Graduate Student Research Seminar

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Effect of Composition and Structure on Mechanical Properties of Tendon-to-bone Insertion

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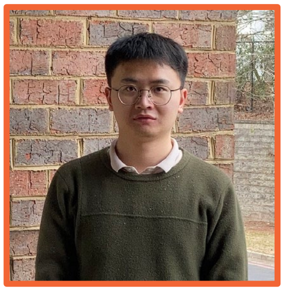

Monday, April 22nd
3:00 pm (EST) – 132 EIB

Abstract

Tendon-to-bone fibrocartilaginous insertion (enthesis) is a heterogeneous, complex structured interfacial region between the tendon and bone. It connects two dissimilar materials, i.e., tendon and bone, and effectively transfers forces between them. Given that tendon and bone have disparate mechanical properties that result in failure-inducing stress concentrations, the mechanical-robust tendon-to-bone insertion provides fascinating design strategies for mechanical joining dissimilar materials. Researchers found that tendon-to-bone insertion has a gradient composition and structure from tendon side to bone side, which is believed to have played a critical role in developing its excellent function. However, the composition-structure-function relation of tendon-to-bone insertion is still not clear, especially at the discrete fibrous scale. This study approaches this end using the computational method by investigating the dependence of the insertion's mechanical properties on the related compositional and structural factors.

In this study, mesoscale simulation models of the distinct fiber organization at tendon-to-bone insertion are developed in which the branched structures from tendon fibers to interfacial fibers and the different mineralization scales are captured. Three key compositional or structural characteristics are recognized, i.e., mineralization degree of interfacial fibers, mean angle of interfacial fibers, and angular dispersion of interfacial fibers. Tensile test simulations on insertions with various compositional or structural characteristics are performed to mimic the major type of loading condition applied to the insertion. Five representative mechanical property indicators are extracted and analyzed which are strength, Young's modulus, toughness, resilience, and failure strain. The simulation results reveal that the five indicators are largely influenced by the three key characteristics. For example, the toughness and failure strain of the insertion tend to increase with a larger mean angle of the interfacial fibers, while the strength, Young's modulus, and resilience of the insertion have reversed trends. The trends become complicated when it comes to the effect of mineralization degrees. Specifically, the strength and resilience appear to be saturated beyond certain mineralization degrees, while the failure strain and Young's modulus show a monotonic increasing trend with mineralization. However, there seems to be an optimal mineralization degree for the toughness resulting from the tradeoff between strength and failure strain. The influence of angular dispersion is found to vary with the mean angle of interfacial fibers. Basically, the angular dispersion has a greater influence at larger mean angles. Overall, tradeoffs widely exist between the selected mechanical property indicators as the key characteristics change. Moreover, the mechanisms behind those trends are discussed based on fiber-scale force, strain, and angle distributions. Our study contributes to a fundamental understanding of the composition-structure-function relationships of tendon-to-bone insertion, greatly complementing recent experimental studies. The mechanic's insights of our work can also guide the future biomimetic design of fibrillar adhesives for joining dissimilar materials.

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