

Can ultrasound shear wave elastography detect changes of tendon mechanical properties?

Naoya Iida¹, Andrew R Thoreson², Ramona L Reisdorf¹, Ichiro Tsukamoto¹, Hicham El Hor¹, Peter C Amadio¹, Chunfeng Zhao¹
¹Department of Orthopedic Surgery, Mayo Clinic, Rochester, MN, ²Department of Physical Medicine and Rehabilitation, Mayo Clinic, Rochester, MN
 Email of Presenting Author: iidan0512@gmail.com

Disclosures: None of the presenters has any conflict of interest to disclose.

INTRODUCTION: Tendon injuries are a common cause of pain and disability in the musculoskeletal system. These injuries, referred to as tendinopathy, often result in changes to the mechanical properties of a tendon through structural changes such as tendon fibrosis or calcification that increases the tendon hardness/stiffness or by an overuse tendon tear or inflammatory tendinopathy which can cause tendon softening. Therefore, evaluating the mechanical properties of the tendon is crucial for diagnosis, prognosis, determining treatment efficacy, and assessing the healing process. Ultrasound shear wave elastography (SWE) is an ultrasound-based imaging modality that provides a non-invasive estimation of tissue elasticity by measuring the speed of shear wave propagation through soft tissue. However, it is unclear if SWE can accurately detect increases or decreases of the tendon mechanical properties. To bridge this knowledge gap, the purpose of this study was to investigate the consistency of the elastic modulus measured with SWE with values obtained through mechanical testing using tendons that were artificially altered by chemical modifications to reliably change mechanical properties. We hypothesized that the elastic modulus measured with SWE and mechanical testing would be similarly affected by chemical modification and that variation in SWE shear modulus would be sufficiently explained by changes in the elastic modulus measured with mechanical testing.

METHODS: A total of 36 canine flexor digitorum profundus (FDP) tendons from 5 dogs were used. Animals were sacrificed for other studies which were approved by our institutional animal care and use committee (IACUC). To mimic tendon mechanical property changes induced by tendinopathy conditions, tendons were softened by treating with collagenase to cause collagen digestion or were stiffened through treatment with 1-Ethy-3-(3-Dimethylaminopropyl) carbodiimide hydrochloride (EDC) that caused chemical crosslinking in the tissue. Tendons were randomly assigned to one of three groups: immersion in phosphate buffer saline (PBS) as a control group (n=12), collagenase treatment (n=12), or EDC treatment (n=12). Immediately following SWE measurement of each tendon, mechanical compression testing was performed as a gold standard to validate the SWE measurement. Both tests were conducted before and after treatment. As a statistical analysis, the compressive modulus and SWE shear modulus were compared between pre- and post-treatment conditions using a paired t-test in each treatment group. Second, the percent change of the compressive modulus and SWE shear modulus was calculated. A regression analysis was conducted with percent change of the compressive modulus as the dependent variable and SWE shear modulus as the independent variable to investigate how accurately SWE shear modulus can explain the actual mechanical performance of the material that were measured directly. The level of significance was set at $P < 0.05$.

RESULTS: The compressive modulus and SWE shear modulus were significantly decreased after collagenase treatment (**Figure 1, 2**). Conversely, both moduli were significantly increased after EDC treatment (**Figure 1, 2**). There was no significant difference in either modulus before and after PBS treatment (**Figure 1, 2**). A regression analysis showed the best fit regression was an exponential function and the coefficient of determination was 0.687 (**Figure 3**).

DISCUSSION: This result suggests that the percent change of SWE shear modulus can account for 68.7% of the percent change of compressive modulus. Therefore, SWE may be useful in detecting changes in tendon mechanical properties, although it may not be entirely accurate. It is important to note that the compression modulus is calculated based on the short-axis deformation of the fiber and interstitial material, whereas SWE measurement represents the stiffness based on shear deformation. If the moduli based on a mechanical test applying shear stress with the shear plane aligned perpendicular to the collagen fibrils had been used instead of the compression test, the coefficient of determination of the regression analysis may have been higher. This study has several limitations. First, there is a difference in the deformation direction of the fiber for calculating modulus between the mechanical testing and SWE measurement as above mentioned. Second, the changes in the mechanical properties induced in this study were more exaggerated than the actual changes that occur in tendinopathy in vivo. In conclusion, this study revealed that SWE measurement can explain approximately 70% of the change in compressive modulus.

SIGNIFICANCE/CLINICAL RELEVANCE: SWE may be helpful in evaluating and diagnosing tendinopathy in a clinical practice.

ACKNOWLEDGEMENTS: This study was funded by Mayo Foundation.

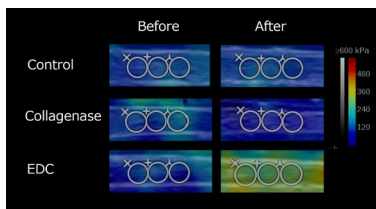


Figure 1: Typical SWE images before and after the treatment.

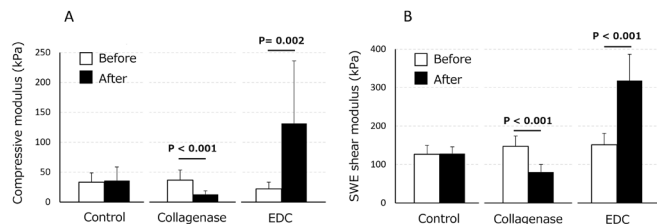


Figure 2: Compressive modulus (A) and SWE shear modulus (B) before and after the treatment.

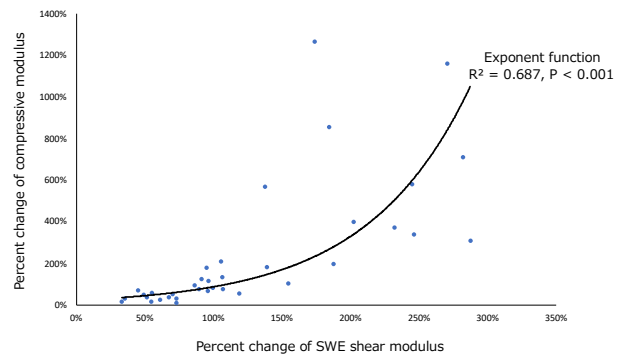


Figure 3: Scatter plot of the percent change of the compression modulus and SWE shear modulus.