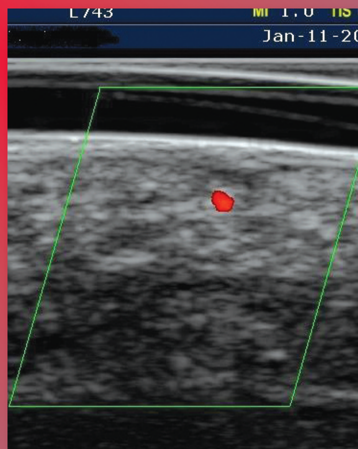
Musculoskeletal Ultrasound of the Foot and Ankle

This tool is useful in diagnosing soft tissue injuries of the foot and ankle.

BY JOHN COZZARELLI, DPM



Goals/Objectives

After reading this CME article, the reader will be able to:

1) Understand the history of ultrasound and its use in the podiatric practice.

2) Integrate this technology into the podiatric practice.

3) Increase the awareness of the newest trends in podiatric ultrasound.

4) Understand the difference between transducers and the latest imaging physics.

5) To utilize the proper jargon when describing an ultrasound image.

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*Following this article, an answer sheet and full set of instructions are provided (pg. 194).—**Editor***

History and Physics of Ultrasound

Non-audible, high frequency sound waves greater than 20kHz or 20,000 cycles/second are termed ultrasound and have existed in nature for over one million years. Bats, for example, utilize ultrasound to navigate and find food. This ability was suggested in experiments performed by Lazzaro Spallazani (1729-1799), an Italian priest and physiologist. Spallanzini found a bat could navigate better when blindfolded than when its mouth was covered leading

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to conclude that a bat's ears functioned more efficiently than its eyes in helping it to navigate. At the time of the experiment, the exact nature of this navigation ability was not well understood, and "Spallanzani's Bat Problem" remained a mystery until 1938, when Harvard students Donald Griffin and Robert Galambos were able to use a sonic detector to record the ultrasound directional noises that bats make when flying. The term for this ability, *"echolation,"* describes the application of directional sound reflections to detect objects and measure distances.

Echolation describes the application of directional sound reflections to detect objects and measure distances.

The history of ultrasound technology began with the development of piezoelectric effects in 1880. In 1912, Reginald A. Fessenden patented a device that used active echolation. The first apparatus was built in 1914, and the technology was utilized after the sinking of the Titanic. During World War I, Constatin Chilowsky and Paul Lanevin constructed a prototype on an underwater sandwich sound generator that used quartz crystals and two steel plates, considered the first ultrasound machine similar to today's units. The military adopted this technology for a variety of applications, such as SONAR, (**SO**und **NA**vigation and **R**anging), which was used to detect and sink a German U-boat on April 23, 1916. As the military continued to refine ultrasound, they eventually developed what was called a reflectoscope, or flaw detector. This was utilized to detect flaws during the fabrication of aircrafts and ships. The continued development of this technology led to the development of medical ultrasound.

Medical Applications

The first medical application of diagnostic ultrasound was utilized by Karl Dussik in 1942 to detect brain tumors. Dussik continued his work, and in 1958 published the first paper on musculoskeletal ultrasonography. He measured the acoustic attenuation of articular and periarticular tissues including skin, adipose tissue, muscle, tendon, articular capsule, articular cartilage, and bone.

1968 ushered in the development of *B-mode,* **B**rightness **mo**dulation, a display of two-dimensional dots and pixels. The amplitude of the echo determines the brightness of each dot and pixel. B-mode uses 256 shades of gray. The gray scale allows our eyes to see the difference in tissue texture. The human eye can only differentiate approximately 20 shades. Finally, in 1984, real-time ultrasound-created images were introduced. These images are seen almost instantaneously and change as the orientation of the transducer to the tissue is being evaluated. This became known as a linear array piezoelectric transducer.

Ultrasound imaging of the soft tissue is based on the pulse-echo principle. It uses a vibrating source that is referred to as a piezoelectric crystal in a transducer. The transducer causes the molecules in tissue to vibrate. The vibrations are a series of mechanical compressions and rarefactions moving away from the transducer into the tissue. They are commonly known as ultrasound waves. When the ultrasound waves contact an interface they are reflected back to the transducer. That signal then is sent to the computer processing unit to make an image on the monitor. The signal needs to be perpendicular to the subject being imaged.

Transducers and Standoffs

In general physics, the term *"transducer"* refers to a device that takes electrical energy and converts it to mechanical energy. The transducer crystal takes electrical energy and converts it to sound waves and vice versa. Ultrasound transducers work on the piezoelectric principle. *Piezein* is a Greek word, which means to press or pressure. The configuration or thickness and composition of the crystals has a unique resonant frequency, thus transducers are available at different frequencies (3.5, 5.0. 7.5, 10, 12, 15). Linear array transducers are typically 40mm in length and are best utilized to view musculoskeletal structures. The newest transducers are now 50 or 52mm in length. The latest development in transducers is the ability to have variable frequency. They have what is called tissue harmonic imaging. The transducer can have a blended frequency from 7.5-10, 8-13, 8-15. The beam comes out of the transducer perpendicular to the subject being imaged, and at the same time, with compound imaging, there are two other beams imaging on a thirty degree angle. The principle is that if you have a sphere being imaged, traditional imaging would just provide images of the surface and not the sides.

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Ultrasound, however, suffers from an inherent imaging artifact called speckle. Speckle is the random granular texture that obscures anatomy in ultrasound images and is usually described as "noise." Speckle is created by a complex interference of ultrasound echoes made by reflectors spaced closer together than the ultrasound system's resolution limit. Considerable work has been done to re-

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duce speckle in ultrasound systems. Compound imaging allows part of the sphere to be imaged on the sides. It produces a much smoother image.

It was thought that in musculoskeletal imaging, the higher the frequency the better the resolution of the image that would be obtained. This is true but there is a trade-off. The higher the resolution, the less is the penetration of the tissue being imaged. So, if imaging of a foreign body in superficial tissue occurs, it is best imaged with a higher resolution probe. If an ultrasound-guided injection is going to be done, a lower frequency is best utilized, such as 7.5MHz. In vascular applications, lower frequencies are also required for good Doppler sensitivity. The point is that a single frequency probe is not practical. Blended frequency probes provide a much more realistic approach to daily applications in a podiatric practice.

Standoffs utilized today are made from a synthetic silicone material. The distance in the latest standoffs are 0.5 cm in thickness. Standoff pads provide an interface to confirm to an irregular surface of the body. At the same time, it also pushes the image down on the screen about 0.5 cm. This allows the sound signal to quiet down. A standoff pad may be used to insonate the subcutaneous structures. This is a powerful tool that should be implemented by every examiner in musculoskeletal ultrasound.

The Language of Musculoskeletal Ultrasound

Talk the talk and walk the walk. The jargon utilized in ultrasound scanning responds to characteristic features of the anatomic structure being scanned. These terms (see box on this page) are used when describing the echo appearance as seen on the monitor.

The higher the resolution, the less is the penetration of the tissue being imaged.

- Tendons are hyperechoic on ultrasound imaging, demonstrating a fibrillar pattern.
- Muscles appear relatively hypoechoic to tendon fibers. Close observation of the muscle belly reveals hypoechoic fibers separated by hyperechoic septae that converge on a hyperechoic aponeurosis.
- Ligaments are hyperechoic on examination.
- The ultrasound beam does not penetrate the cortex of bone. The very bright echo produced at the interface allows the recognition of the cortex but also can demonstrate fracture, spurring, hematoma formation, and bone callus bridging. Abnormal soft tissue calcification and ossification also produces bright reflective echoes.
- Articular hyaline cartilage appears hypoechoic. The presence of fluid within the joint outlying the cartilage produces a thin bright echo at this interface.
- Peripheral nerves are hyperechoic relative to muscle.
- Simple fluid on ultrasound scan appears anechoic, and may demonstrate enhanced soft tissue echoes posterior to the fluid collection. An inflamed metatarsal bursa and calcaneal bursa depict fluid swelling.

Standoff pads provide an interface to confirm to an irregular surface of the body.

- Ulcerations on an ultrasound scan will appear as hypoechoic. If a sinus tract is present, this structure will appear hyperechoic as compared to the surrounding ulceration.
- Absorbable fixation such as Or-

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Near Field	(anterior) (Fresnel zone)
Far Field	(posterior) (Fraunhofer zone)
Hyperechoic	(Bright)
Hypoechoic	(Dark)
Isoechoic	(Doesn't change echo appearance)
Anechoic	(Black)
Echogenic	(Bright white)
Anisotrophy	(Echogenic signal changes based on the angle of the beam)
Homogenous	(Uniform echo appearance)
Heterogenous	(Irregular echo appearance)
Longitudinal Scan	(Sagittal Scan) (Long Axis)
Transverse Scan	(Frontal Scan) (Short Axis)

thosorb® appears as a hyperechoic structure with a surrounding zone being hypoechoic to the bone and surrounding tissue. This represents the degradation of the fixation.

Artifacts

Anisotropy is the property of being independent of direction.

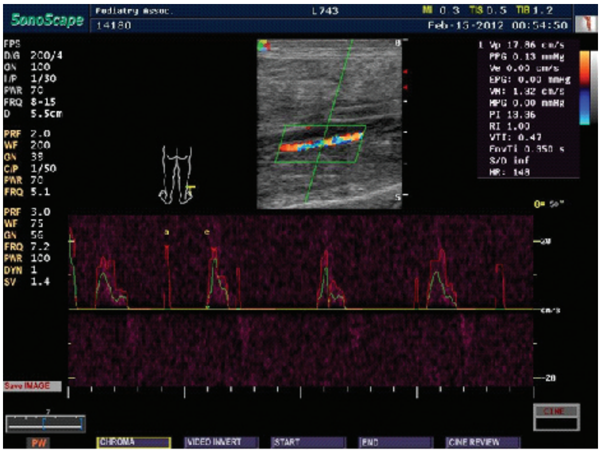

Figure 1: Color flow applied demonstrating proper wall to wall flow without aliasing present.

Anisotropy is the opposite of isotropy. Something that is anisotropic may appear different or have different characteristics in different directions. This phenomenon is created if the ultrasound examiner does not position the transducer perpendicular to the structure being imaged. If the transducer is held on a slight angle, the beam being sent back will be reflected, resembling pathology known as an artifact. This is why ultrasound imaging is operator-dependent.

Reverberation is when a sound wave travels into a structure with acoustic impedance that is significantly different from its neighbor and a large amount of the sound wave is reflected back to the transducer. The reverberations produce artifactual echo signals at the interface. A fracture can produce reverberations.

Near Field Artifact is when the skin-transducer interface is very strong because there are a lot of echoes from the skin-transducer in the immediate subcutaneous tissues. This artifact makes it difficult to evaluate the superficial structures in the epidermis. Use of the standoff will avoid this near field artifact.

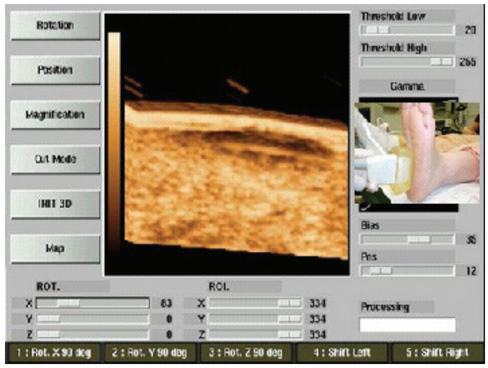

Figure 2: Foreign Body in 3-D mode using color mapping. Glass is imaged as hyperechoic with hypoechoic area surrounding it.

Anisotropy is the ability to create an artifact by angulating the transducer to the structure being imaged.

Shadowing occurs when imaging a bone or calcified object. Sound wave will not penetrate bone, so the entire wave is reflected back. This will display a very echogenic cortex and shadowing will occur deeper to it.

Enhancement occurs when traveling through fluid which is not attenuated. There is very little reflection back and most of the waveform is conducted though fluid, thus creating an increase in amplitude of the echoes distal to the fluid.

Aliasing in pulsed Doppler ultrasonography is an artifact occurring when the velocity of the sampled object is too great for the Doppler frequency to be determined by the system (Figure 1.)

Ultrasound Imaging of Soft Tissue

Tendons: Ultrasound is considered more effective in tendon disease diagnosis than MRI, especially in the ankle. Tears, inflammation, and dislo-

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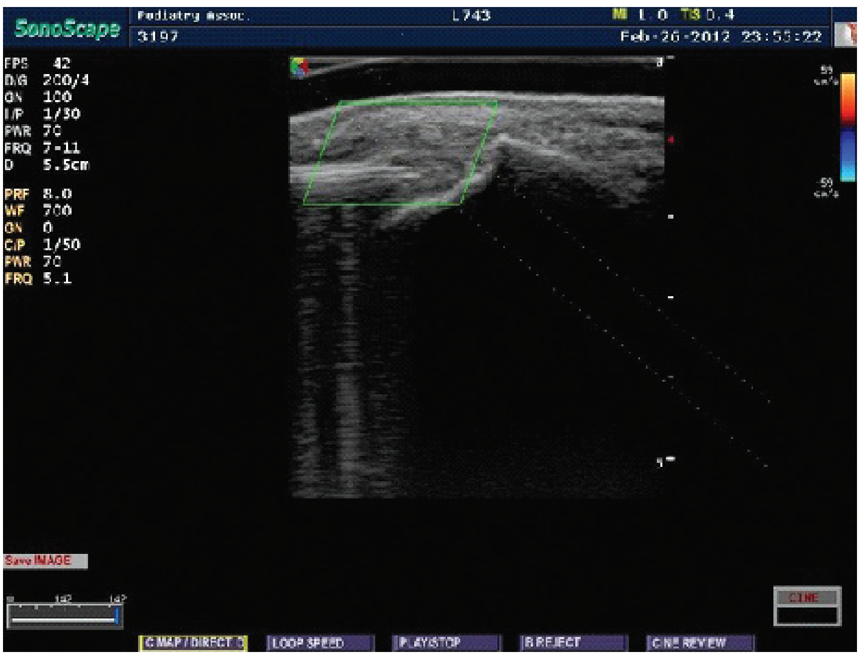

Figure 3: Tenex Health FAST™ procedure demonstrating proper needle guidance in the Achilles tendon at low frequency demonstrating proper reverberation.without aliasing present.

cations are visible.

Ligaments: Tears of ligaments are shown that heal more slowly than bony fractures and may produce long-standing pain.

Joints: Arthritic processes and potentially treatable adjacent tendon damage may be serially followed with this modality. Fluid collections, which increase pain, may be diagnosed.

Muscles: Muscle strains may be separated from more serious muscle ruptures. Hematomas and contusions may be followed.

Bones: Occult fractures of the foot and ankle are routinely detected that are missed by conventional x-rays.

Soft Tissues: Foreign bodies and abscesses are found and removed. Ultrasound guidance may be used to drain fluid collections. Post-traumatic neuromas in the forefoot may be diagnosed. Heel pain syndromes including plantar fasciitis are quickly imaged.

Nerves: Nerves, centrally and peripherally, are imaged. Hematomas or masses adjacent to nerves causing neurological findings may be disclosed.

Ultrasound Guided Injections and/or Aspirations: It has been well documented in the literature that ultrasound guidance provides a more accurate placement of a steroid injection.

Typical MSK Imaging on a Daily Basis in a Podiatric Practice

Typically on a routine day in a busy podiatric practice, diagnostic ultrasound is utilized every day. Plantar fasciitis/fasciosis is quickly and efficiently imaged. Normal fascia is imaged, and the band will measure from 3.2mm to 3.8mm in thickness. Always compare to the asymptomatic side. With heel spur syndrome, ultrasound imaging has allowed the practitioner to hone down his or her skills to make an accurate diagnosis of a medial vs. a central band fasciitis, and to determine if there is a nerve compression present. The Achilles tendon is also quickly scanned to diagnose a tendonitis, partial tear, and or complete rupture.

The high frequency transducer is best utilized to help in the removal of the foreign body.

This is a dynamic test, quickly performed. Neuromas are visualized most effectively on the cine loop replay. The higher the bank memory on the ultrasound unit, the longer the loop will be. The dynamic loop is critical to diagnosing a neuroma. Ankle injuries are also dynamically scanned. This is a very accurate way to assess if the ATF ligament is partially torn. Tibilias posterior dysfunction is easily visualized dynamically, which provides excellent medical documentation. When we look at ganglion cysts, it is an excellent practice management tip to take the transducer and push down on the ganglion to see if it fluctuates. If it does, then the cyst can be aspirated. If it does not compress, then it is solitary and needs to surgically excised. Foreign bodies are easily identified utilizing a

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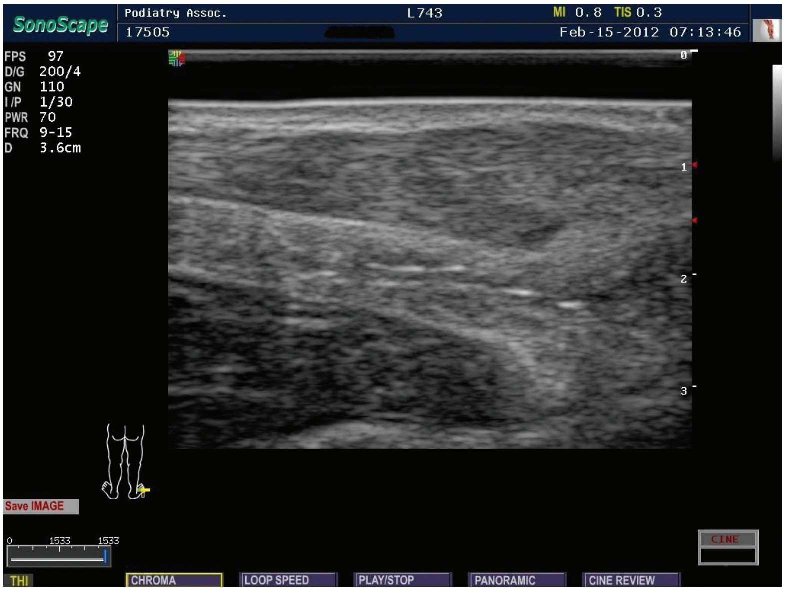

Figure 4: Achilles tendonitis with tissue harmonics applied along with standoff and speckle reduction at 15mm.

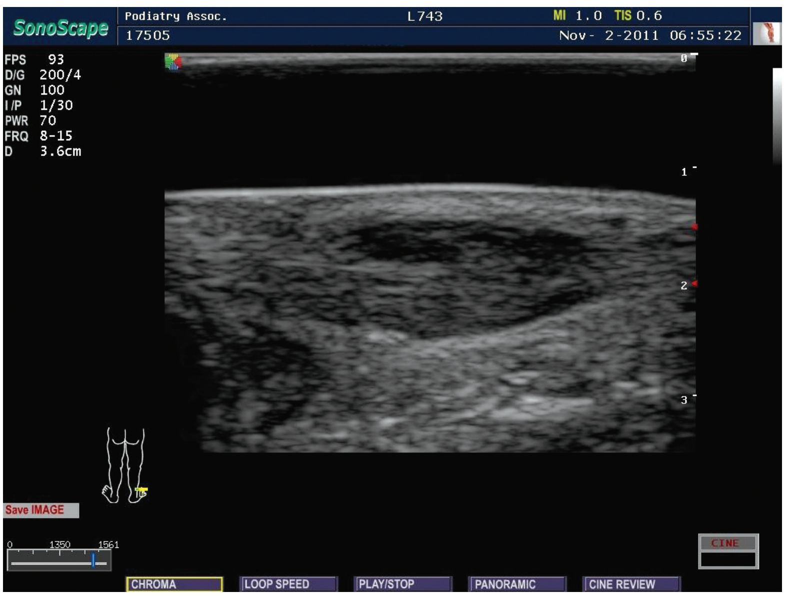

Figure 5: Partial Achilles tendon tear with standoff, tissue harmonics and speckle reduction applied on long axis.

stand-off pad. The high frequency transducer is best utilized to help in the removal of the foreign body. Different color mapping or filters can be used to help aid in the visualization of the foreign body (Figure 2).

Latest Technology Requiring Ultrasound Assisted Imaging

Ultrasound-guided extracorporeal shock wave therapy for plantar fasciitis is dynamically utilized while the procedure occurs. The endovenous radiofrequency ablation VNUS® Closure® procedure by Covidien for chronic venous insufficiency is completely dependent on musculoskeletal ultrasound with duplex color flow. **F**ocused **A**spiration of **S**car **T**issue (FAST™ procedure by Tenex Health) is completely ultrasound guided. Nerve block guidance is routinely performed by ultrasound guidance (Figure 3).

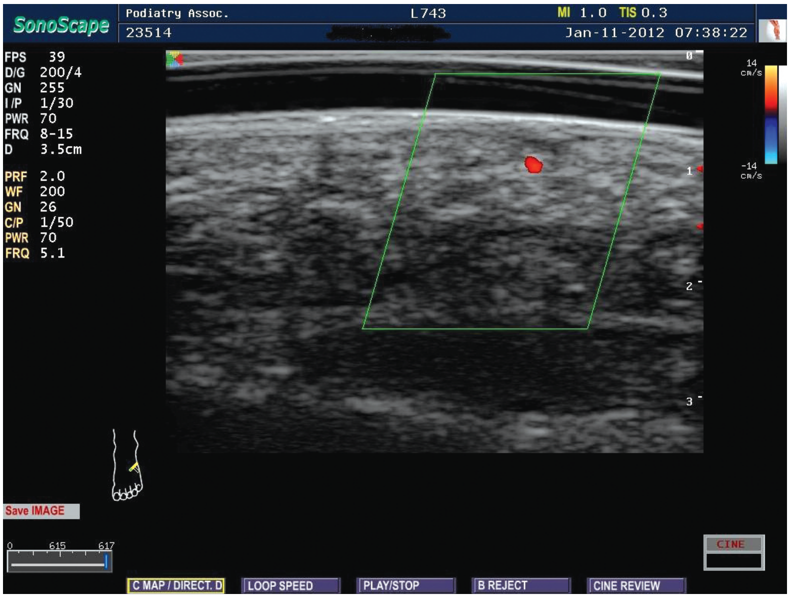

Figure 6: Triplex Power Doppler demonstrating capillary blood flow to verrucae with standoff pad applied.

The Future in Musculoskeletal Imaging

Ultrasound imaging has undergone immense changes within the last 15 years. With the use of speckle reduction (Figure 4), tissue harmonic imaging (Figure 5), freehand 3-D imaging, triplex Dopplers (Figure 6), blended frequency linear array transducers, and unparalled image storage capabilities via Dicom, it appears that the podiatric physician will be well-equipped for the development of new procedures. **PM**

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CME EXAMINATION

SEE ANSWER SHEET ON PAGE 195.

1) Echolation describes the application of
- A) Directional sight
- B) Directional touch
- C) Directional sound
- D) Directional motion

2) In 1942, Karl Dussik was the first to use ultrasound to detect
- A) Achilles tendon tear
- B) Bladder cancer
- C) Brain tumors
- D) Plantar fasciitis

3) Ultrasound is non-audible, high frequency sound waves greater than
- A) 15,000 cycles/second
- B) 20,000 cycles/second
- C) 25,000 cycles/second
- D) 30,000 cycles/second

4) When visualizing musculoskeletal structures, the best transducer to be used is
- A) Linear Array
- B) Curvilenar
- C) Hockey stick
- D) 3-D

5) Speckle is
- A) Complex spacing in the pulsed echo theory
- B) Random spacing that enhances the ultrasound image
- C) Random granular texture that obscures anatomy in ultrasound imaging and is described as noise
- D) Described as SONAR

6) Higher Frequency transducers
- A) Image superficial structures best
- B) Image deep structures best
- C) Image deep structures most efficiently
- D) Image both superficial and deep structures adequately

7) The term hypoechoic best describes
- A) A decrease in fluid uptake appearing dark
- B) An increase in fluid uptake appearing light
- C) An uptake in fluid appearing dark
- D) A decrease in fluid appearing light

8) Tendons typically appear
- A) Hypoechoic
- B) Hyperechoic
- C) Anechoic
- D) Isoechoic

9) If a tendon is normal, it is described as
- A) Heterogenous
- B) Homogeneous
- C) Anechoic
- D) Isoechoic

10) Anisotropy is the ability of creating an artifact by
- A) Holding the transducer parallel to the structure being imaged
- B) Holding the transducer perpendicular to the structure being imaged
- C) Angulating the transducer to the structure being imaged
- D) Using a stand off pad

11) The plantar fascia is normally, how many mm in thickness?
- A) 2-2—3.8mm
- B) 3.2—3.8mm
- C) 1.5mm—4.0mm
- D) 3.2—4.0mm

12) Endovenous Radiofrequency Ablation employs the use of
- A) Free Hand 3-D Imaging
- B) Color Flow
- C) High Frequency Linear Array Transducer
- D) 4-D Imaging Transducer

13) Standoff pads are utilized to
- A) Conform to irregular surfaces
- B) Raise the near field
- C) Use when your hand is tired
- D) Protect the transducer

14) When viewing a neuroma, it is best to view it via
- A) Sharp loop
- B) Dull loop
- C) Cine loop
- D) Moving loop

15) Articular cartilage is best described as
- A)Hypoechoic
- B) Hyperechoic
- C) Anechoic
- D) Isoechoic

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CME EXAMINATION

16) The near field is also called
   A) Anterior, Fresnel zone
   B) Posterior, Fraunhofer zone
   C) Anterior, Fraunhofer zone
   D) Posterior, Fresnel zone

17) The linear array transducer is comprised of
   A) Transistors
   B) Piezoelectric crystals
   C) Capacitors
   D) Heat Sink

18) When pulsed Doppler ultrasonography is utilized and an artifact occurs when the velocity of the sample object is too great for the Doppler frequency to be determined by the system it is called
   A) Needle guidance
   B) FAST procedure
   C) Insonate
   D) Aliasing

19) When giving an ultrasound-guided injection, the best frequency to use is
   A) 10MHz
   B) 15MHz
   C) 7.5MHZ
   D) 9MHz

20) When imaging a foreign body in the near field to quiet the sound signal down, the following is used:
   A) Biopsy guide
   B) Step off
   C) Push off
   D) Stand off

See answer sheet on page 195.

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Please print clearly...Certificate will be issued from information below.

Name ____ Soc. Sec. # ____________________
Please Print: FIRST MI LAST

Address ____

City ______________________________ State ______________ Zip ____________________

Charge to: _____Visa _____ MasterCard _____ American Express

Card # ______________________________Exp. Date ______________

Note: Credit card is the only method of payment. Checks are no longer accepted.

Signature ____________________ Soc. Sec.# ______________ Daytime Phone ____________________

State License(s) __________________ Is this a new address? Yes _______ No _______

Check one: ______ I am currently enrolled. (If faxing or phoning in your answer form please note that $2.50 will be charged to your credit card.)

______ I am not enrolled. Enclosed is my credit card information. Please charge my credit card $22.00 for each exam submitted. (plus $2.50 for each exam if submitting by fax or phone).

______ I am not enrolled and I wish to enroll for 10 courses at $169.00 (thus saving me $51 over the cost of 10 individual exam fees). I understand there will be an additional fee of $2.50 for any exam I wish to submit via fax or phone.

Over, please

Continuing Medical Education

ENROLLMENT FORM & ANSWER SHEET *(continued)*

EXAM #6/12
Musculoskeletal Ultrasound of the Foot and Ankle (Cozzarelli)

Circle:

1.	A	B	C	D	11.	A	B	C	D
2.	A	B	C	D	12.	A	B	C	D
3.	A	B	C	D	13.	A	B	C	D
4.	A	B	C	D	14.	A	B	C	D
5.	A	B	C	D	15.	A	B	C	D
6.	A	B	C	D	16.	A	B	C	D
7.	A	B	C	D	17.	A	B	C	D
8.	A	B	C	D	18.	A	B	C	D
9.	A	B	C	D	19.	A	B	C	D
10.	A	B	C	D	20.	A	B	C	D

LESSON EVALUATION

Please indicate the date you completed this exam

____

How much time did it take you to complete the lesson?

______ hours ______minutes

How well did this lesson achieve its educational objectives?

_______Very well ________Well

_______Somewhat _________Not at all

What overall grade would you assign this lesson?

A B C D

Degree____________________________

Additional comments and suggestions for future exams:

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