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Biomechanical and Structural Properties at Tendon-Bone Insertion

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Introduction and Background

Current Knowledge

- Tendon-bone insertion tissue is structurally and functionally graded to alleviate stress concentration from soft tendon to hard bone
- Gradation in microstructure is not recreated in a healing insertion as in a native tissue

Current Limitations

- There is insufficient understanding of tissue microstructure and the property governing regeneration and repair post injury
- It is unclear how to reproduce the native structural inhomogeneity through implants and surgical reattachment

Objectives and Approaches

- Nonlinear and anisotropic *in situ* response of insertion tissue is examined via equilbiaxial testing using strain control protocol
- Strain rate dependent mechanical behavior is studied by generating biaxial tension data at varying strain rates
- Variation of tissue tangent moduli is observed at slow and fast strain rates across three different strain ranges
- Degree of anisotropy is examined by comparing stress-strain data along and transverse to the physiological loading direction
- Microstructural inhomogeneity is examined based on collagen and elastin structure variation across the width and depth of the insertion tissue through brightfield microscopy

Methods and Results

Mechanical Testing: Strain Rate Dependency

- Experiments were performed on porcine forelimbs (i.e., digital flexor tendon to coffin/pedal bone). Porcine trotters from large were obtained from the local abattoir immediately after slaughtering and were returned to the laboratory within 60 minutes of sacrifice for dissection.
- Equilbiaxial pre-load of 10mN was applied to release residual stresses inside tissue, followed by 11 preconditioning cycles of stretch up to 35% true strain and a 30s rest period.
- Porcine digital flexor tendon insertion specimens were immersed in HBSS at 37°C and stretched equilbiaxially on the BioTester 5000 (Fig. 1) at 7%/s and 15%/s to a peak of 75% true strains in two separate experiments.

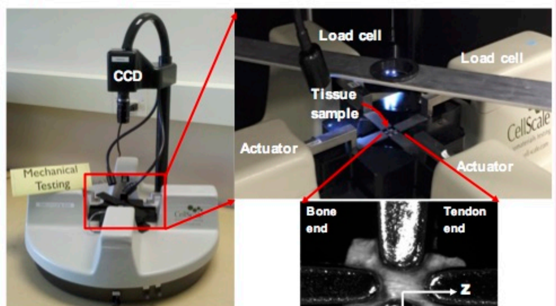


Fig. 1: BioTester for mechanical testing

x = medio-lateral
z = longitudinal
scale bar = 1 mm

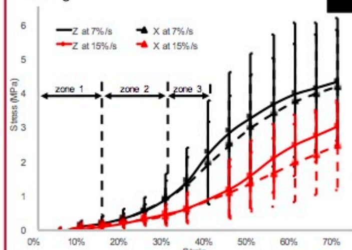


Fig. 2: Non-linear anisotropy mechanical property of tendon-bone insertion tissues at different strain-rates

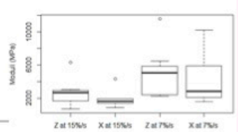


Fig. 3: Comparisons of moduli at zone 3

Results and Discussion

Histology

- Histological slides (with Hematoxylin & Eosin (H&E) and Verhoeff-Van Gieson (VVG) stains) of the insertion in the sagittal (i.e., y-z plane in red) and horizontal (i.e., x-z plane in blue) planes are observed for through the Zeiss Axiophot microscope.

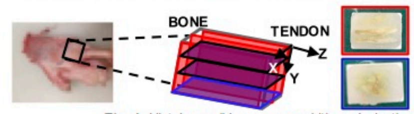
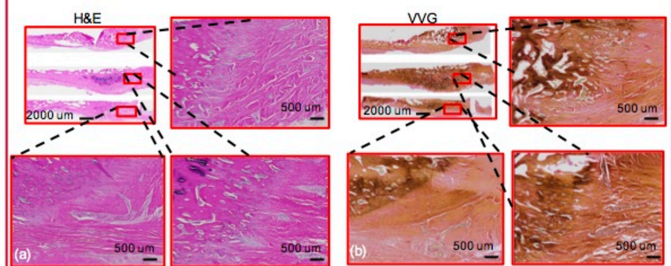


Fig. 4. Histology slides across width and depth of insertion tissue



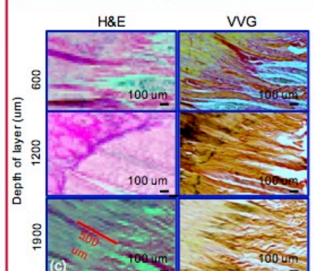


Fig. 5. Tendon-bone insertion under brightfield microscopy (water immersion, x400)

Transition in Microstructures

Collagen fiber orientation is largely along the physiological loading direction with no drastic reorientation across the width or thickness. However, fiber density is highest at mid-height (belly region) plane section

Mechanical Property of Insertions

In the equilbiaxial testing, increased stiffening beyond toe region is observed at the slower strain rate. Although the stresses along the tendon-longitudinal axis (z in Fig.2) are consistently higher, observed anisotropy is not significant.

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