Introduction
Tendons transmit contractile forces from muscle to bone and also stabilize joints with which they are mechanically associated. Structurally, normal tendons are composed of dense, fibrous connective tissue with an extracellular matrix (ECM) composed of parallel-arranged collagen type I fibrils. Tendinopathy involves tendon structural damage. Histologically, the ECM of tendinopathic tissues exhibit a reduced total collagen content and an elevation in the percentage of denatured collagen. Currently, tendinopathy management is guided by traditional ultrasonography, which can only provide morphological assessment of the injured tendon but does not quantify biomechanics. Biomechanic measures, such as tendon elasticity, would serve as a more direct biomarker in guiding the decision to undergo aggressive surgical intervention vs. conservative physical therapy. Shear wave elastography (SWE) imaging is an ultrasound-based elastography technique for the noninvasive quantification of tendon biomechanics. SWE tracks shear wave propagation through tendon tissue and calculates shear wave speed (SWS). SWS is proportional to the tissue elastic modulus and may predict tissue damage. Biomechanic measures, such as tendon elasticity, are commonly used in guiding treatment approaches.

Methods

32 porcine flexor tendons (PFTs)

Injections: Performed midway between the tapering of the proximal origin and distal insertion. Collagenase tendons were injected with a 0.05 mL bolus of 1.5% collagenase solution to induce structural damage. Control tendons were injected with saline.

Incubation: 8 tendons from each group were incubated for 37 °C for 3.5 hours. The remaining 8 tendons from each group were incubated for 7 hours. A pilot study was performed to generate incubation periods that resulted in distinct degrees of structural damage as determined by microscopy.

SWE: Tendons stretched to 0% and 1% strain using a Mark-10 Force Measurement System. Simultaneously, SWE images were acquired proximal to (PROX), at (ROI), and distal to (DIST) the injection site using a Supersonic Imagine Aixplorer clinical ultrasound scanner.

Results

SWS calculations: A previously developed MATLAB function was used to calculate the three rectangular regions of the tendon within each acquired SWE image. The function calculated the average SWS within the rectangle. Average SWS calculations were performed in this manner for the SWE images captured at the three locations (PROX, DIST & ROI) for each tendon.

Quantification of tissue degradation: It was expected that collagen content, determined by thresholding, would be similar between saline and collagenase tendons at corresponding locations along the PROX and DIST regions. Significant differences were expected along the center of the ROI region (where injections were originally performed) with collagenase tendons exhibiting less collagen content than saline tendons. From Fig. 10 it can be concluded that collagenase injections using the clamping method didn’t result in completely localized structural degradation. The 7 hour collagenase tendons analyzed using color thresholding demonstrated less collagen content in the DIST region as well as the ROI region.

Conclusion
Collagenase-mediated tendon structural damage does appear to convey decreased SWS, proportional to tissue elasticity, on images captured via SWE when ex vivo tendons are incubated for 7 hours. These findings suggest that SWE may be a useful tool for predicting ultimate tissue strength in tendinopathic tissues.

Future Direction
Injection method: Alternative approaches to improve collagenase localization should be investigated. Tighter clamping is a possible modification to the method utilized in this study but care must be taken to avoid insulting the tissue integrity by the clamps themselves.

SWE image analysis: The regional rectangular circumscription method used with the MATLAB function to generate average SWS within the ROI region did not purely isolate the clamped injection site and, instead, included regions proximal and distal to where degradation was intended to occur. Alternative approaches to reproducibly and objectively circumscribe the clamped region should be investigated.

Pull-to-failure testing: Should be performed to correlate decreased SWS, and therefore elasticity, with decreased forces at failure.