meaning blood flow is moving towards the transducer. The color blue is used to demonstrate a negative Doppler shift meaning that blood flow is moving away from the transducer. A mosaic of colors may represent disturbed or turbulent flow. The color black is used to represent the color flow Doppler zero baseline, may indicate that no Doppler shift was detected and/or that there was a change in the direction of flow. The sonographer is able to invert the color map.
8. **B.** Power Doppler is a color flow Doppler technique which displays the amplitude (strength) of the returning Doppler shift signal. Blood flow velocity and direction information cannot be determined with color power Doppler on.
9. **B.** Virtual beam sonography has higher color flow Doppler frame rates because it does not use the pulse-echo operating system. Since virtual beam sonography is not tethered to the pulse-echo system, this allows time for real time presentation of two-dimensional imaging and Doppler (e.g; real time triplex imaging). Since each pixel is focused, color flow Doppler artifacts such as flash artifact is eliminated.

Ultrasound Imaging Artifacts

Axial resolution artifact occurs because the spatial pulse length which determines axial resolution has a finite length and structures may be too small (e.g.; small cardiac valve vegetation) to be detected. **Lateral resolution** artifact is similar to the axial resolution artifact. Lateral resolution is determined by sound beam width and reflectors lying perpendicular so the sound beam path may not be detected if the sound beam width is too wide to detect the reflectors as two separate reflectors. **Beam width artifact** makes a narrow reflector appear wider than the reflector actually is (e.g.; point-spreading). When acquiring PW or CW Doppler, the beam width may be wide enough to present flow from outside the region of sampling interest. **Slice thickness** (**partial-volume artifact**) artifact is similar to the axial resolution artifact and lateral resolution artifact. The sound beam is "thick" and images a section of tissue and places that tissue section onto a flat display screen. Reflectors within that volume of tissue may be placed in the wrong location or may even fill-in anechoic areas (e.g. mass in the left atrium when it is actually just slice thickness). **Acoustic speckle** is apparent tissue texture caused by scatter reflectors combining constructively or destructively which may result in an inaccurate presentation of organ parenchyma (e.g.; liver, kidney, spleen, thyroid). **Reverberation(s)** are multiple echoes, equally spaced often associated with structures close to the transducer (e.g.; chest wall) or highly reflective structures such as mechanical (metal) prosthetic heart valves. **Comet tail** is a type of reverberation associated with a highly reflective structure (e.g.; bullet, BB, prosthetic heart valve). The **ring down** artifact is similar in appearance to the comet tail artifact but originates from a gas bubble and may be longer in length. **Mirror image** is a type of reverberation artifact which results in the duplication of a strong reflector. The mirror image artifact may be seen with color flow Doppler on (e.g.; duplication of vessels with color flow displayed in the true vessel and the duplicated vessel – e.g.; duplication of the descending thoracic aorta (DTA) in the suprasternal long axis view). **Multipath** is a type of reverberation artifact involving two structures. The primary sound beam reflects off anatomy at an angle with a portion of that sound energy returning to the transducer – another portion of the sound energy strikes a second structure before returning to the transducer. The second reflection will be placed deeper than where the true reflector is located.

Shadowing is defined as low level amplitude echoes located behind a highly reflective (e.g.; highly attenuating) structure (e.g. calcific plaque, mitral annular calcification). **Refraction** may result in lateral displacement (duplication) of structures (e.g.; two left ventricles in the subcostal short axis of the left ventricle). **Edge shadowing** results from a decrease in reflected echoes due to refraction at rounded boundaries (e.g.; reduction in the amplitude of echoes of the antero-lateral wall of the left ventricle and the infero-septal wall in the parasternal short axis of the left ventricle).

Enhancement is the increase in the amplitude (strength) of reflections from structures located behind a low attenuating structure (e.g. fluid fill cyst). **Side lobes** are extraneous sound beams emanating from the primary sound beam of a single disc transducer. **Grating lobes** are extraneous sound beams originating from the primary sound beam and are associated with phased array transducers. Apodization and sub-dicing are processes the manufacturer uses to reduce grating lobes and side lobes.

Propagation speed error occurs when the medium sound is traveling through is not the assumed constant 1540 m/sec and will result in placement of reflectors at the wrong depth. **Range ambiguity** results from receiving echoes from a previous transmitted pulse. Only one pulse can travel in the body at one time. If a pulse is transmitted before the echoes from the previous pulse are received, those echoes from the previous pulse will be placed too close to the transducer. Pulse repetition frequency may be automatically reduced to avoid the range ambiguity artifact. The signal to noise ratio is important. Signal represents the meaningful part of the data. Noise is the inaccurate part of the data. A **low signal to noise** ratio is not considered a true ultrasound artifact but a low ratio indicates that there are too many extraneous echoes being displayed and do not represent a true, accurate depiction of the structure(‘s) being imaged.

Aliasing occurs with PW Doppler and color flow Doppler (described with color flow Doppler on as apparent flow reversal) when the Doppler exceeds the Nyquist limit. **Spectral mirroring** is the placement of Doppler spectral information (e.g.; PW Doppler, CW Doppler) on both sides of the zero baseline due to high Doppler gains or a Doppler incident angle close to 0 degrees. Color flow Doppler **flash artifact** is the application of color on moving tissue. The color black with color flow Doppler on may indicate an inappropriate Doppler incident angle (e.g.; 90-degree incident angle) or a change in the direction of blood flow.

A Sonographer’s Summary

- Recognizing ultrasound artifacts is important.

- For cardiac imaging realizing that structures such as vegetations, thrombus may be too small to be detected (axial and lateral resolution artifact) is important.
- The beam width artifact may result in structures appearing wider than the actual true width. Knowing where the transmit focus is can be useful as the beam width is narrowest at the focus.
- The beam width artifact may present two flows to be present when acquiring Doppler. The sonographer may be intending to sample the mitral valve at the leaflet tips in the apical four chamber view but the beam width may be wide enough to include flow across the left ventricular outflow tract. Changing the angulation (e.g.; tilting downward and moving the transducer more lateral) may avoid this dual presentation of flows in this example.
- Slice thickness artifact may result in an overcall (e.g.; a mass when no mass is present).
- Comet tail may be present when a prosthetic heart valve is being imaged. It is useful to look for this artifact when looking for a bullet.
- The most well-known propagation speed error is the Starr-Edwards ball and cage prosthetic heart valve where the silastic ball has a propagation speed much lower than 1540 m/sec which results in the ball being placed outside the cage.

- Prosthetic heart valves are highly reflective structures and may cause shadowing. The best example of this is when examining a mitral valve replacement (MVR) while using the apical views. The evaluation of mitral regurgitation is made very difficult because the soft tissue (e.g.; blood) – prosthetic heart valve acoustic impedance mismatch (difference) is significant. Most of the sound energy will be reflected at this interface meaning less sound energy to interrogate the left atrium for mitral prosthetic heart valve regurgitation. This is an example of shadowing (e.g; involves a highly reflective structure – the prosthetic heart valve – with reduced amplitude of echoes behind the highly reflective structure) and may be referred to as flow masking. Parasternal views (e.g.; parasternal long axis, parasternal short axis of the aortic valve to examine the left atrium, subcostal four chamber) or off-axis views may be useful. Transesophageal echocardiography (TEE) may be required.
- The placement of color on moving tissue (flash artifact) is challenging when attempting to evaluate shunt flow especially at the interatrial septal level. Reduce the color flow Doppler gain, increase the color flow Doppler wall filter and increase the Doppler velocity scale (but not too high a velocity scale setting) may be useful.
- Two imaging rules seem to apply for ultrasound artifacts: 1. Move the transducer; 2. Require two orthogonal planes before making a diagnosis while using ultrasound imaging.
- Virtual beam sonography significantly reduces the occurrence of ultrasound artifacts.

Ultrasound Artifacts Multiple Choice Questions

1. Two reflectors lie parallel to the sound beam path and are separated by less than one-half the spatial pulse length. This may result in the artifact called:
    A. Axial resolution
    B. Lateral resolution
    C. Slice thickness
    D. Propagation speed error
2. The sound beam width is too wide to detect reflectors perpendicular to the sound beam path. This artifact is called:
    A. Axial resolution
    B. Lateral resolution
    C. Slice thickness
    D. Contrast resolution
3. A patient is sent to the operating room for removal of left atrial myxoma which was reported to be present on a recent echocardiogram. At surgery, no myxoma was present. This could be due to the artifact called:
    A. Comet tail
    B. Ring down
    C. Shadowing
    D. Partial-volume
4. The artifact referred to as point spreading is caused by the artifact called:
    A. Acoustic speckle
    B. Beam width
    C. Propagation speed error
    D. Enhancement
5. Apparent tissue texture is:
    A. Shadowing
    B. Acoustic speckle
    C. Slice thickness artifact
    D. Propagation seed error
6. Multiple echoes, equally spaced usually located near the transducer are:
    A. Reverberations
    B. Comet tail
    C. Ring down
    D. Grating lobes
7. Multiple echoes, equally spaced caused by a highly reflective structure such as a bullet is:
    A. Reverberations
    B. Comet tail
    C. Ring down

D. Grating lobes

8. Multiple echoes, equally spaced due to a gas bubble is:

A. Reverberations
B. Comet tail
C. Ring down
D. Grating lobes

9. Extraneous sound beams originating from the primary sound beam which are associated with phased array transducers are:

A. Reverberations
B. Comet tail
C. Ring down
D. Grating lobes

10. The technique used to eliminate grating lobes is:

A. Subdicing
B. Autocorrelation
C. FFT
D. Polarization

11. The propagation speed of a medium is 1450 m/sec. The reflections will be placed too: _____ to the transducer.

A. Close
B. Far
C. Not affected
D. Cannot be predicted

12. The reduction in the amplitude of returning echoes due to a highly reflective structure is called:

A. Shadowing
B. Enhancement
C. Slice thickness
D. Propagation speed error

13. The increase in the amplitude of returning echoes due to an intervening weak reflective structure (e.g.; fluid filled cyst) is called:

A. Shadowing
B. Enhancement
C. Slice thickness
D. Propagation speed error

14. Which ultrasound artifact does **NOT** provide anatomical information?

A. Shadowing
B. Enhancement
C. Slice thickness
D. Ring down

15. Which of the following will produce a better-quality image?

A. Low transmit frequency
B. High signal to noise ratio
C. Longer spatial pulse length

D. Increasing the gain

16. The application of color on moving tissue while using color flow Doppler is called:

A. Reverberation
B. Enhancement
C. Flash artifact
D. Propagation speed error

17. Which of the following will have fewer ultrasound artifacts?

A. Virtual beam sonography
B. Conventional sonography

Ultrasound Imaging Artifacts Multiple Choice Questions Answers-Explanations

1. **A.** Axial resolution is equal to spatial pulse length (SPL) divided by 2. If two reflectors are positioned parallel to the sound beam path and spaced closer together than one-half the spatial pulse length, the reflectors will be seen as one reflector instead of two separate reflectors. This is due to the finite length of the pulse and is called the axial resolution artifact.
2. **B.** Lateral resolution is equal to the sound beam width (diameter). If two reflectors lie perpendicular to the sound beam path closer than the sound beam width, the two reflectors will be seen as one reflector. This is called the lateral resolution artifact.

3. **D.** The sound beam is thick and a volume of soft tissue is being imaged and placed on a flat display screen. Echoes may be placed in echo-free (anechoic) regions and those echoes represent the volume of tissue scanned. For example, there may appear to be a mass in the atrium but may actually represent the soft tissue volume being imaged at that depth. This would be an example of the slice thickness (partial-volume) artifact.
4. **B.** The physical characteristics of the sound beam are labeled near field-focus-focal region-far field. The sound beam width varies as the sound beam travels from the transducer. To create a two-dimensional frame, the ultrasound beam is swept through the soft tissue. Narrow (small) reflectors can be made to appear wider than they actually are (as wide as the sound beam that is interrogating the narrow reflector). This is referred to as the beam width artifact or point spreading artifact. Focusing helps minimize the beam width (point spreading) artifact. The beam width artifact may result in flows being presented during the Doppler examination outside the sonographer’s region of interest. The beam width (point spreading) artifact is non-existent with virtual beam sonography.
5. **B.** Acoustic speckle is described as apparent tissue texture. Scatter reflectors can appear as bright spots or dark spots in a gray scale image not representing the true nature of the reflectors being presented on the display. This is especially true when evaluating organ parenchyma.
6. **A.** Reverberations are multiple echoes, equally spaced and are often located near the ultrasound transducer because ultrasound energy becomes “trapped” between the ultrasound transducer and skin surface. Tissue harmonic imaging has reduced the occurrence of reverberations located close to the transducer.

7. **B.** When looking for a bullet in the body, a useful imaging artifact is the comet tail.
8. **C.** Ring down and comet tail are similar in appearance.
9. **D.** Grating lobes can produce horizontal type echoes across the display. Grating lobes are associated primarily with phased-array transducers. Apodization, subdicing and tissue harmonic imaging have reduced the occurrence of grating lobes.
10. **A.** Grating lobes are created by the "edges" of the piezoelectric elements and subdicing and apodization are used to eliminate the sound energy emanating from these edges which will reduce extraneous sound energy. Tissue harmonic imaging reduces the occurrence of grating lobes.
11. **B.** The ultrasound machine range equation assumes a sound average propagation speed of 1540 m/sec in soft tissue. If the propagation speed of a medium is lower than 1540 m/sec, the time it takes to go out and back through this medium will be longer and the machine will place the reflectors farther from the transducer than they are in reality.
12. **A.** Shadowing is an example of an attenuation artifact and is associated with highly attenuating reflective structures such as calcific plaque or prosthetic heart valves.
13. **B.** Enhancement is an example of an attenuation artifact and is associated with low attenuating structures such as fluid filled cysts.

14. **C.** Shadowing suggests a highly reflective structure such as calcific plaque or prosthetic heart valve. Enhancement suggests a low attenuating structure such as fluid (e.g.; fluid filled cyst). Ring down suggests the presence of air. Slice thickness (e.g; elevational resolution) is an inherent problem in the thickness of the ultrasound beam being produced by the ultrasound transducer.
15. **B.** A high signal to noise ratio is preferred. Increasing the gains (e.g.; transmit, gain, time gain compensation (TGC), lateral gain compensation (LGC) will not improve the signal to noise ratio because both the signal returned by the imaged structure(s) will be increased in amplitude but the noise will also be amplified.
16. **C.** The application of color on moving tissue is called flash artifact. Flash artifact can be reduced by reducing the color gain, increasing the color flow Doppler velocity scale, changing the color threshold or color flow Doppler wall filter.
17. **A.** Because the sound beam is created (virtual) in virtual beam sonography several ultrasound artifacts can be expected to be minimized including lateral resolution artifact, slice thickness (partial-volume) artifact, side lobes, grating lobes, reverberation and color flow Doppler flash artifact.

Elevational Resolution (Azimuthal) (Slice thickness)

Elevational resolution is the ability to resolve structures which lie perpendicular to the plane formed by the axial and lateral dimensions of the sound beam. It is determined by the thickness (e.g.; height) of the ultrasound sound beam. The sound beam samples a certain thickness (volume) of tissue and the returning echoes are placed on a flat display screen. Echoes from the sampled section may fill-in anechoic areas which may lead to misdiagnosis (e.g.; tumor in the atria when the echoes in the atria are due to the tissue outside the atria) (e.g.; partial-volume artifact). Focusing, (e.g. with an acoustic lens), tissue harmonic imaging and 1.5-D array transducers decrease sound beam thickness and improve elevational resolution.

A Sonographer's Summary

- The ultrasound sound beam has three dimensions- axial, lateral and elevational. When imaging anechoic structures such as cardiac chambers and vessels (e.g.; atria, ventricles, aorta, inferior vena cava), knowing that echoes outside these chambers can be placed in the anechoic areas is useful.
- Use two orthogonal views to confirm the presence of an echo and pertinent clinical information to avoid a diagnostic mistake.
- Virtual beam sonography reduces the occurrence of the slice thickness (e.g.; partial volume) artifact.

Elevational Resolution Multiple Choice Questions

1. Which resolution is dependent upon the ultrasound beam thickness?
   A. Axial
   B. Lateral
   C. Temporal
   D. Contrast
   E. Elevational

2. The artifact associated with poor elevational resolution is:
   A. Smearing
   B. Partial-volume
   C. Point spreading
   D. Aliasing

3. Which of the following may improve elevational resolution?
   A. 1.5-D array transducers
   B. Damping
   C. Increasing display dynamic range
   D. Decreasing scan line density

4. Which imaging system reduces the occurrence of the slice thickness (partial-volume) artifact?
   A. Conventional sonography
   B. Virtual beam sonography

Elevational Resolution Multiple Choice Questions Answers-Explanations

1. **E.** Elevational resolution is the ability to discern between two points perpendicular (e.g.; 90 degrees) to the sound beam's path. Elevational resolution is determined by the thickness (height) of the ultrasound beam.
2. **B.** Partial-volume artifact is the filling in of anechoic structures such as cysts, cardiac chambers. This fill-in may result in misdiagnosis.
3. **A.** 1.5-D array transducers, focusing with a curved lens reduce the sound beam thickness.
4. **B.** Virtual beam sonography is not a "physical" sound beam but is created by how the reflections are processed. The resultant virtual sound beam can be imagined as narrow, thin (which reduces the chance of the slice thickness (partial-volume) artifact and uniform with focusing for each pixel.

The Five Resolutions – A Review

Axial resolution is how close two structures may be **PARALLEL** to the sound beam path and still be resolved as two separate structures. Axial resolution is determined by spatial pulse length:

Axial resolution (mm) = Spatial pulse length (mm) ÷ 2

Axial resolution is improved by increasing transmit frequency (sonographer) and damping (manufacturer). Axial resolution is not affected by image depth. The shorter the spatial pulse length, the better the axial resolution.

Lateral resolution is how close two structures may be **PERPENDICULAR** to the sound beam path and still be resolved as two separate reflectors. Lateral resolution is determined by the sound beam width (diameter).

Lateral resolution (mm) = Sound beam width (mm)

Increasing transmit frequency, tissue harmonic imaging, focusing, increasing line density improve lateral resolution. Lateral resolution changes with depth because the sound beam width changes with image depth. The narrower the sound beam, the better the lateral resolution. Lateral resolution is significantly improved by virtual beam sonography.

Temporal resolution is the ability to resolve fast moving structures accurately. Temporal resolution is determined by frame rate.

Temporal resolution = Frame rate (Hz)

The frame rate may be increased by decreasing image depth, decreasing the field of view (e.g.; sector width), decreasing the number of transmit focuses, decreasing scan line density. The higher the frame rate, the better the temporal resolution. Virtual beam sonography significantly improves temporal resolution with the ability to create frame rates 1000 Hz (or greater).

Contrast resolution is the ability to distinguish between different echo amplitudes. Contrast resolution is determined by the number gray shades displayed.

Contrast resolution (dB) = Gray shades displayed

Contrast resolution may be improved by tissue harmonic imaging, altering the display dynamic range and using the appropriate gain settings. Virtual beam sonography improves contrast resolution by eliminating clutter, reverberations, side lobes, grating lobes, noise, haze).

Elevational resolution is the ability to resolve structures within an axis perpendicular to the plane formed by the axial and lateral dimensions. Elevational resolution is determined by the thickness of the ultrasound sound beam.

Elevational resolution (mm) = Sound beam thickness (mm)

Elevational resolution is improved by tissue harmonic imaging, focusing with an acoustic lens and 1.5-D array transducers. Virtual beam sonography significantly improves elevational resolution because the virtual sound beam created can be thought of as narrow, thin, uniform, laser-like.

A Sonographer's Summary

- High quality diagnostic imaging is the goal. Knowing the basics of the five imaging resolutions is important.

Resolution Review Multiple Choice Questions

1. How close two structure may **PARALLEL** to the sound beam path and still be resolved as two separate structures is: ______ resolution.
   A. Axial
   B. Lateral
   C. Temporal
   D. Contrast
   E. Elevational
2. How close two structures may be **PERPENDICULAR** to the sound beam path and still be resolved as two separate structures is called: ______ resolution.
   A. Axial
   B. Lateral
   C. Temporal
   D. Contrast
   E. Elevational
3. The ability to resolve fast moving structures accurately is: __________ resolution.
   A. Axial
   B. Lateral
   C. Temporal
   D. Contrast
   E. Elevational
4. The ability to distinguish between different echo amplitudes of adjacent structures is: ____ resolution.
   A. Axial
   B. Lateral
   C. Temporal
   D. Contrast
   E. Elevational

5. The ability to resolve structures within an axis perpendicular to the plane formed by the axial and lateral dimensions is: _______ resolution.

A. Axial
B. Lateral
C. Temporal
D. Contrast
E. Elevational

6. Which two ways may axial resolution be improved?

A. Focusing; Increasing transmit frequency
B. Increase transmit frequency; Damp
C. Decrease sector width; Decrease image depth
D. External focusing; 1.5-D array transducer

7. Which of the following would **NOT** improve lateral resolution?

A. Decrease sector width
B. Increase transmit frequency
C. Transmit focus
D. Increase scan line density

8. Which of the following would **NOT** improve temporal resolution? Decrease:

A. Image depth
B. Field of view (sector width)
C. Scan line density
D. Transmit frequency

9. Which of the following would **NOT** improve contrast resolution?

A. Tissue harmonic imaging
B. Increasing transmit gain
C. Altering the display dynamic range
D. Altering the post-processing curves

10. Which of the following would **NOT** improve elevational resolution?

A. Focusing
B. 1.5-D array transducer
C. Decreasing image depth
D. Tissue harmonic imaging

11. Which imaging system have the best lateral, temporal, contrast and elevational resolution?

A. Virtual sonography
B. Conventional sonography

Resolution Review Multiple Choice Questions Answers/Explanations

1. **A.** Axial resolution may be improved by decreasing spatial pulse length by increasing transmit frequency (sonographer) and damping (manufacturer). Axial resolution is not by affected by image depth.
2. **B.** Lateral resolution is improved by decreasing sound beam width by increasing transmit frequency, tissue harmonic imaging, focusing and increasing line density. Lateral resolution is affected by image depth because the sound beam changes in width as it travels from the ultrasound transducer. Virtual beam sonography improves lateral resolution because the “virtual beam” is narrower (laser-like).
3. **C.** Temporal resolution is determined by frame rate. Decreasing image depth, decreasing field of view (sector width), decreasing the number of transmit focuses and decreasing line density increase the frame rate and improve temporal resolution. Virtual beam sonography improves temporal resolution because it is not dependent on the time required for conventional sonography to produce a frame.
4. **D.** Contrast resolution is determined by the number of gray shades displayed. Using tissue harmonic imaging, altering the display dynamic range and using the instrument controls such as transmit gain, gain, time gain compensation, lateral gain compensation can determine contrast resolution. Virtual beam sonography improves contrast resolution because there are less imaging artifacts such as clutter, reverberations, side lobes, grating lobes, noise, haze.
5. **E.** Elevational resolution is determined by the thickness of the ultrasound beam. Tissue harmonic imaging, focusing with an acoustic lens and matrix transducers improve elevational resolution. Virtual beam sonography eliminates the slice thickness (partial volume) artifact because the virtual beam is “thinner”.
6. **B.** To improve axial resolution - decrease the spatial pulse length: – 1. Increase the transmit frequency (sonographer); 2. Damp (manufacturer)
7. **A.** To improve lateral resolution - decrease the sound beam width: 1. Increase transmit frequency; 2. Use tissue harmonic imaging; 3. Focus (including increasing the number of transmit focuses); 4. Increase scan line density.
8. **D.** To improve temporal resolution – increase the frame rate: 1. Decrease image depth; 2. Decrease the field of view (sector width); 3. Decrease the number of focuses; 4. Decrease scan line density.
9. **B.** To improve contrast resolution – alter the gray scale: 1. Use the appropriate gain settings (e.g.; transmit gain, gain, time gain compensation, lateral gain compensation; display dynamic range), 2. Use tissue harmonic imaging; 3. Alter the post-processing curve choice.
10. **C.** To improve elevational resolution – produce a “thinner” sound beam: 1. Increase transmit frequency; 2. Use tissue harmonic imaging; 3. Focus; 4. Use 1.5-D array transducers.
11. **A.** Because the sound beam is created (e.g.; virtual), the characteristic physical sound beam’s disadvantages are eliminated which will result in improved lateral, temporal,

contrast and elevational resolutions. The virtual (created) sound beam is narrower (better lateral resolution), thinner (better elevational resolution), presents images without clutter, reverberations, side lobes, grating lobes, noise, haze (better contrast resolution), higher frame rates created (better temporal resolution).

Quality Assurance (QA)

The purpose of the quality assurance program in medical ultrasound is to ensure that the equipment and clinical practices are safe, and the information obtained from a clinical ultrasound imaging procedure is accurate. The individuals involved in a quality assurance program include the sonographer, physician, bioengineer and manufacturer. Quality assurance is primarily composed of three factors: 1. Routine preventative maintenance; 2. Routine performance tests and 3. Acceptance testing. Preventative maintenance (PM) should be performed on a routine, regular basis.

Sonographer responsibilities for quality assurance (QA) include:

- Check transducer cables for damage, cracks, separations, discolorations
- Visually check for vertical shadows and streaks caused by dead elements of a transducer
- Clean gel from transducer and ultrasound machine
- Clean and check display monitor for damage-cracks
- Check for damage to power cords or PACS connections
- Identify and report improper operations of switches or knobs
- Clean rooms for dust, dirt and infection control
- Clean dust from console air filters
- Check machine for dents and other damage
- Thoroughly clean the ultrasound machine console and other equipment in the scan room

Devices which may be used for performance testing include the tissue equivalent test object (TETO) (most common) which mimics the characteristics of soft tissue, spatial resolution phantoms, contrast resolution phantoms, training phantoms and flow phantoms which can mimic blood flow in soft tissue. The tissue equivalent test object (TETO) may be used to evaluate spatial (axial, lateral) resolution, range (depth) accuracy, horizontal accuracy, lesion detection, slice thickness. Flow phantoms may evaluate the accuracy of Doppler spectral waveforms (e.g.; velocities, spectral broadening) and color flow Doppler parameters.
The manufacturer provides valuable quality assurance (QA) information and should be consulted when organizing a quality assurance (QA) program.

A Sonographer's Summary

- The sonographer plays an important role in quality assurance on a daily basis. Understanding and knowing the responsibilities of the sonographer and all others involved in quality assurance is useful.

Quality Assurance – Multiple Choice Questions

1. How often should quality assurance (QA) be performed in the ultrasound laboratory?
    A. Daily
    B. Weekly
    C. Monthly
    D. According to the recommendations of the manufacturer
2. Who is responsible for routine preventative maintenance such as cleaning the ultrasound equipment filters?
    A. Physician
    B. Sonographer
    C. Manufacturer representative
    D. Laboratory supervisor
3. Which of the following may be used to test the ultrasound equipment's spatial resolution, depth and horizontal accuracy and slice thickness?
    A. Hydrophone
    B. Tissue equivalent test object (TETO)
    C. AIUM 100 mm test object
    D. Oscilloscope

Quality Assurance Multiple Choice Questions Answers-Explanations

1. **D.** There are three components to a quality assurance program – 1. Preventative maintenance; 2. Performance testing and 3. Acceptance testing. Each component will have a schedule which may be daily, monthly, yearly. The manufacturer provides invaluable information concerning quality assurance and should be consulted prior on deciding how and how often certain tasks ensuring quality assurance should be performed.
2. **B.** The sonographer is responsible for cleaning the ultrasound machine surfaces, cleaning exhaust fans and filters, assessing cable and transducer integrity and providing low level disinfection by using an approved germicide. High level disinfection of a transesophageal (TEE) probe requires the probe (but not the entire TEE device) to be immersed in a disinfecting solution. Sterilization of a device is required (referred to as "critical") when the device penetrates the skin or mucous membrane and the manufacturer's
Recommendations should be reviewed by the sonographer. Autoclaving cannot be used to sterilize an ultrasound transducer.
3. **B.** The tissue equivalent test object (TETO) is a plastic box which contains a mixture of gelatin, wires, cystic/solid cysts material and graphite powder in order to mimic the acoustic characteristics of soft tissue. The TETO may be used to test the ultrasound machines spatial (axial, lateral) resolution, contrast resolution, slice thickness, penetration (sensitivity), range (horizontal, depth) accuracy and measurement accuracy.

Bioeffects

There are three primary mechanisms for bioeffects: 1. Cavitation (stable, transient); 2. Thermal and 3. Direct mechanical. The sonographer may reduce the risk of bioeffects by adhering to ALARA (**A**s **L**ow **A**s **R**easonably **A**chievable). ALARA is comprised of prudent use (e.g.; use ultrasound only when clinically indicated), minimize exposure intensity by reducing transmit gain and emphasizing instrument controls which reduce the ultrasound "dose" such as transmit frequency, gain, time gain compensation (TGC), lateral gain compensation (LGC) and display dynamic range and minimizing exposure time by reducing scan time. In addition, the sonographer should have a general idea of the intensity values for each scanning modality.

There are two types of cavitation: 1. Stable cavitation which is the expansion and contraction of a gas bubble which may result in microstreaming. 2. Transient cavitation which is the implosion of a gas bubble. In general, transient cavitation is considered more harmful than stable cavitation. The mechanical index (MI) is used as an indicator for the potential for cavitation to occur. The mechanical index (MI) is equal to the peak rarefactional pressure divided by the square root of the center frequency of the pulse bandwidth. The mechanical index (MI) is posted on the ultrasound machine's display monitor. The mechanical index (MI) can be affected by the sonographer when using transmit gain. The FDA (Food and Drug Administration) requires a maximum mechanical index (MI) of ≤ 1.9. The mechanical index (MI) should be kept as low as possible. A mechanical index (MI) of 1 does not indicate that cavitation is occurring but should indicate to the sonographer to institute the ALARA principle. A low mechanical index (MI) setting (e.g.; MI of 0.15 to 0.3) should be used when acquiring a transpulmonary contrast exam to avoid destruction of the contrast gas bubble.

Due to absorption, most of the sound energy delivered to the patient is converted into heat. Increase in temperature especially coupled with an increase in time may result in thermal bioeffects.

The thermal index (TI) is defined as the transducer acoustic power divided by the estimated power to raise tissue temperature 1 degree Centigrade (C). The estimated power calculation for thermal index involves frequency, aperture and intensity. The thermal index - soft tissue (TIS) is the indicator which may be found on the ultrasound machine's image display and refers to the sound beam traveling through soft tissue and does not encounter bone. The other thermal measurements are: Thermal Index Bone (TIB) (bone significantly absorbs sound energy) and Thermal Index Cranial (TIC).

If the thermal index (TI) or the mechanical index (MI) exceeds 1, then the sonographer should consider using the ALARA principle – reduce transmit gain, reduce scan time.

The bioeffect danger of using a cracked transducer is electrical shock.

A hydrophone has a small piezoelectric element attached to a narrow tube and may be used to measure several parameters including amplitude, power and intensity.

Important Bioeffect Numbers/Terms

- The Food and Drug Administration (FDA) overall intensity upper limit for clinical imaging ultrasound is **720 mW/cm² SPTA.**
- The Food and Drug Administration (FDA) maximum value for the **mechanical index (MI) is ≤1.9** and must be displayed on the ultrasound machine's image display.
- The Food and Drug Administration (FDA) maximum value for thermal index **– soft tissue (TIS) is 6.**
- For exposure times up to 50 hours, there have been no significant, adverse biological effects observed due to temperature increases **≤ 2 degrees Centigrade.**
- Fetal exposure time should be limited when the **thermal index exceeds 1.**
- There have been no confirmed bioeffects for focused sound beams less **than 1 W/cm² SPTA** and non-focused sound beams less than **100 mW/cm² SPTA.**

  Harmful effects in the fetus have been demonstrated for temperature increases greater than **39 degrees Centigrade (C).**

  The Food and Drug Administration (FDA) 510(k) guide for SPTA intensity upper limits
  Trans-ophthalmic: 17 mW/cm² SPTA
  Fetal imaging: 94 mW/cm² SPTA
  Small parts: 94 mW/cm² SPTA
  Pediatric echo: 94 mW/cm² SPTA
  Adult echo: 430 mW/cm² SPTA
  Vascular: 720 mW/cm² SPTA

Typical Acoustic Outputs:

- B-mode: 19 mW/cm² SPTA
- M-mode: 73 mW/cm² SPTA
- Color flow Doppler: 234 mW/cm² SPTA
- Pulsed Doppler: 1140 mW/cm² SPTA

A Sonographer's Summary

- Ultrasound has proven to be safe and there have been no known reports of bioeffects. The key phrase is "no known" – the knowing (discovering) the unknown may be important.
- The sonographer should adhere to ALARA – prudent use (e.g.; scanning for knowing the gender is not prudent use) - minimize transmit gain – and reduce scan time.
- Knowing the intensity values for the imaging modalities can be useful – scanning modalities such as B-mode (two dimensional) have lower output intensities than non-scanning modalities (e.g.; PW Doppler) with color flow Doppler and M-mode in between the two.
- PW Doppler has the highest intensity value and should be limited in use especially when acquiring a fetal ultrasound exam.

Bioeffects – Multiple Choice Questions

1. The best way to reduce the risk of bioeffects is:
    A. Increase transmit gain
    B. Decrease scan time
    C. Use unfocused transducers only
    D. Scan at the maximum mechanical index (MI)
2. Which gain is governed by the ALARA principle?
    A. Transmit gain
    B. Gain
    C. Receiver gain
    D. Overall gain
    E. Time gain compensation (TGC)
3. The expansion and contraction of a gas bubble which may result in microstreaming is:
    A. Stable cavitation
    B. Unstable cavitation
    C. Transient cavitation
    D. Direct mechanical
4. The implosion of a gas bubble with a significant release of energy which may result in significant tissue damage is:
    A. Direct mechanical
    B. Stable cavitation
    C. Transient cavitation
    D. Unstable cavitation
5. There is swirling of transpulmonary contrast at the apex of the left ventricle. Which of the following would be **LEAST** useful to eliminate the swirling?
    A. Move the transducer focus
    B. Alter the MI
    C. Inject more contrast
    D. Alter the LGC
6. The risk of using a cracked transducer is:
    A. Lower frame rates
    B. Electrical shock
    C. Higher MI
    D. Increase in TIC
7. Which of the following imaging modalities is associated with the highest acoustical output?
    A. B-Mode
    B. M-mode
    C. PW Doppler

D. Color flow Doppler

Bioeffects Multiple Choice Questions Answers-Explanations

1. **B.** Reducing the scan time reduces the "ultrasound dose" delivered to the patient.
2. **A.** ALARA (**A**s **L**ow **A**s **R**easonably **A**chievable) is the acronym which guides the sonographer in limiting the ultrasound "dose".
3. **A.** Stable cavitation is the expansion and contraction of a gas bubble and is associated with microstreaming.
4. **C.** Transient cavitation is the implosion of a gas bubble and may be present when transpulmonary contrast is introduced into the heart's cavities. If the mechanical index (MI) is too high, the transpulmonary contrast may implode.
5. **D.** Swirling implies that there is not enough transpulmonary contrast present. Altering the lateral gain compensation would be least useful in creating the appearance of more transpulmonary contrast.
6. **B.** Using a cracked transducer with a water-based ultrasound gel could lead to electrical shock.
7. **C.** PW Doppler should be used with caution during a fetal ultrasound examination. In general, modalities which sweep the sound beam (e.g.; B-mode) have lower acoustical output than modalities which have increased dwell times such as PW Doppler.

Conventional Sonography and Virtual Beam Sonography

Conventional Sonography (pulse-echo; traditional, principle 1)

Conventional sonography has been in use for nearly 50 years. It is based on the pulse-echo principle. The pulse-echo principle can be described as the ultrasound image is acquired by transmitting an ultrasound pulse of a few cycles of sound down a line of sight, reflected back to the source (ultrasound transducer), converted into an electrical signal and the one scan line is created. To build one frame, this is repeated by sweeping the ultrasound beam through the soft tissue to create a number of scan lines to create a frame (e.g.; 100 to 150 scan line sin one frame). The sound beam can be described as a "physical" sound beam that is transmitted down each scan line and has certain characteristics – near field zone, focus, focal region and far field with lateral resolution determined by these sound beam characteristics. (e.g. lateral resolution is best at the focus because the beam width is narrowest and poorest close to the transducer and in the far field because the sound beam is wide.) The sound beam also has a certain thickness (elevational resolution, slice thickness) which images a core sample of soft tissue and displays this core sample on a flat display screen. The conventional sonography pulse-echo principle takes time with the deeper the imaging depth, the longer it takes to create one frame. If multiple transmit focuses are added, even more time is required to create one frame because each transmit focus requires one pulse. Conventional sonography is limited by this time requirement and so temporal resolution must be compromised. Temporal resolution is determined by the frame rate and the deeper the image depth, the lower the frame rate and the poorer the temporal resolution. The conventional sonography pulse-echo system's spatial resolution (axial, lateral) is determined by transmit frequency – the higher the transmit frequency – the better the spatial (axial, lateral) resolution. But higher transmit frequency sound waves have higher attenuation rates than lower transmit frequency meaning the sonographer's primary decision on each patient is dictated by the image depth needed to acquire the information from the structure(s) the ultrasound examination is being requested to interrogate. This presents the sonographer of the difficult choice: depth of penetration vs resolution. Finally, the sound beams used in conventional sonography have the potential of creating certain ultrasound artifacts such as reverberation, beam width artifacts, clutter, side lobes, grating lobes, slice thickness artifact and electronic noise.

Challenges of Conventional (Pulse-Echo) Sonography

- Lateral resolution (limited by the sound beam characteristics – near field-focus-focal region-far field)
- Temporal resolution (limited in creating high frame rates due to required image depth and number of transmit focuses in use)
- Elevational resolution (limited by the fact the sound beam has a certain thickness)
- Ultrasound artifacts (reverberation, beam width artifacts, clutter, noise, side lobes, grating lobes)
- Extended learning curve (multiple instrument controls must be coordinated to create high quality diagnostic images)

Virtual Beam Sonography (Synthetic aperture ultrasound; Synthetic aperture method; **Principle 2)**

The principles of virtual sonography are new and proprietary. A multi-array transducer is in use and a small number of elements are used to transmit an unfocused or weakly focused ultrasound pulse and all of the transducer array elements receive the returning signals. This transmit-reception is repeated several times (but not as often as conventional sonography's pulse repetition frequency (PRF)). Hundreds of pulses similar to conventional sonography are not required because the unfocused or weakly focused sound beam will fan out to cover the structures needed to be interrogated (similar to radar). The location of the low-resolution reflections returning back to the transducer can be determined by the geometric distance from the transmitting element to the imaging point and the propagation speed of the sound in soft tissue. This is done for every point being imaged and by combining the low resolution images, full dynamic focusing can be performed for each point (pixel) in the image. Since all points (pixels) will be dynamically (individually) focused means that the highest possible resolution will be achieved for each pixel. Each pixel is synthetically focused. This requires significant computer processing which can be achieved by current graphics processing units (GPU – Sony's reference to the Play-Station console) using parallel processing techniques which can perform 500 billion calculations per second.

Lateral resolution is improved markedly because there is no longer a dependence on the physical characteristics of the transmitted sound beam (physical beam) – near field-focus-focal region-far field. Instead, a virtual sound beam is created which has the characteristics of a narrow, thin, uniform laser beam. The dependence on transmit focus is eliminated which means the image is uniform throughout the display and frame rates can be increased because there is no need for multiple focuses. Contrast resolution is improved because clutter, reverberation, side lobes, grating lobes, noise, haze are no longer a factor. Elevational resolution is improved because the slice thickness (partial-volume artifact) is diminished because the virtual sound beam is used instead of the "thick" transmitted sound beam. Temporal resolution is improved because frame rates are no longer tied to the number of pulses-scan lines produced. Depth of penetration is better because the amplitude in each pixel is maximized. Sensitivity (the ability to detect weak amplitude signals) is improved for the same reason the depth of penetration is improved. Virtual sonography allows for simultaneous triplex Doppler (B-mode imaging + PW/CW Doppler imaging + Color flow Doppler) sonography which improves the real-time presentation of information. Real-time color flow Doppler vector velocity imaging which shows the blood flow direction (arrow direction) and velocity (length of arrow) with arrows is made possible. Retrospective PW Doppler sampling is available with the possibility of sampling multiple sites simultaneously. The color flow Doppler frame rate is increased into the hundreds versus conventional sonography's much lower color flow Doppler frame rates. Flash artifact is eliminated.

The primary point to begin to understand the differences between conventional sonography and virtual beam sonography is that with conventional sonographer the sound beam is "real". The sound beam transmitted in conventional sonography has certain real – physical characteristics (near filed-focus-focal point-focal region-far zone) which implies several inherent challenges. In virtual beam sonographer, there is no real-physical ultrasound beam being transmitted – it is created retrospectively – with powerful processing creating a scan line without the challenges the physical sound beam presents.

Simply stated: Conventional sonography uses a "physical" sound beam – Virtual beam sonography uses a created sound beam.

Advantages of Virtual Beam Sonography

Improved lateral resolution ("laser beam" presentation versus conventional sonography's hourglass (e.g.; near field-focus-focal region-far field) sound beam)

The sound beam width artifact is minimized

Improved temporal resolution (frame rates > 1000 versus conventional sonography's standard of 60 Hz)

Improved contrast resolution (clutter, reverberation, side lobes, grating lobes, noise, haze eliminated)

Improved elevational resolution (slice thickness (partial volume artifact) is eliminated due to the thin laser beam (virtual sound beam) of virtual beam sonography

Better depth of penetration (each reflection's (pixel) amplitude is maximized) which means the sonographer challenge of transmit frequency with better spatial (axial, lateral) versus depth of penetration points towards better spatial (axial, lateral) resolution with virtual beam sonography

Doppler imaging improves - virtual beam sonography allows for real-time triplex imaging

Color flow Doppler frame rates are increased significantly

Color flow Doppler vector velocity imaging is made practical

Ultrasound artifacts are minimized (e.g.; clutter, reverberations, beam width artifact, side lobes, grating lobes, noise, haze, partial-volume artifact, flash artifact)

Three-dimensional (3-D) and 4 dimensional (4-D) is improved due to the increase in computing power

The learning curve may be reduced because less dependence on the sonographer balancing all of the available instrument controls (e.g.; image depth, transmit gain, gain, time gain compensation, lateral gain compensation, display dynamic range, write zoom, B-color) due to the increased “automation” of virtual beam sonography

A Sonographer’s Summary

- Knowing that there are now two separate operating principles 1. Conventional sonography (Pulse-echo; Traditional; Principle 1) and 2. Virtual beam sonography (Synthetic aperture ultrasound; Synthetic aperture method; Principle 2) available for clinical imaging is important because there are significant fundamental differences between the two.
- Understanding the advantages of virtual beam sonography compared to conventional sonography will change the way the sonographer acquires and reviews ultrasound examinations.
- The student sonographer will be required to learn both conventional sonography and virtual beam sonography.
- It is important to realize that there is no physical ultrasound beam in the form of an hourglass (e.g.; near field-focus-focal region-far field) being transmitted in virtual beam sonography as there is in conventional sonography – understanding this point is critical for understanding the differences between conventional sonography and virtual beam sonography.
- The physical transmitted sound beam of conventional sonography has been replaced with a virtual sound beam which gives virtual beam sonography advantages which include significant improved resolutions (e.g.; lateral, temporal, contrast, elevational), better depth of penetration, reduced ultrasound artifacts, real-time triplex imaging and color flow vector velocity imaging.

Conventional Sonography-Virtual Beam Sonography Multiple Choice Questions

1. Which of the following transmits an ultrasound pulse down one scan line at a time, waits for the returning reflections from that one scan line and processes and displays the reflected information from that scan line and then repeats the process 100 to 150 times to create one ultrasound frame?
    A. Conventional sonography
    B. Virtual beam sonography
2. Which of the following transmits a few unfocused or weakly focused ultrasound pulses detects the returning reflections and then processes and displays the returning echoes using powerful computing?
    A. Virtual beam sonography
    B. Conventional sonography
3. Which of the following transmits a physical sound beam with a near field, focus, focal region and far field?
    A. Conventional sonography

B. Virtual beam sonography

4. Which of the following uses a virtual sound beam?
   A. Virtual beam sonography
   B. Conventional sonography

5. Which of the following has the better lateral resolution, temporal resolution, contrast resolution and elevational resolution?
   A. Virtual beam sonography
   B. Conventional sonography
6. Which of the following imaging systems has better depth of penetration?
   A. Conventional sonography
   B. Virtual beam sonography
7. Which of the following imaging systems has the least ultrasound artifacts?
   A. Virtual beam sonography
   B. Conventional sonography
8. Which of the following imaging systems has real-time triplex imaging?
   A. Conventional sonography
   B. Virtual beam sonography
9. Which imaging system provides for color flow vector velocity imaging?
   A. Virtual beam sonography
   B. Conventional sonography
10. Which of the following imaging system will change how the sonographer learns, interacts with the ultrasound machine and how the national board examiners present their tests?
    A. Conventional sonography
    B. Virtual beam sonography

Conventional Sonography-Virtual Beam Sonography Multiple Choice Questions Answers-**Explanations**

1. **A.** Conventional sonography transmits a physical ultrasound pulse with certain sound beam characteristics (e.g.; near field-focus-focal region-far field). Conventional sonography requires time to acquire one ultrasound frame because to build one frame requires 100 to 150 scan lines one scan line at a time.
2. **A.** In virtual beam sonography there is no actual physical sound beam with the characteristics of a conventional sonography sound beam. A few unfocused or weakly focused ultrasound pulses are transmitted, received and processed. The result of this is a display created by the image processor that is that of a virtual sound beam not a physical one.
3. **A.** Conventional sonography transmits a sound beam with specific characteristic one scan line at a time.
4. **A.** Virtual beam sonography processes the returning information to create an image not from a physical sound beam but one that is computed to provide a laser-like display.
5. **A.** Lateral resolution is improved because there is no dependence on the physical hour-glass shaped ultrasound beam. The virtual sound beam can be thought as being created to be narrow (laser-like), thin, uniform, consistent throughout the image depth. Temporal

resolution is improved because much higher frame rates (>1000 Hz) are possible because virtual beam sonography is not required to build frame one scan line a time. Contrast resolution is improved because clutter, reverberation, side lobes, grating lobes, noise, haze are eliminated. Elevational resolution is better because the virtual sound beam is created to be thin and uniform – no slice thickness (partial-volume artifact). The beam width artifact is minimized. Axial resolution in both conventional sonography and virtual beam sonography are similar as short pulses of ultrasound are required for both systems.

6. **B.** Virtual beam sonography is able to provide for better depth of penetration because each pixel in the display is focused and amplified.
7. **A.** Virtual beam sonography has less ultrasound artifacts because the virtual beam creates a laser-like quality without the side lobes and grating lobes, width and thickness a conventional sonography physical ultrasound beam has.
8. **B.** Virtual beam sonography is able to provide real-time triplex imaging because time is not a factor as compared to conventional sonography.
9. **A.** Virtual beam sonography presents color flow Doppler information using velocity vector imaging because time is not a factor.
10. **B.** Virtual beam sonography presents a challenge to instructors – a new complex modality with much of the information proprietary will require instructors to search for new resources of information. Current student sonographers will need to learn two entirely different imaging systems. Board examiners will need to begin to plan how to change testing in order that the fundamentals of both conventional sonography and virtual beam sonography are tested.

A Sonographer's Summary of the WASHVU Ultrasound Physics and Instrumentation Course

TOP 5

1. Image using the highest transmit frequency that the structure(s) of interest (e.g.; adult heart) will allow (preferably with tissue harmonics imaging on).
2. "Fill-up" the display. Image at the shallowest image depth with the narrowest sector with the minimum amount of transmit focuses and decrease scan line density when indicated.
3. "Blood's black". Anechoic areas should essentially be echo-free. This requires the appropriate use of transmit gain, gain, time gain compensation (TGC), lateral gain compensation (LGC), post-processing curves, display dynamic range and transmit focus.
4. Be parallel (0 degrees) to blood flow when acquiring cardiac Doppler examinations (e.g.; PW, CW, TDI, Color flow) and 90 degrees (perpendicular) when imaging the heart's specular reflectors. "0 for Doppler"; "90 for imaging".
5. Use two orthogonal views when in doubt.

Top 5 Multiple Choice Questions

1. To maximize spatial (axial, lateral) resolution choose (the):
    A. Highest transmit frequency
    B. Deepest image depth

C. Transmit gain
D. Display dynamic range

2. To maximize temporal resolution, which of the following would **NOT** be useful? Decrease:
   A. Transmit frequency
   B. Image depth
   C. Field of view (sector width)
   D. Number of focuses
   E. Scan line density
3. Which of the following will help choose the correct gain settings and display dynamic range?
   A. BART
   B. "Blood's black"
   C. TDI
   D. SPTP
4. The preferred Doppler incident angle which will maximize the magnitude of the Doppler shift (and peak velocity) is ____ degrees and the preferred incident angle for imaging specular reflectors is: _____ degrees.
   A. 90; 0
   B. 60; 90
   C. 20; 1
   D. 0; 90
5. Ultrasound artifacts first require:
   A. Intracardiac ultrasound
   B. Three-dimensional (3-D) examination
   C. Transesophageal (TEE) echocardiogram
   D. Two orthogonal views

TOP 5 Multiple Choice Questions Answers-Explanations

1. **A.** To improve spatial (axial, resolution) choose the appropriate highest transmit frequency for the structures to be imaged with tissue harmonic imaging on.
2. **A.** Temporal resolution is important in adult echocardiography – "Fill-up" the display. Image at the shallowest depth with the narrowest field of view, reduce the number of focuses and decrease scan line density. (Note: Decreasing scan line density may degrade lateral resolution).
3. **B.** Cardiac chambers filled with blood should be relatively anechoic. At most, light background echoes is acceptable. An over-gained image is rarely diagnostic. Using the correct amount of transmit gain, gain, time gain compensation (TGC), lateral gain compensation (LGC), post-processing curves, display dynamic range and transmit focus is a challenge. Review the brightness and contrast settings of the display monitor (e.g.; ultrasound machine and the display monitor used by the interpreter).
4. **D.** Echocardiography uses the peak velocity to classify the severity of disease. For example, the peak velocity of the tricuspid regurgitation jet allows calculation of the right ventricular systolic pressure (RVSP) and systolic pulmonary artery pressure (SPAP) which allows for the evaluation of the severity of pulmonary hypertension. Being parallel to flow

is important because it maximizes the Doppler shift (peak velocity). If not parallel to flow, the peak velocity will be underestimated and the severity of the disease (such as in the example of pulmonary hypertension) will be underestimated. The heart walls, cardiac valves and vessels (e.g.; aorta, main pulmonary artery, inferior vena cava) are specular reflectors and a 90-degree (perpendicular) angle of incidence is preferred. “0 for Doppler”. “90 for imaging”.

5. **D.** To avoid over-diagnosing, use two orthogonal views to confirm the diagnosis. If in doubt, further testing may be required (e.g.; Transesophageal (TEE), Intracardiac echocardiography (ICE).

WASHVU – Ultrasound Physics and Instrumentation in One Sentence

Nature of Ultrasound in One Sentence

- Sound is a mechanical, **longitudinal** wave where the particles of a required medium (no vacuum) move parallel to the direction of sound travel creating a series of compressions (high pressure, high density) and rarefactions (low pressure, low density) regions.

Frequency (f) in One Sentence

- Choose the highest transmit frequency (frequency - the number of cycles per second (Hz) for this will provide the best spatial (axial, lateral) resolution) for the structure(s) needing to be imaged keeping in mind that higher transmit frequencies have better spatial (axial, lateral) resolution but attenuate more rapidly than lower transmit frequencies.

Tissue Harmonic Imaging (THI) (Native Tissue Harmonic Imaging NTHI) in One Sentence

- Begin every ultrasound examination with tissue harmonic imaging by choosing the highest transmit tissue harmonic frequency allowed by the structure(s) required to be imaged because tissue harmonic imaging transmits a low fundamental frequency (e.g.; 1.6 MHz) which improves depth of penetration and displays double (twice) the fundamental frequency (e.g. 3.2 MHz) which improves resolution.

Period (T) in One Sentence

- Choose the highest transmit frequency permissible for the structure being imaged because the higher transmit frequency will result in a shorter period (period is the time it takes for one cycle to occur) and the higher transmit frequency will also shorten pulse duration (pulse duration is period × number of cycles in a pulse), wavelength, spatial pulse length which improves axial resolution.

Wavelength (λ) in One Sentence

- Choose the highest transmit frequency permissible for the structure being imaged because the higher the transmit frequency, the shorter the distance covered by a single cycle - wavelength and the shorter the spatial pulse length which improves axial resolution.

Propagation Speed (c) in One Sentence

- Remember propagation speed, which is determined primarily by the stiffness of the medium, is a constant in clinical imaging ultrasound (e.g.; 1.54 mm/µsec; 1540 m/sec), for this will help explain wavelength, spatial pulse length, range equation, temporal resolution, the magnitude of the Doppler shift and range ambiguity artifact.

Amplitude (A) in One Sentence

- Amplitude, the maximum variation of an acoustic variable expressed most often in decibels (dB), is a measure of the strength of ultrasound being transmitted to the patient and is controlled by transmit gain so reduce transmit gain to reduce amplitude and practice ALARA.

Power (P) in One Sentence

- Power is the rate of sound energy transfer in Watts (W) or milliWatts (mW), representing the strength of sound transmitted to the patient and reducing transmit gain reduces power allowing the practice of ALARA.

Intensity (I) in One Sentence

- Intensity is (power ÷ area) a measure of the strength of sound delivered to the patient with
  1 W/cm^2 SPTA being safe for focused sound beams and is controlled by the transmit gain which can be reduced by the sonographer to practice ALARA.

Acoustic Impedance (Z) in One Sentence

- Acoustic impedance is the opposition to sound travel and a reflection will occur at the boundary of two media with different acoustic impedances and the greater the acoustic impedance difference – the greater the reflection with less sound energy transmitted.

Specular Reflectors in One Sentence

- Specular are large, smooth surfaced, “mirror-like” reflectors (e.g.; cardiac valves, heart walls, vessel walls) which require using a 90-degree (perpendicular incidence) incident angle to maximize the amount of reflection.

Scatter Reflectors in One Sentence

- Scatter reflectors are small and/or rough surfaced reflectors, provide tissue texture information (e.g.; organ parenchyma) and are not angle dependent but transmit frequency dependent - increase frequency – increase backscatter.

Perpendicular Incidence in One Sentence

- A 90-degree incident angle is perpendicular incidence which is the preferred incident angle for specular reflectors (e.g.; cardiac valves, heart walls, vessel walls).

Oblique Incidence in One Sentence

- Oblique incidence is present when the incident angle is not 90 degrees (perpendicular) to a boundary and is associated with the following facts: incident angle equals the reflected angle; refraction is the change in the direction of sound as it crosses a boundary (refraction is governed by Snell's law), lateral displacement (duplication of structures) and edge shadowing are ultrasound artifacts due to refraction.

Attenuation in One Sentence

- As sound travels it becomes weaker (attenuation) due to reflection, scatter and absorption (absorption – the conversion of sound energy into heat - the number one cause for attenuation in soft tissue).

Attenuation Coefficient in One Sentence

- The attenuation coefficient for soft tissue is 0.5dB/cm/MHz or simply 0.5 × transmit frequency.

Total Attenuation in One Sentence

- Total attenuation in soft tissue can be calculated as 0.5 dB × transmit frequency × path length indicating that attenuation is dependent on transmit frequency and the distance to the reflector.

Piezoelectric Effect in One Sentence

- Ultrasound transducers operate on the piezoelectric effect which is the conversion of electrical energy into sound energy (on transmission) and sound energy into electrical energy (upon reception) using man-made materials (e.g.; PZT) given the piezoelectric property by exposing the man-made materials to the Curie temperature (e.g.; high heat in an magnetic field) and cannot be exposed to high heat again (e.g.; autoclave) or the piezoelectric property will be lost.

Transducer Construction in One Sentence

- The thin matching layer(s) is placed on the front of the piezoelectric element(s) to improve transmission and reception by reducing the acoustic impedance difference between the transducer and skin surface and the damping material is placed on the back of the piezoelectric element(s) to reduce the ringing of the element(s) resulting in a shorter spatial pulse length, better axial resolution, wider bandwidth, increased fractional bandwidth, lower quality (Q) factor, reduced efficiency and sensitivity.

Bandwidth (BW) in One Sentence

- Clinical imaging transducers are heavily damped which creates a wide range of frequencies which means a wide bandwidth (bandwidth – range of frequencies produced by a damped element) in order to produce a short spatial pulse length (e.g.; 1 to 3 cycles) which improves axial resolution.

Quality (Q) Factor in One Sentence

- Clinical imaging transducers are damped to create short pulses which results in a wide bandwidth and a low quality (Q) factor (Q factor = Operating frequency ÷ bandwidth) transducer with better axial resolution (which is the purpose of damping).

Sound Beam Formation in One Sentence

- The physical “hourglass shaped” sound beam is wide (near field – from the transducer face to the focus where the sound beam narrows as it travels) – narrow (focus and focal region) – wide (far field – region beyond the focal point where the sound beam diverges) and knowing this is important when evaluating structures in each of the wide – narrow – wide regions.

Focusing in One Sentence

- All focusing - internal, external, transmit, dynamic receive, dynamic aperture – in essence reduce the sound beam width improving lateral resolution (the narrower the sound beam width – the better the lateral resolution).

Lateral (Angular, Transverse, Azimuthal) Resolution in One Sentence

- The narrower the sound beam width, which is accomplished by increasing the transmit frequency, tissue harmonic imaging, focusing, increasing the line density (e.g.; write zoom), increasing transducer diameter (manufacturer) the better the lateral resolution.

Axial (Longitudinal, Range, Radial, Depth) Resolution in One Sentence

- The shorter the spatial pulse length, which is accomplished by increasing transmit focusing and damping, the better the axial resolution.

Transducer Types in One Sentence

- The most common transducer type used in transthoracic echocardiography (TTE) is the relatively small sized sector phased array which is an electronic transducer (e.g.; no moving parts), which sweeps (steers) and focuses the sound beam electronically creating a sector (e.g.; “pie-shaped”, “pizza slice”) display.

Range Equation in One Sentence

- The ultrasound machine needs to know where to place the returning reflections and is programmed to note that the time it takes for an ultrasound pulse to travel in one centimeter round-trip in soft tissue is 13 µsec.

Pulse Repetition Frequency (PRF) in One Sentence

- Pulse repetition frequency (the number of pulses created per second) is determined by image depth and is important in determining frame rate (temporal resolution), when aliasing will occur (e.g.; Nyquist Limit = PRF ÷ 2), the setting of the Doppler velocity scales and affects how much color will be displayed when acquiring a color flow Doppler examination.

Pulse Repetition Period (PRP) in One Sentence

- Pulse repetition period (the time from the onset of one pulse to the next pulse) is the reciprocal of pulse repetition frequency:
  (PRP (msec) = 1 ÷ PRF (kHz).

Pulse Duration (PD) in One Sentence

- Increasing the transmit frequency decreases period and pulse duration (the time it takes for one pulse to occur) which improves axial resolution.

Spatial Pulse Length (SPL) in One Sentence

- Increasing the transmit frequency decreases wavelength and spatial pulse length (the length of one pulse) which improves axial resolution (Axial resolution (mm) = Spatial pulse length ÷ 2).

Duty Factor (DF) in One Sentence

- The duty factor (the amount of time spent producing a pulse) for continuous wave (CW) is 1 or 100% and 0.1 to 1% for clinical imaging ultrasound meaning clinical imaging is listening the majority (e.g.; 99%) of the time.

Transmit Gain in One Sentence

- Transmit gain is the instrument control which affects the amount of sound energy transmitted to the patient – is controlled by the sonographer, affects echoes throughout the image display and ALARA and the Mechanical Index (MI) guides its use.

Gain (Receiver Gain, Overall Gain) in One Sentence

- Use gain (but do not over use as that will saturate the entire image display) to amplify the returning signals and this amplification of the returning signals allows the ALARA principle to be followed.

Time Gain Compensation (TGC) in One Sentence

- Time gain compensation compensates for attenuation – meaning echoes from similar soft tissue should appear equal in amplitude regardless of depth.

Display Dynamic Range in One Sentence

- Display dynamic range affects the number of gray shades displayed – a narrow dynamic range increases the contrast (more black and white) and may eliminate important weak amplitude echoes; a wide dynamic range reduces contrast (displays more shades of gray) and may provide more information and less contrast (less black and white).

Rejection (Threshold) in One Sentence

- Rejection (threshold) eliminates low level amplitude echoes and electronic noise and is most often accomplished by the manufacturer using high pass filters.

Write Zoom and Read Zoom in One Sentence

- Write zoom, which is preferred over read zoom, may improve spatial (axial, lateral) resolution by devoting more pixels to a smaller region, improve temporal resolution by increasing frame rate and may be useful to use when evaluating difficult structures to image such as cardiac valve vegetations or when acquiring challenging "close-up" measurements such as the left ventricular outflow tract diameter.

Contrast Resolution in One Sentence

- Contrast resolution refers to the ability to distinguish between different echo amplitudes of adjacent structures and is determined by the number of gray shades displayed – controls such as display dynamic range, transmit gain, gain, time gain compensation, lateral gain compensation, post-processing curves affect contrast resolution.

Amplitude (A) Mode in One Sentence

- Amplitude (A) mode displays returning reflections as spikes – the greater the amplitude of the returning reflection, the higher the spike.

Brightness (B) Mode in One Sentence

- Brightness (B) mode, is an ultrasound image display which is composed of bright dots - the stronger the amplitude of the returning echo – the brighter the dot and B-mode provides for visualization, motion and quantification of anatomical structures.

M-Mode (Time-Motion mode; TM mode) in One Sentence

- M-mode is a brightness (B) mode operation which displays depth (distance), time (duration) and motion of reflectors (standard sweep speed is 50 mm/sec) and, because it transmits 3000 to 5000 pulses along one scan line, provides excellent temporal resolution.

Two-Dimensional (2-D) (Two-D) in One Sentence

- Two-dimensional imaging is a brightness (B) mode operation which provides for depth (distance), width and motion and is the "heart" of clinical imaging ultrasound.

Three-Dimensional (3-D) and Four-Dimensional (4-D) in One Sentence

- Three-dimensional (3-D) and four-dimensional imaging (4-D) are made possible by matrix array transducers which allow for three-dimensional acquisition of volumes (e.g.; end-diastolic volume, end-systolic volume, ejection fraction) to be more accurate.

Temporal Resolution in One Sentence

- Temporal resolution is the ability to resolve fast moving structures accurately, is an important resolution in echocardiography, depends on the number of frames displayed per second (frame rate) which can be increased (which improves temporal resolution) by reducing image depth, decreasing the field of view (sector width), decreasing the number of focuses, reducing scan line density (at the cost of lateral resolution) and parallel processing (manufacturer).

Doppler in One Sentence

Know the Doppler equation:

Doppler shift (Fd) (kHz) = 2 × Transmit frequency (f_0) (kHz) × Blood velocity (V) (cm/sec) × Cosine Θ of the incident angle ÷ propagation speed (c) (cm/sec)

because it tells us that transmit frequency, blood velocity and Doppler incident angle are important with parallel to flow being imperative (e.g.; cosine of the incident angle of 0 degrees (parallel) is 1) in echocardiography.

Color Flow Doppler in One Sentence

- Color flow Doppler is a PW Doppler technique, has lower pulse repetition frequency and frame rates compared to two-dimensional imaging, aliasing appears as apparent flow reversal, a mosaic represents turbulent flow, the color gain instrument control and color velocity scale can influence the amount of color displayed and parallel to flow (like all Doppler (except power Doppler) is important.

Ultrasound Artifacts in One Sentence

- To avoid misinterpretation, know the following artifacts: **axial resolution** – the spatial pulse length can be too long; **lateral resolution** – the sound beam width may be too wide; **slice thickness** (partial-volume) the sound beam can be too thick**; acoustic speckle** (apparent tissue texture) results in tissue texture inaccurately being over/under-represented; **reverberations** causes multiple echoes, equally spaced to appear near the transducer (at the top of the image display (improved with tissue harmonic imaging); **comet tail** is associated with a highly reflective structure (e.g.; bullet); ring down may indicate an air bubble; **mirror image** and **multipath** may result in duplication of structures; **shadowing** indicates a highly attenuating structure (e.g.; calcific plaque); **enhancement** indicates a low attenuating structure (e.g.; fluid filled cyst); **refraction** causes lateral displacement and edge shadowing; **side lobes** and **grating lobes** are extraneous sound beams improved with sub-dicing and apodization;

  propagation speed error results in structures being placed too close or too far from the transducer; range **(depth) ambiguity** places structures too close to the transducer; **aliasing** is associated with PW Doppler (loss of direction, velocity and character of blood flow information due to blood flow velocity exceeding the Nyquist limit) and color flow Doppler (apparent flow reversal) and **flash artifact** is a color flow artifact of placing color on moving tissue.

Elevational Resolution in One Sentence

- The sound beam has a certain thickness which means the sound beam collects a volume of soft tissue and places it on a flat display screen – which can result in echoes being placed in anechoic regions (e.g.; tumor appears to be in the left atrium – not confirmed at surgery).

The Five Resolutions in On Sentence

- **Axial resolution:** determined by spatial pulse length – the shorter the spatial pulse length the better; **Lateral resolution:** determined by the sound beam width – the narrower the sound beam width the better; **Temporal resolution:** determined by frame rate – the higher the frame rate the better; **Contrast resolution:** determined by gray scale – more grays - less contrast; **Elevational resolution:** determined by sound beam thickness – the thinner the sound beam the better.

Quality Assurance in One Sentence

- Preventative maintenance (sonographer dependent), performance testing and acceptance testing should be done routinely (acceptance testing is done when the ultrasound equipment is delivered) to ensure that high quality ultrasound examinations are acquired.

Bioeffects in One Sentence

- Clinical imaging ultrasound appears to be safe (e.g.; there are no known bioeffects for focused ultrasound for intensities below 1 W/cm^2 SPTA) but certain principles should be followed (the "no known" is currently unknown) – ALARA, attention to the indexes (thermal (e.g.; TIS) and mechanical MI), knowing the acoustic outputs of the different imaging modalities
  (B-mode < M-mode < color flow Doppler < PW Doppler) are important responsibilities.

Conventional Sonography – Virtual Beam Sonography in One Sentence

- Conventional sonography has disadvantages – it requires a physical sound beam with certain characteristics (e.g.; near field – focus – focal region – far field) and time is required to build a frame (only one pulse can travel in the body at one time) – virtual beam sonography does not require a physical sound beam which suggests better lateral and contrast resolution is possible and virtual beam sonography does not need as much time as conventional sonography to build one frame (better temporal resolution).

Post-Test – Ultrasound Physics and Instrumentation
West Africa School of Heart and Vascular Ultrasound - WASHVU

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West **A**frica **S**chool of **H**eart and **V**ascular **U**ltrasound **(WASHVU)**
The **WASHVU** Essentials
Volume 1: Ultrasound Physics and Instrumentation
Course Evaluation

Instructors:
Terry Reynolds BS, RDCS

Date: ....

Use a 1 to 5 scale: 1: Strongly Agree; 2: Agree; 3: Neutral; 4: Disagree; 5: Strongly Disagree

- ✓ **The objectives of the course were clearly defined. …………….**
- ✓ **The topics presented were relevant to me. …………….**
- ✓ **The content was organized and easy to follow. ……………….**
- ✓ **This course will be useful to me. ………………**
- ✓ **The instructor was easy to contact for questions/concerns. ……………….**
- ✓ **I would recommend this course to other sonographers-allied health personnel. …………**
- ✓ **Suggestions on how to improve the course:**

  ……

  ……

  ……

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- ✓ **Return by e-mail or by mail:**

reynoldsterry58@gmail.com
Terry Reynolds
1931 East Mountain View Road
Phoenix, Az 85020

West **A**frica **S**chool **of H**eart **and V**ascular **U**ltrasound **(WASHVU)**
The **WASHVU** Essentials
Volume One: Ultrasound Physics and Instrumentation
Post-Test

INSTRUCTIONS

Complete the attached answer sheet and submit by e-mail: reynoldsterry58@gamail.com or by mail: Terry Reynolds 1931 East Mountain View Road Phoenix, Az 85020. The Post-Test will graded, returned graded with Answers-Explanations included.

1. A sound wave is (a):
   A. Transverse
   B. Electromagnetic
   C. Mechanical, Transverse
   D. Mechanical, Longitudinal
2. The sonographer notes that the middle section of the image display is too bright. Which of the following instrument controls would be best to adjust to improve the quality of the displayed image?
   A. Gain
   B. Transmit gain
   C. Time gain compensation (TGC)
   D. Focus
3. Sound speed is determined by the:
   A. Transmit frequency
   B. Medium
   C. Transducer type
   D. Amplitude of the sound wave
4. Extraneous sound beams originating from the primary sound beam and are associated with phased-array transducers are called:
   A. Reverberations
   B. Comet tail
   C. Grating lobes
   D. Slice thickness
5. The intensity reflection coefficient for a soft tissue-air interface is approximately: ___ %.
   A. 1
   B. 20
   C. 60
   D. 99
6. A large (compared to the wavelength), smooth surfaced reflector which is mirror-like is considered a: ____ reflector.
   A. Scatter
   B. Rayleigh
   C. Specular
   D. Backscatter

7. The frequency range for audible sound is:
   A. Less than 20 Hz
   B. 20 Hz to 20 kHz
   C. Greater than 20000 Hz
   D. 2 to 15 MHz

8. For tissue harmonic imaging the fundamental frequency transmitted is 1.8 MHz. The received and displayed tissue harmonic frequency would be: ___ MHz.
   A. 0.9
   B. 1.8
   C. 3.6
   D. 5.4

9. As transmit frequency increases, which of the following will **NOT** decrease?
   A. Period
   B. Wavelength
   C. Depth of penetration
   D. Attenuation

10. The **AVERAGE** speed of sound in soft tissue is:
   A. 1.54
   B. 1.54 mm
   C. 1540 m
   D. 1.54 mm/µsec

11. Which of the following is **NOT** considered a measure of the strength of sound?
   A. Frequency
   B. Amplitude
   C. Power
   D. Intensity

12. For focused ultrasound beams, there have been no proven biological effects for sound intensities below:
   A. 1 W
   B. 100 mW
   C. 100 mW/cm^2 SPTA
   D. 1 W/cm^2 SPTA

13. Predict the intensity transmission coefficient for a fat-muscle interface: ___ %
   A. 99
   B. 60
   C. 20
   D. 1

14. Which of the following is considered a scatter reflector?
   A. Liver parenchyma
   B. Carotid artery
   C. Abdominal aorta
   D. Pericardium

15. The ultrasound beam strikes the boundary of two media at 89.9 degrees. This is: ___ incidence.

A. Normal
B. Perpendicular
C. Direct
D. Oblique

16. The primary cause of attenuation in soft tissue is:

A. Reflection
B. Absorption
C. Scatter
D. Frequency

17. The attenuation coefficient for soft tissue is:

A. 5 dB
B. 5 dB/cm
C. 0.5 dB/cm/MHz
D. 0.5 × T

18. The conversion of sound energy into electrical energy is called the: ____ effect.

A. Piezoelectric
B. Bernoulli
C. Continuity
D. Doppler

19. The range of frequencies produced by a damped piezoelectric element is called:

A. Quality factor (Q factor)
B. Pulse-wave
C. Bandwidth
D. Tissue harmonics

20. The narrowest region of the sound beam where lateral resolution is best and intensity is highest is the:

A. Near field
B. Focal point
C. Far field
D. Fraunhofer

21. Focusing improves ____ resolution.

A. Axial
B. Lateral
C. Temporal
D. Contrast
E. Elevational

22. Lateral resolution is determined by:

A. Frame rate
B. Gary scale
C. Beam width
D. Spatial pulse length

23. Axial resolution is determined by:
A. Beam width
B. Dynamic range
C. Spatial pulse length
D. Focus

24. The most common imaging transducer type use in echocardiography is the:
A. Annular
B. Linear phased array
C. Pedof
D. Sector phased array

25. The ultrasound pulse round trip in soft tissue is 39 µsec. The reflector depth is: ___ cm.
A. 1
B. 2
C. 3
D. 30

26. Image depth is increased during an echocardiogram. Which of the following will **LEAST** likely be affected?
A. Pulse repetition frequency
B. Spatial pulse length
C. Pulse repetition period
D. Frame rate

27. The formula SPL ÷ 2 = _____.
A. Nyquist limit
B. Axial resolution
C. Frame rate
D. Wavelength

28. The duty factor for continuous-wave (CW) ultrasound is:
A. 1
B. 1%
C. .1
D. 10%

29. The transmit gain is altered during an ultrasound scan. Which of the following will **NOT** be affected?
A. Propagation speed
B. Amplitude
C. Power
D. Intensity

30. Which instrument control eliminates electronic noise?
A. Gain
B. Threshold
C. TGC
D. Transmit gain

31. The number of cycles which occur per second is:
   A. Frequency
   B. Period
   C. Wavelength
   D. Propagation speed

32. As transmit frequency increases, attenuation:
   A. Decreases
   B. Halves
   C. Increases
   D. Doubles

33. For soft tissue, which of the following transmit frequencies will have the shortest wavelength? ___ MHz.
   A. 10
   B. 8
   C. 5
   D. 2

34. Assuming the same transmit frequency, which medium will have the shortest wavelength?
   A. Air
   B. Fat
   C. Muscle
   D. Bone

35. The units for amplitude are:
   A. Hertz
   B. Decibels (dB)
   C. Rayls
   D. Millimeters (mm)

36. The lowest measured intensity is:
   A. SPTP
   B. SPTA
   C. SATA
   D. SATP

37. Intensity is:
   A. 1 ÷ PRF
   B. PRF ÷ 2
   C. Wavelength x n
   D. Power ÷ Area

38. Increasing the pulse repetition frequency will increase:
   A. Image depth
   B. Frame rate
   C. Spatial resolution
   D. Reverberations

39. An increase in the sound intensity by 6 dB in soft tissue will result in an increase in the original intensity by: ____ times.
   A. 2
   B. 4
   C. 10
   D. 100

40. The original sound intensity in soft tissue is increased by 30 dB. The new sound intensity is: ___ times greater than the original intensity.
   A. 10
   B. 100
   C. 1000
   D. 10000

41. Which of the following is the Nyquist limit formula which predicts when aliasing will occur?
   A. 1 ÷ PRF
   B. Period × n
   C. PRF ÷ 2
   D. Frequency × wavelength

42. The change in the direction of sound as it crosses a boundary is:
   A. Refraction
   B. Reflection
   C. Reverberation
   D. Rarefaction

43. The distance to a reflector is doubled. The pulse round trip time in soft tissue is:
   A. Halved
   B. Unchanged
   C. Doubled
   D. 13 μsec

44. Which transducer diameter will produce the narrowest sound beam overall and improve lateral resolution overall? ___ mm.
   A. 3
   B. 5
   C. 8
   D. 10

45. How close two structures may be **PERPENDICULAR** to the sound beam path and still be resolved is ____ resolution.
   A. Axial
   B. Lateral
   C. Contrast
   D. Temporal
   E. Elevational

46. Which instrument control is best used to adjust for attenuation using horizontal slide pods?
  A. Transmit gain
  B. TGC
  C. Gain
  D. Display dynamic range

47. Which of the following is **INCORRECT** concerning the matching layer of an ultrasound transducer?
  A. Placed on the back of the piezoelectric element(s)
  B. Reduces the acoustic impedance difference between the transducer and skin surface
  C. Improves transmission and reception of ultrasound
  D. May have multiple layers

48. Which of the following determines axial resolution?
  A. Pulse repetition frequency
  B. Pulse repetition period
  C. Pulse duration
  D. Duty factor

49. How close two structures may be **PARALLEL** to the direction of sound travel and still be resolved is ____ resolution.
  A. Axial
  B. Lateral
  C. Temporal
  D. Contrast
  E. Elevational

50. The range of frequencies produced by a damped piezoelectric element is:
  A. Quality factor (Q factor)
  B. Bandwidth
  C. Center frequency
  D. Pulse repetition frequency

51. The principle which explains how a transducer with multiple piezoelectric elements can produce a uniform sound beam is the: ____ principle.
  A. Doppler
  B. Bernoulli
  C. Continuity
  D. Huygen

52. The damping material improves: ____ resolution.
  A. Axial
  B. Lateral
  C. Temporal
  D. Contrast
  E. Elevational

53. The formula used to determine axial resolution is:
A. Wavelength × n
B. SPL ÷ 2
C. 1 ÷ PRF
D. PRF ÷ 2

54. The most effective way to increase near field length is to increase:
A. Transmit frequency
B. Transducer diameter
C. Frame rate
D. Spatial pulse length

55. Which of the following is **NOT** a descriptor for the sound beam's distance from the transducer to the focus?
A. Fraunhofer
B. Near field
C. Near zone
D. Fresnel

56. Calculate the beam width at one near field length for a 20 mm transducer diameter (assume single disc unfocused CW transducer). ___ mm
A. 10
B. 15
C. 20
D. 40

57. Which of the following will improve axial resolution?
A. Increase frame rate
B. Decrease image depth
C. Increase transmit frequency
D. Change transducer type

58. As pulse repetition frequency increases, which of the following decreases?
A. Pulse duration
B. Duty factor
C. Pulse repetition period
D. Spatial pulse length

59. Which instrument control directly affects the mechanical index (MI)?
A. Transmit gain
B. Gain
C. Time gain compensation (TGC)
D. Dynamic range

60. The unit for pressure is the:
A. Rayl
B. Watt
C. Decibel (dB)
D. Pascal

61. A cracked transducer:
   A. Is safe to use
   B. May be taped and then used
   C. Is associated with electrical shock
   D. Can be approved for emergency use

62. Which index predicts the risk for cavitation?
   A. MI
   B. TIS
   C. TIC
   D. TIB

63. The amplification of all returning signals regardless of depth is:
   A. Transmit gain
   B. Gain
   C. Time gain compensation (TGC)
   D. Threshold

64. An increase in display dynamic range will increase:
   A. Image depth
   B. Shades of gray
   C. Spatial resolution
   D. Frame rate

65. A way to reduce the risk of bioeffects is to:
   A. Use CW ultrasound only
   B. Decrease transmit frequency
   C. Reduce transmit gain
   D. Increase scan time

66. The primary advantage of M-mode is _____ resolution.
   A. Axial
   B. Lateral
   C. Temporal
   D. Contrast
   E. Elevational

67. The y axis on an M-mode scan represents:
   A. Time
   B. Depth
   C. Duration
   D. Gary scale

68. The sonographer would like to test an ultrasound machine's ability to identify fluid-filled cysts. Which test phantom would be best to use?
   A. TETO
   B. AIUM 100 mm test object
   C. SUAR
   D. Hydrophone

69. The sonographer reduces the sector width from 60 degrees to 30 degrees. The frame rate will:

A. Remain unchanged
B. Double
C. Triple
D. Halve

70. Which resolution is determined by frame rate?

A. Axial
B. Lateral
C. Temporal
D. Contrast
E. Elevational

71. Which of the following will **NOT** improve temporal resolution?

A. Increase transmit frequency
B. Reduce image depth
C. Decrease the field of view
D. Reduce scan line density

72. The difference between the transmit frequency and the received frequency is the Doppler: ___.

A. Principle
B. Effect
C. Shift
D. Cosine

73. Color flow Doppler demonstrates the ___ velocity.

A. Peak
B. Mean
C. Modal
D. Maximum

74. The sonographer increases the Doppler transmit frequency from 2 MHz to 4 MHz. The magnitude of the Doppler shift will:

A. Halve
B. Double
C. Quadruple
D. Remain unchanged

75. The preferred Doppler incident angle which will maximize the magnitude of the Doppler shift is ___ degrees.

A. 20
B. 0
C. 90
D. 60

76. The x axis on a Fast Fourier Transform (FFT) Doppler spectral display represents:
   A. Duration
   B. Velocity
   C. Gray shade
   D. Character of blood flow

77. Which of the following predicts when aliasing will occur?
   A. Bernoulli
   B. Huygen
   C. Doppler
   D. Nyquist

78. The number of pulses transmitted down one line to produce one scan line of color flow Doppler is called:
   A. Doppler shift
   B. Packet size
   C. Power Doppler
   D. Pulse repetition frequency

79. Which of the following affects the amount of color flow Doppler displayed?
   A. Color baseline
   B. Velocity scale
   C. Packet size
   D. Color map

80. Which color flow Doppler map uses the color green to depict turbulent flow?
   A. Directional
   B. Intensity
   C. Hue
   D. Variance

81. Which type of reflector directs sound energy directly back to the transducer?
   A. Specular
   B. Scatter
   C. Diffuse
   D. Rayleigh

82. Which imaging modality **BEST** allows for the evaluation of the volume of a tumor?
   A. M-mode
   B. B-mode
   C. Three-dimensional (3-D)
   D. Color flow Doppler

83. Which of the following determines the brightness of a reflection on the image display?
   A. Acoustic impedance mismatch
   B. Frame rate
   C. Transducer type
   D. Pulse repetition frequency

84. The sonographer changes the Doppler incident angle from 60 degrees to 20 degrees. The magnitude of the Doppler shift will:

A. Increase
B. Remain unchanged
C. Decrease
D. Double

85. Force ÷ Area =

A. Pressure
B. Density
C. Volume
D. Nyquist limit

86. Which imaging artifact would **NOT** provide anatomical information?

A. Enhancement
B. Ring down
C. Shadowing
D. Slice thickness

87. Rayleigh scattering is associated with the:

A. Diaphragm
B. Vessel walls
C. Red blood cell
D. Cardiac valve leaflets

88. If a 2.5 MHz transducer has a piezoelectric element thickness of 5 mm. A 5 MHz transducer would have a piezoelectric element thickness of: ___ mm.

A. 5
B. 3.0
C. 2.5
D. 0

89. Which type of focusing may directly affect frame rate?

A. Internal
B. External
C. Electronic transmit
D. Dynamic receive
E. Dynamic aperture

90. The process used to reduce grating lobes is called:

A. Damping
B. Interpolation
C. Subdicing
D. Parallel processing

91. The number of pulses created per second is called:

A. Pulse repetition frequency
B. Pulse repetition period
C. Pulse duration
D. Spatial pulse length
E. Duty factor

92. Which transducer type is most commonly used to examine patients in the right parasternal location?

A. Sector phased array
B. Linear phased array
C. Curved phased array
D. Pedof

93. A change in transmit frequency does **NOT** directly affect:

A. Period
B. Attenuation
C. Image depth
D. Acoustic impedance

94. Arrange the following in **INCREASING** order according to the propagation speed.

A. Air, fat, muscle, bone
B. Bone, air, fat, muscle
C. Air, fat, bone, muscle
D. Bone, muscle, fat, air

95. The amplitude of a sound wave is doubled. Power will be:

A. Halved
B. Doubled
C. Quadrupled
D. Remain unchanged

96. The acoustic impedance range for soft tissue is approximately:

A. 20 to 20000 Hz
B. 2 MHz to 15 MHz
C. 1.25 to 1.75 MRayls
D. -10 kHz to + 10 kHz

97. The propagation speed of sound in medium one is 1450 m/sec. The propagation speed of sound in medium two is 1570 m/sec. The incidence angle is 36 degrees. The reflected angle is ___ degrees.

A. 0
B. 18
C. 36
D. 72

98. An acoustic couplant (e.g.; ultrasound gel) is required because the acoustic couplant (e.g.; ultrasound gel) reduces the acoustic impedance difference between the:

A. Damping material and the piezoelectric element(s)
B. Matching layer and damping material
C. Ultrasound transducer face and the skin surface
D. Individual piezoelectric element(s)

99. Which of the following would **NOT** help avoid the Doppler artifact of aliasing?

A. Increase the Doppler velocity scale
B. Increase the transmit frequency
C. Decrease image depth
D. Alter the Doppler zero baseline

100. Which sonography method produces a physical ultrasound beam with a defined near field-focus-focal region and far field?

A. Virtual beam sonography
B. Conventional sonography
C. Synthetic aperture ultrasound
D. Principle