Influence Of Shear Stiffness On the Behavior Of The Achilles Tendon With Tendinosis.

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INTRODUCTION: The proteins of tendons and other body structures tend to become more chemically bonded to their neighbors as a result of aging. These new chemical bonds are known to increase the lateral force transfer between collagen molecules and consequently increase shear stresses [1, 2]. In the context of solid mechanics, such lateral bonds between fibers can be represented as an increase in the shear modulus of a material model. Acute ruptures of the Achilles tendon are often the result of prior accumulation of damage that weakens the tendon's resistance to an eventual overload. The presence of a damaged region alters the load distribution among the tendon fibers, and the amount of lateral bonding is expected to influence the load transfer between fibers. This work investigates the correlation between aging and the perceived level of severity of a given lesion by using a computational model of the Achilles tendon.

METHODS: A computational model of the Achilles tendon is used to compare three levels of lesion severity on two different Achilles tendon models (young and elderly). Both models have the same geometry and receive the same load of 600 N. The load was not equally distributed among the three subtendons: The soleus subtendon received 300 N, the medial gastrocnemius subtendon received 200 N, and the lateral gastrocnemius subtendon received 100 N. The model includes the representation of the interface separating the three subtendons as a region with non-zero thickness. It includes the subtendon twist and the fiber orientation twist. An anisotropic material model is used in order to properly represent the mechanical properties of the healthy tendon, the lesion area, and the transition to muscle tissue as the tendon becomes more proximal. The transitions from muscle tissue to tendon tissue and from tendon tissue to lesion tissue were made smoothly.

RESULTS SECTION: The low and the high levels of lesion severity show no difference between the elderly and the young cases, but the medium level of severity shows that the lower shear modulus of the young case presents a more homogeneous stress field, while the elderly case shows more stress concentration near the lesion site (Figure 1).

DISCUSSION: The higher shear stresses in the elder case can act as an amplifier of stress concentrations, making the tendon more susceptible to acute ruptures induced by previous lesions. The lower lateral force transfer in young tendons reduces this effect, shielding the tendon by distributing the stresses more uniformly across the cross-section. For the low level of lesion, both cases showed uniform stress fields, suggesting that if a lesion is small enough, both the elder and young cases have sufficient shear mobility to protect the tendon. On the other hand, at the high level of lesion severity, both cases show a highly nonuniform stress field, with large regions where the stress was more than twice the values for the no lesion case, suggesting that if the lesion is large enough, even the shear mobility of the young case is not sufficient to protect the tendon.

SIGNIFICANCE/CLINICAL RELEVANCE: This work provides a detailed mechanical explanation of a possible mechanism that relates age to the probability of acute ruptures in individuals with similar levels of physical fitness.

REFERENCES:
[1] G. Fessel, Y. Li, V. Diederich, M. Guizar-Sicairos, P. Schneider, D. R. Sell, V. M. Monnier, J. G. Snedeker, Advanced glycation end-products reduce collagen molecular sliding to affect collagen fibril damage mechanisms but not stiffness, PLoS ONE 9 (2014). doi:10.1371/journal.pone.0110948.
[2] Y. Li, G. Fessel, M. Georgiadis, J. G. Snedeker, Advanced glycation end-products diminish tendon collagen fiber sliding, Matrix Biology 32 (2013) 169–177. doi:10.1016/j.matbio.2013.01.003.URL http://dx.doi.org/10.1016/j.matbio.2013.01.003

ACKNOWLEDGEMENTS: The authors would like to thank the support of the following agencies: Coordination for the Improvement of Higher Education Personnel (Capes); National Council for Scientific and Technological Development (CNPq); Research Development Foundation of the Federal University of Minas Gerais (Fundep - Grant No.: 29083-144), Brazilian Micro and Small Business Support Service (SEBRAE - Brazil).

IMAGES AND TABLES:

Figure 1: Stress in the local direction of the fibers for the lesion of medium level of severity case. Dark blue = 0 MPa, green = 16 MPa, red ≥ 32 MPa. Upper image is the healthy tendon (no lesion) center image is from the young subject lower image is from the elderly subject.