Master's Thesis : Image-based mechanical analysis of tendon-to-bone attachment

Auteur : Volders, Tim
Promoteur(s) : Ruffoni, Davide
Faculté : Faculté des Sciences appliquées
Diplôme : Master en ingénieur civil biomédical, à finalité spécialisée
Année académique : 2019-2020
URI/URL : http://hdl.handle.net/2268.2/10895

Biomedical Engineering
Academic year 2019-2020

Image-based mechanical analysis of tendon-to-bone attachment

Author: Timothy VOLDERS

Supervisor: Davide RUFFONI - PhD student supervisor: Alexandra TITS

The attachment between soft and hard tissues such as tendon and bone, also called the enthesis, exhibits multiple gradients in composition, structure and mechanical properties. This project is focused on the attachment of the Achilles tendon to the calcaneus bone. Specifically, the bone side of the interface is studied.

Multiple disorders can affect the bone near the attachment site, such as enthesophytes (apparition of bone spur) and avulsion fractures. Moreover, pathologies linked to the enthesis often require the reattachment of the tendon to the bone. Unfortunately, such procedure exhibits high rate of failure. One possible common issue among different clinically relevant disorders is the local stress concentration at the interface and within the bony region close to it. Therefore, a better understanding of the stress distribution at the tendon interface and inside the bone beneath the attachment is required to better understand enthesis related pathologies.

This thesis proposes a computational framework based on experimental data to achieve this goal. The main focus is to study the morphological and mechanical adaptation of the bone beneath the Achilles tendon and plantar fascia insertion and more particularly the bony tuberosity. The experimental dataset comprises low and high resolution micro-computed tomography (μCT) images of the calcaneus bone of rats.

Firstly, the influence of a staining process on the samples before scanning is assessed. Our results show that staining is not necessary to clearly identify the Achilles tendon and plantar fascia attachment locations on the resulting images. Due to the additional noise (unwanted stained tissues) that it introduces, we choose to work with the unstained samples.

A computational image processing method is then developed to compute the attachment surfaces of both Achilles and the plantar fascia using these μCT images. The values of the resulting surface areas are very consistent across all the analyzed samples, despite some variability in the samples whole morphology. Moreover, by visualizing the attachment of both soft tissues on the two sides of the tuberosity, it appears that such bony protrusion could favor the force transmission from tendon to bone and then to the plantar ligament.

The major part of this thesis is devoted to the development of multiple finite element (FE) models of the calcaneus bone to evaluate its bio-mechanical behavior under different loading conditions. Using a continuum FE approach, we explored the link between the pulling direction of the tendon and the corresponding stresses flowing into the bone. We also demonstrate a substantial impact of the plantar fascia on the stress distribution within the tuberosity, despite carrying much smaller forces than the Achilles tendon. Using micro-structural models, we highlight that a change of bone size along the cranio-caudal direction does not impact the mechanical environment in the tuberosity region. A progressive inclusion of different degrees of porosity leads to a redistribution of stresses and strain energies and induces local concentrations around the micro-pores. Nevertheless, the tuberosity still remains the highest stressed region, maybe acting as a protective structure to avoid high stresses within the entire bone. Finally, the inclusion of gradients in elastic properties is explored based on experimental measures of the local mineral content. Results show only a minor impact of the gradients on the local stress distributions, which are predominately influenced by the microporosity.

Keywords: Biomechanics, Finite Element Modeling, Image Analysis, Achilles Tendon