Introduction to Musculoskeletal Ultrasound: Physics, Instrumentation and Image Optimization

Jeffrey A. Strakowski, MD
Clinical Associate Professor, Dept of PM&R
The Ohio State University
Associate Director of Medical Education, PM&R
Riverside Methodist Hospital
Director of Musculoskeletal Research,
The McConnell Spine, Sport & Joint Center

Learning Objectives

- Understand the Fundamental Principles for Imaging Soft Tissue Structures with High Frequency Ultrasound.
- Become Familiar with the Echogenic Appearance of Peripheral Nerves and Other Common Structures Evaluated with MSK Ultrasound.
- Become Familiar with the Basic Terminology and Principles Utilized in Diagnostic Ultrasound Including Image Optimization.
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
Rectus Strain - Longitudinal

Rectus Strain
AIUM: American Institute for Ultrasound in Medicine

- Summer 1951, 24 physicians attending the American Congress of PM&R in Denver found a common interest the validity of ultrasonic energy as a medical tool.

- Disraeli Kobak, MD was 1st president

- www.aium.org
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.

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 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
Terms and Appearance

Echogenicity (hypo, hyper)
Tendon Appearance

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

Tendon Structure

Fig. 1
Anatomy of a normal tendon.
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

- Hypo-echoic - closely follows hyper-echoic bone interface

Bursal Appearance

- Hypo-echoic - need to know anatomic landmarks
Nerve Appearance

*Displays a fasicular pattern. “Honeycomb” appearance in transverse view

Nerve Appearance - Longitudinal
Anisotropy

Ultrasound signal must be perpendicular to the orientation of the tendon.

Anisotropy
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
Depth

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

Focal Zone vs Frame Rate
Frequency
Grey Scale Gain
Time Gain Compensation (TGC)

Optimized Image
Power Doppler

Achilles Tendonitis: Power Doppler
Extensor Tendons

Power Doppler
Power Doppler

Color Doppler
Color Doppler

Advanced Imaging

- Needle Visualization Enhancement
- Panoramic Viewing
- Virtual Convex
- 3-Dimensional Ultrasound
Needle Visualization Enhancement

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

Flexor Tendons - Panoramic
Achilles Panoramic

3D Imaging
3D Imaging
3D Imaging

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

- Imaging Plane:
  - Long axis of transducer
  - Orient yourself
Scanning Techniques

- Toggle
- Heel-toe rock
- Up/Down/All Around
- Not too many moving parts!
- Don’t forget anatomy that you already know!