Principles of Musculoskeletal Ultrasound

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Disclosures

- None
Outline

- Introduction
- Benefits and Limitations of US
- Ultrasound (US) Physics
- Terminology
- Equipment
- Normal US appearance of structures
- Artifacts
- Injection technique
- Conclusions
Introduction

- Physiatrists involved in US ~ 6 decades
  - Founded American Institute for Ultrasound in Medicine (AIUM) in 1951
- Initially: therapeutic US
- High frequency, real-time MSK US imaging – 1980’s
- Now used by many physiatrists
  - Diagnostic
  - Interventional
Introduction

- Definition:
  - Use of high frequency sound waves (3-17 MHz) to image soft tissues and bony structures in the body for the purposes of diagnosing pathology or guiding interventional procedures
  - Detailed images of MSK system
    - Sub-millimeter images
    - Higher resolution than MRI for superficial structures
Introduction - Indications

- Interventional
  - Injections
  - Tenotomy
  - Aspiration/lavage
  - Biopsy
- Diagnostic
  - Tendon (tendinopathy, tears)
  - Muscle (strains, contusions)
  - Nerve (entrapment)
  - Ligament (sprains)
  - Joint (effusions)
  - Dynamic

Figure 1: Needle advancing under ultrasound guidance.
Benefits of MSK US

- Ability to image in real-time = hands-on, dynamic, fast
- Interactive – allows feedback from patient
- Generally unaffected by metal artifacts
- No radiation to patient or provider
- Exam of contralateral limb for comparison
- High resolution
- Real-time guidance for interventional procedures
- Portable
- Relatively inexpensive
Limitations of MSK US

- Limited field of view
  - Detailed picture of relatively small area
- Limited penetration
  - Lower resolution at greater depths
  - Unable to penetrate bone
- Operator dependent
  - Education (anatomy), scanning skills and interpretation
- Lack of current individual certification
- Equipment – cost, quality variable
Ultrasound Physics

- Transducer (probe)
  - Contains linear array of thin crystals (lead zirconate titanate) linked to the electrical system of the machine

- Machine
  - Applies a rapidly alternating electrical current to the crystals → vibration → generate sinusoidal sound wave (mechanical energy) = Piezoelectricity
Ultrasound Physics

- The frequency and amplitude of the sound waves are determined by:
  - electrical current used to stimulate the crystals
  - material properties of the crystals
  - thickness of the crystals

- A range of frequencies are produced (Bandwidth)

- There is a preferential frequency

- Higher frequency → higher resolution but increased scatter (reduced penetration)
Ultrasound Physics

- Emission (requires a medium)
  - Forward transmission until acoustic interface (change in the density of adjacent tissues): **Recognizes differences**
- Partial Reflection
  - Back to the transducer (now a receiver) → Sound energy transformed into electrical signal
- Processing
  - Computer calculates amplitude, depth and time of return signal and generates 2-D black/white B-mode image of the body
Ultrasound Physics

- **Echoes**
  - Perpendicular incidence
    - Reflected pulse - reflected directly back
    - Transmitted pulse – passes straight through
  - Oblique incidence
    - Some reflected back at an angle
    - Some passes through refracted (transmission angle)
Reflection

- Specular Reflection
  - Reflection from a smooth surface

- Scattering
  - Redirection of sound in several directions due to rough edges (torn tissue) or heterogeneous media
  - Some of the sound is reflected back to the transducer (= backscatter)
  - visualization of the media
Ultrasound Physics

- **Attenuation**
  - Weakening of sound amplitude and intensity as the wave propagates through a medium
  - Absorption, Reflection, Scattering

- **Attenuation coefficient**
  - Reduction (in dB) per centimeter (cm) traveled
  - Dependent on the tissue
  - Soft tissue attenuation / cm = 0.5 x freq (MHz)

- Higher frequency ⇒ More attenuation
Ultrasound Physics

- Impedance (Acoustic interface)
  - US waves are reflected at the interface of two different tissues, dependent on the properties of each tissue
  - Echogenicity = Ability to reflect sound waves back to transducer
  - If reflects large amount of sound $\rightarrow$ brighter
    - Interface composed of very different tissues
    - e.g. interface between bone and muscle (bone = bright)
  - Less reflection $\rightarrow$ darker
    - More similar tissues

- Important point
  - Images are based on the relative material properties of the tissue compared with adjacent regions
### Acoustic Impedance

- Greater the difference = Greater reflection

<table>
<thead>
<tr>
<th>Material</th>
<th>Density (kg/m³)</th>
<th>Velocity (m/s)</th>
<th>Acoustic Impedence (kg/m²s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>1.3</td>
<td>330</td>
<td>429</td>
</tr>
<tr>
<td>Water</td>
<td>1000</td>
<td>1500</td>
<td>1.5 X 10⁶</td>
</tr>
<tr>
<td>Fat</td>
<td>925</td>
<td>1450</td>
<td>1.38 X 10⁶</td>
</tr>
<tr>
<td>Blood</td>
<td>1060</td>
<td>1570</td>
<td>1.59 X 10⁶</td>
</tr>
<tr>
<td>Muscle</td>
<td>1075</td>
<td>1590</td>
<td>1.70 X 10⁶</td>
</tr>
<tr>
<td>Bone</td>
<td>1908</td>
<td>4080</td>
<td>7.78 X 10⁶</td>
</tr>
</tbody>
</table>
Ultrasound Use

- Step 1
  - Transducer selection
- Step 2
  - Depth
- Step 3
  - Focal zone
- Step 4
  - Adding focal zones
- Step 5
  - Gain
- Step 6
  - Time gain compensation
Step 1: Transducers

- Frequency
  - Expressed in megahertz (MHz)
  - High frequency
    - Greater resolution, shallow penetration (attenuation)
    - Best for more superficial structures
  - Low frequency
    - Lower resolution, greater penetration
    - For deeper structures
Transducers

- Linear array
  - End of transducer flat
  - Sound waves exit perpendicular
  - Less anisotropy
  - Limited field of view
  - Good for superficial structures

- Curvilinear array
  - End of transducer curved
  - Sound waves emitted in a fan
  - Increased anisotropy
  - Large field of view
  - Good for deep structures
Transducer positioning

- Simultaneous contact with:
  - Transducer
  - Skin surface,
  - Examiner’s hand
- Maintains proper pressure of transducer on the skin
- Avoids involuntary movement of the transducer

- Allows fine adjustments in transducer positioning
- “Full contact sport” – Jay Smith, MD
Transducer Positioning

- **Longitudinal**
  - Parallel to long axis of the structure

- **Transverse**
  - Perpendicular to the long axis of the structure
Transducer Handling

- Heel-Toe
- Wagging
- Rotation
Step 2: Depth

- Adjust depth to place image at middle to bottom of screen
- Decreases attenuation, increases resolution
- Scale allows localization
Step 3: Focal Zone

- Beam narrows to $\frac{1}{2}$ width and then widens
  - Narrowest region of beam has most concentrated sound waves → best resolution
- Set Focal Zone to location of interest
Step 4: Adding Focal Zones

- Can add zones if multiple areas or broad area of interest
- Multiple focal zones reduce temporal resolution
- Cost/Benefit
Step 5: Gain

- Overall Brightness of image
- Auto gain on some machines
- Optimize for structure of interest
Step 6: Time Gain Compensation

- Gain at certain depths
- Sliding switches on machine
- Automatic on some machines
- Adjusts brightness at a certain depth to control for attenuation
Image Identification
Terminology - Echotexture

- Refers to the internal pattern of echoes
  - Coarseness
  - Homogeneity and heterogeneity
Terminology - Echogenicity

- **Hyperechoic**
  - More sound waves reflected
- **Isoechoic**
  - Same amount of sound waves reflected
- **Hypoechoic**
  - Fewer sound waves reflected
- **Anechoic**
  - No sound waves reflected

- Difference is more important
  - Consider surrounding tissues
### Normal US Characteristics

#### Table 1. Normal ultrasonographic characteristics of soft tissues

<table>
<thead>
<tr>
<th>Tissue</th>
<th>Echogenicity</th>
<th>Transverse</th>
<th>Longitudinal</th>
<th>Susceptibility to Anisotropy</th>
<th>Compressibility</th>
<th>Doppler Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tendon</td>
<td>Hyperechoic</td>
<td>Broom end</td>
<td>Fibrillar</td>
<td>+++</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Ligament</td>
<td>Hyperechoic</td>
<td>Broom end</td>
<td>Fibrillar</td>
<td>++</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Nerve</td>
<td>Mixed echogenicity</td>
<td>Honeycomb</td>
<td>Fascicular</td>
<td>+</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Muscle</td>
<td>Mixed echogenicity</td>
<td>Starry night</td>
<td>Pennate or &quot;feather like&quot;</td>
<td>+</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Vessel</td>
<td>Hypoechoic or anechoic</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>++^a - +++^v</td>
<td>+^v - +++^a</td>
</tr>
</tbody>
</table>

--- = absent; + = mildly present; ++ = moderately present; +++ = significantly present; ^a = arteries; ^v = veins.
Normal Appearance - Muscle

Longitudinal

“Feather or veins on a leaf pattern”

Transverse

“Starry night pattern”
Normal Appearance - Tendon

Longitudinal
“Fibrillar appearance”

Transverse
“Broom end pattern”
Normal Appearance - Ligament

MCL Longitudinal

“Fibrillar”

MCL Transverse

“Broom end”
Normal Appearance - Bone

- Cortex = bright
- Hyperechoic
Normal Appearance – Hyaline Cartilage

- Anechnoic
- Not to be confused with effusion
- Hyerechoic cortex deep
Normal Appearance - Nerve

Longitudinal
“Fascicular”

Transverse –
“Honeycomb pattern”
Normal Appearance – Vasculature

Transverse - CPA

Longitudinal - CPA

Transverse
Extended Field of View

- Panoramic/Extended Field of View
  - Transducer is glided parallel to the scan plane along the structure of interest
  - New echoes added to original image
  - Allows production of pictures wider than the transducer face
Artifacts - Anisotropy

- Anisotropy
  - US beam not parallel to structure
  - Structure appears dark or pathologic due to reflection
  - Avoided by manipulating the transducer to direct the US beam perpendicular to the structure (tilting, heel-toe)
  - Always look for pathology in multiple planes
Artifacts - Anisotropy
Artifacts – Posterior reverberation

- Smooth and flat objects
  - Metal
  - Bone
  - Needle
- Reflects back and forth
- Series of echoes
Artifacts – Posterior Acoustic Shadowing

- Anechoic below bone or calcification
- i.e. calcific tendinitis
Artifacts – Posterior acoustic enhancement (increased through-transmission)
Artifacts

- Beam-width artifact
  - If a structure is smaller than the ultrasound beam, artifact may be eliminated (e.g. small calcification with no posterior acoustic shadowing)
- Adjust focal zone
- Scan in multiple planes
Injection Considerations

- Approach
- Room Arrangement
- Image location
- Needle approach
- Sterile technique
- Needle visualization techniques
Injection Approach

(a) In plane, Longitudinal

(b) Out of plane, Transverse

(c) Ultrasound images
Room Arrangement

- Align transducer, patient and screen
- Consider posture
- Place keyboard in accessible location
- Adjust lighting prior
Image location

- Pre-examine approach
- Use Doppler prior
- Place image closer to needle insertion
Needle approach

- Check depth and insert appropriately
- Keep needle parallel to transducer
- Use in-plane approach if possible
Sterile technique

- Sterile Gel
- Probe cover
- Draping as needed
  - Can be sterile work space if extended procedure
Needle visualization

- Smaller gauge = more difficult
- Parallel to transducer
- Hydrodissection
  - Small injection for needle contrast
- Jiggling
  - Back-and-forth needle motion without advancement

*Figure 4.* Longitudinal view of a popliteal cyst in the posterior left knee. (a) A 27-gauge needle (arrow) is barely conspicuous at the cyst capsule margin due to the similar echogenicity of the connective tissue and the needle. (b) Delivery of local anesthetic (1% lidocaine) creates a more reflective acoustic interface (needle vs fluid), dramatically increasing the conspicuity of the needle (arrows). LL, left; POP CYST, popliteal cyst; L5, longitudinal. Orientation similar to Figure 3, with right side of screen being inferior (or distal). (Philips IU22 Ultrasound Machine; Philips Medical Systems, Bothell, WA.)
Conclusions

- Ultrasound has many uses for physiatrists.
- There are many benefits and limitations of US.
- Basic understanding of US physics is important for image optimization.
- Various tissues can be identified due to their anatomic location, echotexture, and echogenicity.
- Always optimize your image first.
- Recognize common artifacts.
- Only use proper injection technique or defer the procedure.
References

ESSR
EUROPEAN SOCIETY OF
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