Introduction to Musculoskeletal and Neuromuscular Ultrasound: Physics, Instrumentation and Image Optimization

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Learning Objectives

- Understand the Fundamental Principles for Imaging Soft Tissue Structures with High Frequency Ultrasound.
- Become Familiar with the Echogenic Appearance of Common Structures Evaluated with MSK Ultrasound and Image Optimization
- Become Familiar with the Basic Terminology and Principles Utilized in Diagnostic Ultrasound
Why Learn MSK Ultrasound?

- Excellent Portable Diagnostic Tool
- Progressive Technology
- Patient Satisfaction
- New Appreciation of Anatomy
- Promote Musculoskeletal Medicine
- Improve Patient Care

Advantages of MSK Ultrasound

- Relatively inexpensive
- Better soft tissue differentiation than MRI
  - Better spatial resolution (150 microns vs 450)
- Can provide focused evaluation
- Dynamic assessment
- Allows easy side-to-side comparisons
- No issues with “claustrophobia”
- No interference with implants or pacemakers
Outline

• Basic Physics
• Ultrasound Equipment
• Image Interpretation – Normal Tissue
• Image Optimization
• Scanning Technique
Physics

- Probe: Piezoelectric Crystal
- Electricity is Converted to Vibrations
- Sound Wave at Interfaces
- Bright Echo: High Impedance Differences
- Crystal Receives Echo → Image

Physics – Breaking it Down

- Sound is a mechanical, longitudinal wave that travels in a straight line.
- Sound requires a medium through which to travel.
- Ultrasound is a mechanical, longitudinal wave with a frequency exceeding the upper limit of human hearing, which is 20,000 Hz or 20 kHz.
- Medical Ultrasound 2MHz to 18MHz
Physics-Frequency

• Cycles per second (Hertz, Hz)
• Function of source (transducer)
• Major factor in determining depth of beam penetration
• increase frequency, decrease penetration
• decrease frequency, increase penetration

Physics-Frequency and Wavelength

• Length for complete cycle (= mm)
• As frequency increases, wavelength decreases and vice versa
• Major determinant of image resolution
• increased frequency, increased resolution
• decreased frequency, decreased resolution
Interactions of Ultrasound with Tissue

- Reflection
- Refraction
- Transmission
- Attenuation

Reflection

- The ultrasound reflects off tissue and returns to the transducer, the amount of reflection depends on differences in acoustic impedance.
Reflection

Reflection: Angle of Incidence
Refraction

Waves bend as they pass through different materials
- speed of the wave
- impedance of the materials

Transmission

- Some of the ultrasound waves continue deeper into the body
- These waves will reflect from deeper tissue structures.
Attenuation

- Defined - the deeper the wave travels in the body, the weaker it becomes.
- 3 processes: reflection, absorption, refraction

Physics

- Safety: Lower intensity than therapeutic ultrasound.
- Upper limit: 0.72 watt/cm²

Equipment: Probe Selection

- Need a LINEAR probe of high resolution (minimal 7.5mHz)

Frequency

- Low frequency transducers provide better penetration.
  - Deep: 5-7MHz linear or curvilinear (eg thigh, hip)

- High frequency transducers provide better resolution with more superficial structures.
  - Superficial: 10-17MHz (extremities, peripheral nerves)
Equipment: Standard Base Unit

Advantages:
- Powerful, Fast software,
- High Resolution (15-20Hz)

Disadvantages:
- Not portable
- $$

Equipment: Portable Unit

Advantages:
- Small size, Less expensive

Disadvantages
- Often less resolution
- Less “bells and whistles”

*important to have “expandable” software
Tissue Appearance

Tendon Appearance

- Longitudinally oriented collagen
- fibrils
- US appearance
  - Longitudinal: fine parallel lines,
  - hypoechoic alternating with hyperechoic
  - Axial: Speckled pattern
Tendon Histology

- **Endotenon** is loose connective tissue and allows fascicles to slide against each other.
  - Transitions into perimysium and periosteum.
- Sheathed by **epitenon** (neurovascular supply and lymphatics).
  - White shiny part
- Some tendons are surrounded by **paratenon**. (Separate and further decreases friction)
  - Certain tendons have paratenon replaced by TRUE synovial sheath/ bursa lined by two layers of synovial cells referred to as a **tenosynovium**.
  - Within this sheath are blood vessels to tendon.

Tendon Appearance

- Normal tendon has a characteristic (“fibrillar”) appearance of low reflective tendon fibrils surrounded by reflective collective tissue matrix.
Muscle Appearance

- more hypo-echoic than tendon with intervening hyper-echoic linear perimysium (“starry night”)

Muscle Shapes

- Circular
- Covergent
- Parallel
- Pennate
- Fusiform
Ligament Appearance
• Generally a thin hypo-echoic structure

Bone Appearance
• Hyper-echoic interface with deeper hypo-echoic appearance
Articular Cartilage

- Hyaline cartilage = hypochoic

Normal Nerve

- Endoneurium
  - protective sheath around individual nerve fibers
- Perineurium
  - smooth tubular membrane which is a protective sheath around the fascicles
- Epineurium:
  - outermost layer of connective tissue surrounding a peripheral nerve contains multiple nerve fascicles as well as blood vessels which supply the nerve
US Appearance of Nerve: transverse

- Honeycomb
- Fascicles are dark
- Supporting tissue (peri- and epineurium) is bright (echogenic)
- The number and size of individual fascicles visualized depends on the frequency of the transducer and the type of nerve studied

Nerve Short and Long Axis
Artifacts

Anisotropy

- Ultrasound signal must be perpendicular to the orientation of the tendon
Anisotropy: Heel-toe rock

Heel-to-Toe Rock
Anisotropy as a Tool
Other Artifact: Posterior Acoustic Shadowing

Posterior Acoustic Enhancement
Reverberation Artifact

Instrumentation
Scanning Basics

- Select Appropriate Transducer
- Adjust Depth
- Optimize Focal Zone Localization
- Adjust Frequency
- Adjust Gray Scale Gain
- Doppler when Needed

Image Appearance

- Top: Skin Surface
- Bottom: deep away from transducer
- When imaging in long axis:
  - Left side of image proximal, right distal
Transducers

Linear vs Curvilinear
Depth

Excessive vs Appropriate Depth
Use the Ruler

Depth

(Reflected on right of screen in cm.)
Focal Zone

Focal Zone Appearance
Frequency

- Generally the highest frequency that allows visualization of the structures of interest.

Optimum Frequency
Grey Scale Gain

• Apply to provide the optimum tissue contrast

Time Gain Compensation (TGC)
Optimized Image

Power Doppler
Tendonitis/Synovitis: Power Doppler

- good for low flow states
- single color
- not directional
Power Doppler Flash Artifact

Power Doppler with Gain Too High
Color Doppler

- Directional
- Two Colors
- Better for high flow states

Color Doppler Flash Artifact
Advanced Imaging

- Needle Visualization Enhancement
- Panoramic Viewing
- Virtual Convex
- 3-Dimensional Ultrasound
- Very High Frequency Transducer
Needle Visualization Enhancement

Extended Field of View (aka convex or trapezoid view)
Panoramic

3-D imaging
3-D Imaging

Scanning Technique

- Holding Transducer:
  - Anchor hand/transducer
  - 5th Finger or hand on patient

- Imaging Plane:
  - Long axis of transducer
  - Orient yourself
 Arrange a Comfortable Work Station

Wrong!
Right!

Scanning Techniques

• Toggle
• Heel-toe rock
• Up/Down/All Around
• Not too many moving parts!
• Don’t forget anatomy that you already know!
“The trouble with quotes on the Internet is that you can never know if they are genuine.”

- Abraham Lincoln