ARFI Imaging: Differentiating Between Musculoskeletal Tissues Based on Tissue Displacement

Gerald A. Ferrer[1,4], Waqas Khalid[1,5], Volker Musahl[2,1,4], Kang Kim[3,1,5], Richard E. Debski[1,2,4]

[1] Departments of Bioengineering, [2] Orthopaedic Surgery, & [3] Medicine
[4] Orthopaedic Robotics Lab & [5] Multi-modality Biomedical Ultrasound Imaging Lab
University of Pittsburgh

Introduction

Acoustic Radiation Force Impulse (ARFI) imaging is an ultrasound technique that generates a localized radiation force onto the tissue of interest and the resulting tissue displacement is measured. ARFI imaging is primarily utilized for compliant, isotropic biological tissues such as the breast (modulus ~10 kPa) to detect the presence of tumors. The utility of ARFI imaging for stiffer and anisotropic musculoskeletal tissues is not well understood. The radiation force generated during ARFI imaging may not be strong enough to displace musculoskeletal tissues (eg. Moduli: tendon ~300 MPa, capsule ~30 MPa, muscle ~1 MPa).

Objective

Differentiate between muscle, tendon and capsule tissue based on ARFI tissue displacement

Materials & Methods

- Strips of tissue harvested from 8 cadaveric shoulder specimens (60.9 ± 4.9 years)
  - 5 pectoralis major muscle, 5 glenohumeral capsule, 5 biceps tendon

Tensile Testing

1) Preload: Tendon & Capsule = 1N, Muscle = 0.2N
2) Preconditioning (10 cycles): Tendon = 1 – 10 N, Capsule = 1 – 5 N, Muscle = 0.2 – 2 N
3) Non-destructive load: Tendon = 100 N, Capsule = 50 N, Muscle = 5 N

- Output Parameter: modulus of linear region during final loading set

ARFI Imaging

- All tissues: loaded to 0.1 MPa and embedded in gelatin
- Full-frame ARFI push sequence (Vantage 128, Verasonics) (Figure 1)
  - Focused at 25 mm axial depth
  - Push duration = 192 µs
- Displacement measured using Loupas algorithm [4]
- Output Parameter: Normalized ARFI displacement = $\left(\frac{\text{Tissue Displacement}}{\text{Surrounding Gel Displacement}}\right)$

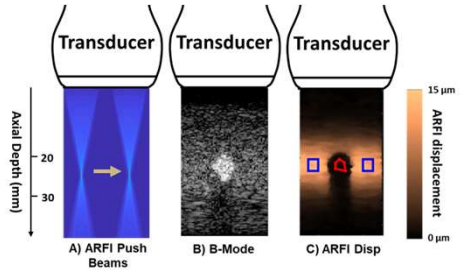

Figure 1: ARFI imaging overview. A) 64 ARFI push beams fired across the transducer aperture width. B) B-mode image of tissue embedded in gelatin. C) ARFI displacement image where tissue displacement (red region) was always lower and normalized to the softer surrounding gelatin (blue region).

Statistics

- ANOVA or Kruskal-Wallis: Effect of tissue type on modulus and normalized ARFI displacement
- Pearson's correlation: Normalized ARFI displacement & natural log of linear region modulus
- Significance set at $p < 0.05$

Results

- Higher modulus tissues had lower normalized ARFI Displacement (Fig 2)
- Large differences between tissues for linear region modulus (Fig 3)
- Small difference between tendon and capsule for normalized ARFI displacement (Fig 4)

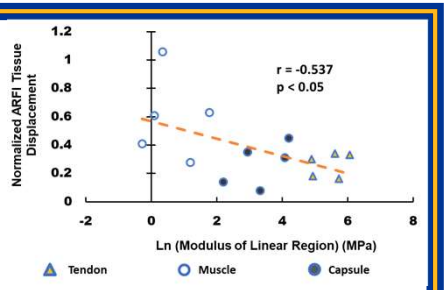

Figure 2: Significant negative correlation between normalized ARFI displacement and natural log of modulus of linear region ($r = -0.537$, $p < 0.05$)

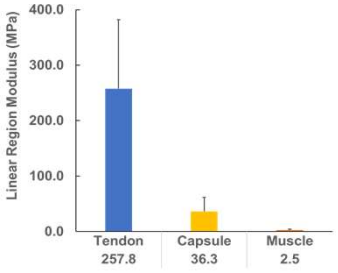

Figure 3: Significant main effect of tissue type on linear region modulus ($p < 0.05$)

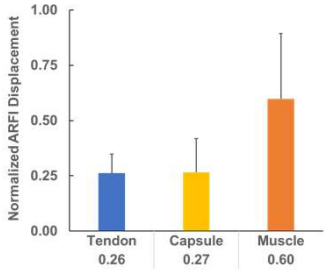

Figure 4: Significant main effect of tissue type on normalized ARFI displacement ($p < 0.05$)

Discussion

- ARFI imaging can be used to differentiate musculoskeletal tissues of varying stiffness
  - Muscle, tendon & capsule: anisotropic and stiffer than more commonly used tissues for ARFI imaging (eg. breast, arteries and liver) [1-3]
- Lower normalized ARFI displacement associated with stiffer tissue
- ARFI displacement plateaued for high stiffness tissues (tendon & capsule)
  - Modulus of linear region for capsule was 87% smaller than tendon → <1% difference in normalized ARFI displacement
  - May be limited by magnitude of ARFI push force

Future Directions

- Differentiate between healthy versus injured tissues (eg. tendinitis)

Significance

- ARFI imaging has a high potential for clinical utility (eg. sports performance) by targeting and evaluating the health of tendons at precise locations

Acknowledgements

University of Pittsburgh Swanson School of Engineering, Department of Bioengineering, Orthopaedic Surgery, and Pitt Innovation Challenge

References

[1] Nightingale et al. Ultrasound Img. 2002
[2] Nightingale et al. Ultrasound in Med and Bio. 2011
[3] Trahey et al. Ultrasound in Med & Biol. 2004.
[4] Pinton et al. IEEE Trans Ultrason Ferroelectr Freq Control. 2006