Quantitative Ultrasound Imaging of Tendon Deformation during Dynamic Loading

Darryl G. Thelen, Ph.D., Laura Chernak, David Bunger
Departments of Mechanical Engineering, Biomedical Engineering, and Orthopedics and Rehabilitation

Musculoskeletal Biomechanics

Motion Analysis
Musculoskeletal Simulations
Finite Element Models
Imaging Biomechanics

Tendon Injuries
Common in work and sports settings
- Acute tears
- Overuse (repetitive loading) injuries

Quantitative imaging of tendon tissue mechanics relevant for:
- Understanding injury mechanisms
- Diagnosis of subtle abnormalities
- Evaluation of treatment outcomes

Acute Musculotendon Strain Injuries
Injuries occur during eccentric contractions (Garrett 1990)

Post-injury remodeling can significantly alter the morphology at the muscle-tendon junction (Silder et al, 2008)
Dynamic MR Imaging of Muscle Tissue Deformations

- Cine PC measurement of 3D muscle tissue velocities
- Integration to track tissue motion

Superior-Inferior Displacement
Healthy
Injured

Silder et al. J. Biomechanics, 2010

Long-Term Changes in Injured Tendon Morphology

How to extract quantitative information regarding mechanics and function?
Chernak et al. ASB 2010

Quantitative Ultrasound Imaging of Tendon Mechanics

- Visually track muscle-tendon junction
- Using multiple probes, compute average stretch

Elastography (Ophir et al. 1991)
- Image tissue in undeformed and deformed states
- Speckle tracking of tissue motion
- High resolution strain information along beam direction

Elastographic imaging of muscle and tendon tissue deformations
- Witte et al. 2006
- Farron et al. 2008
- Deffieux et al. 2008
- Lopatka et al. 2010

Tendon Imaging using Ultrasound Elastography

1. Magnaris, J Biomechanics 2002
4. Ophir et al., Med Phys 2002
5. Magnaris et al., J Biomechanics 2006
6. Farron et al., J Biomech 2008
Challenges for Imaging Muscle-Tendon Dynamics

- Primary motion is transverse to beam direction
- Large deformations and relative motion
- Fibrous architecture

Ex Vivo Tendon Testing

- Porcine flexor tendon
- Sinusoidal stretch
  - 0.5 cycles/sec
  - 4% peak stretch
- Measurements
  - RF data (63 frames/sec)
  - Tendon force

Tissue Motion Tracking

- Place nodes along the fascicles
- 2D frame-to-frame speckle tracking
- Integrate to get cumulative motion

Ex Vivo Tendon Strains

- $e_{xx}$ (along fibers)
- $e_{yy}$ (transverse to fibers)
Achilles Tendon

- Gastrocnemius and soleus muscles insert on to the tendon
- Injuries tend to occur 2-7 cm proximal to insertion


Achilles Tendon Imaging during Eccentric Contractions

- Cyclic motion at 0.5 Hz
- Measurements
  - ankle angle
  - ankle torque
  - RF data (70 fps)

Along Fiber Strain

Soleus Muscle and Tendon Strain
Conclusions

- Ultrasound elastography can be adapted to image muscle and tendon dynamics
- Nonuniform tendon strain patterns emerge during eccentric contractions
- Motion and strain information is relevant for investigating musculotendon function in normal, injured and diseased states

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