Assessment of Patellar Tendons Over the Course of a Collegiate Men’s and Women’s Basketball Season(s) Using Gray-Scale Ultrasound and Shear-Wave Elastography

Clinical Team

Biomedical Engineering Team
Vincent Wang PhD, Carrie Chueng BS, Zachary Kozar
Background

- Tendinopathy - chronic injury to tendons
  - Generally caused by excessive mechanical loading
  - Injuries to the patellar tendon (PT) specifically, are common among participants of sports that involve jumping

- The current standard for diagnosis is primarily based on
  - patient history
  - physical examination
Gray-Scale Ultrasonography (GS-US)

- **Tendon Echogenicity:** capacity of a structure to reflect US waves back to the transducer
- **Marginal Blurring:** definition of boarders
- **Tendon Collagen Linearity:** fibrillar organization
- **Neovascularity:** detects vascular flow pattern
- **Size:** tendon thickness and cross-sectional area

Examples of abnormalities within GS-US:
A: Hypoechoic changes within the proximal tendon;  
B: Marginal Blurring along posterior proximal tendon  
C: Fibrillar disruption in the posterior proximal tendon  
D: Doppler positivity
Elastography

- Offers *objective* way to quantify tendon stiffness over *subjective* observation of tendon structure on grey scale imaging
- Quantitative US measurement
  - Assess tissues macroscopic structure through strain
- Pathologic processes alter elastic properties tissues
- Young’s modulus: elasticity $\times$ strain = stress

- Strain elastography
  - Uses transducer pressure to compare a shift in the US beam
  - Measures the changes in strain

- Sheer wave elastography
Shear Wave Elastography (SWE)

- High intensity pulse transmitted by machine to produce shear waves
- Shear waves may then be tracked with low intensity pulses to find the shear velocity

- SWE has been shown to be
  - reasonable
  - reliable – less user dependent
  - repeatable method of tendon evaluation
Study Design

Primary Aim

• To describe the natural history of patellar tendon health of collegiate men’s and women’s basketball players over the course of a single and multiple seasons by comparing the preseason & post-season GS-US, Power Doppler (PD), and SWE US images

Secondary Aims

• To compared the diagnostic accuracy of SWE to that of B-mode images in collegiate basketball players
• To develop an automated machine learning algorithm that distinguishes between grey-scale ultrasound (GS-US) images of diseased and non-diseased patellar tendons and to assess its preliminary accuracy
Study Protocol
Athlete Imaging Sessions

• Prospective from July 2017 to March 2020
• Informed written consent obtained
• Pre & post season scans from the Virginia Tech Men’s & Women’s Basketball Team of both patellar tendons
  – GS-US,
  – Power Doppler
  – SWE US
• Sports specific data obtained:
  – sport position
  – current training duration per week
  – day/time of most recent workout
  – leg dominance
  – Hx of patellar tendon or knee injury
  – Hx of knee surgery
  – Hx of corticosteroid injection
• A brief knee exam was preformed
Study Protocol
Athlete Imaging Sessions

- US images, scanned in real time by Dr. Kozar & Dr. Woodson with a GE LOGIQ S8 US Machine (General Electric, USA)
- Orientation of the US probe
  - Proximal Transverse 1
  - Proximal Transverse 2
  - Proximal Central Long
  - Central Long
  - Central Transverse
  - Distal Long
  - Distal Transverse
- If athletes develop knee pathology during their season they are to return for a midseason scan
Clinical Grading – GS-US
Grading for tendinopathy based on the criteria set forth by Sunding et al with the modified, 4-grade Ohberg scale

• Tendon Echogenicity
  – Grade 0 = Normal
  – Grade 1 = Focal hypoechoic (<50%)
  – Grade 2 = Diffuse hypoechoic (>50%)
  – Grade 3 = Focal mixed hypo/hyperechoic (<50%)
  – Grade 4 = Diffuse mixed hypo/hyperechoic (>50%)

• Marginal Blurring
  – Present for at least 50%: yes or no

• Tendon Collage Linearity
  – Grade 0 = None
  – Grade 1 = Focal fibrillar disruption (<50%) in width image
  – Grade 2 = Diffuse fibrillar disruption (>50%) in width image

• Neovascularity
  – Grade 0 = no vessels
  – Grade 1 = 1 or more vessel(s) within the surrounding tissue/not tendon
  – Grade 2 = 1 or 2 vessels (throughout tendon)
  – Grade 3 = 3 vessels (throughout the tendon)
  – Grade 4 = 4 or more vessels (throughout the tendon)

• All orientations & locations, anterior & posterior halves of the tendon was independently measured & graded

• Image analysis was consistently performed by independent operators, Dr. Mitchell and Dr. Turnbull
  – Each athlete’s pre to post scan was graded by the same physician

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Clinical Grading - SWE

- Shear Wave images were obtained at 10 sec, 15 and 20 seconds.
- ROIs chosen based on physician interpretation of abnormal regions within GS-US images.
- Mean values of 3 measurements were obtained for ROIs.
Statistical Analysis

- Wilcoxon Signed-Rank test
  - for comparing *Echogenicity* and *Linearity* pre and post season

- McNemar test
  - for comparing *Marginal Blurring* pre and post season

- Paired t-test
  - for comparing mean SWE measurements pre and post
Results

• 34 total athletes scanned
  – 24 completed pre & post season scans
    • 18 over the course of season 1
    • 10 over the course of season 2
    • 3 had pre and post scans over 2 seasons

• 17 female athletes scanned
  – 13 had complete pre & post season scans
    • 9 over the course of season 1
    • 7 over the course of season 2
    • 2 had pre and post scans over 2 seasons

• 17 male athletes scanned
  – 11 completed pre & post season scans
    • 9 over the course of season 1
    • 3 over the course of season 2
    • 1 had pre and post scans over 2 seasons

Women
• Right leg dominant - 11
• Left leg dominant - 2
• ACL with BPB repair - 2

Men
• Right leg dominant - 7
• Left leg dominant - 3
• ACL with BPB repair - 3
• PT surgical repair - 1

Total of 48 knees had pre & post scans, 26 female knees, 22 male knees
# VT Women’s BB Results

**Key**
- \( L = \) Left, \( R = \) Right
- \( X = \) \( p \) value statistically significant
- \( \bullet = \) \( p \) value *almost* statistically significant
- No symbol means no change from pre to post

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## VT Men’s BB Results

### Key
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- **X** = p value statistically significant
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Discussion

Women’s Basketball

• Tendon health worsens over the course of a season
• Worsening within right anterior proximal long central tendon
  • Specifically echogenicity, MB and linearity
  • Suggesting increasing tendinopathy
• Tendency toward decreasing tendon stiffness by SWE measurements in nearly all tendon regions
  • Statistically significant within left transverse proximal 2
  • These locations are consistent with clinical experience and literature, suggesting most patellar disease is in central proximal PT.

Men’s Basketball

• Tendon health worsens over the course of a season
• Worsening within echogenicity mainly within the anterior tendon
  • More so on the right, than left but still present on left
• Secondary to higher number of surgeries affecting the patellar tendon?
• Tendency toward decrease tendon stiffness by SWE measurements in nearly all tendon regions
Discussion

The consistent worsening stiffness of patellar tendons by comparison of SWE measurements pre- and postseason suggests that SWE may lead to

• better objective classification of tendon pathology
• provide prognostic information of tendon’s potential to heal
• potentially guide patient management and treatment at the right stage of disease.
Next Steps

- **Objective Assessment of Tendon Ultrasound Images from Multiple Populations using Shear-Wave Elastography and a Machine Learning Approach**
  - New IRB submitted for 5 year extension of project
  - active recruitment of VT athletes, from multiple sports

- **High-Performance Data Mining via Machine Learning for Analyzing Ultrasound Images**
  - Dr. Kozar & interdisciplinary team received $150K ICTAS TOP Grant starting July 1, 2020.
  - Interdisciplinary team:
    - **PI**: Vincent M. Wang, Ph.D., Assoc. Prof. and Granata Faculty Fellow,
      - Dept. of Biomedical Engineering & Mechanics (BEAM)
    - **Co-PI**: Wu Feng, Ph.D., Prof. and Turner Fellow,
      - Depts. of Computer Science, Electrical & Computer Engineering, Health Sciences, and BEAM
    - **Co-PI**: Bert Huang, Ph.D., Asst. Prof.,
      - Department of Computer Science
    - **Co-PI**: Albert J. Kozar, D.O., FAOASM, R-MSK,
      - Assoc. Prof., Sports Medicine
  - Goal: Large-scale image acquisition for the mechanical engineering large data processing study
  - Acquisition: new **Supersonic Mach 30 US machine** was obtained
    - ability to take GS-US, Doppler, & SWE simultaneously as same probe location
Machine Learning

- **Machine learning** (ML) is a branch of computer science and statistics that uses trends from past data to evaluate future data sets.
- ML algorithms for image analysis can identify differences between images that would otherwise be highly unlikely to be distinguished by the naked eye.

**Methods**
- ML Type: supervised learning
- Images divided into a *Training set* and *Test set*
- Feature Vectors
  - MSER: Maximally stable extremal regions
  - HOG: histogram of gradient features
  - SURF: speeded up robust features

**Results and Discussion**
- Preliminary accuracy of algorithm to correctly identify non-diseased tendons is 70%
- Reported accuracy of physicians in identifying pathologic tendons on US: 83%
- Further improvements in algorithm accuracy is expected as additional images become available (for improved training of algorithm)
Acknowledgements

- **Virginia Tech Men’s and Women’s Basketball teams** for volunteering their time for the multiple imaging sessions
- **Erin Cash, Ernest Eugene and Hisham Ziyout** for the behind the scenes scheduling of all athlete scans
- **Mike Goforth** for supporting and promoting our study within Virginia Tech athletic Department
- **Edward Via College of Osteopathic Medicine** for their initial support in the beginning stages of the study
- **Virginia Tech athletic department** for their support and assistance
QUESTIONS?
References