Three-dimensional constitutive finite element modeling of the Achilles tendon

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The Achilles tendon is commonly subjected to injuries. However, the efficiency of nowadays treatments is not well established, because the biomechanical behaviour of tendons is not yet entirely understood. Computational modeling can provide useful information about tendon mechanics.

The Achilles tendon is located in the lower leg connecting the calf muscles to the heel bone. Its function is to transmit the force created by the muscles to generate locomotion. The Achilles tendon is employed in common activities such as walking, running and jumping.

Tendons consist of a complex structure of highly organized collagen fibers oriented along the longitudinal axis and embedded in a hydrated matrix. The main component is water making approximately 70% of the total weight. Collagen accounts for 65-80% of the dry weight and the rest is accounted as ground substances composing the matrix.

Various biomechanical material models have been developed to represent the mechanical behaviours of tendons in terms of stresses and strains. This study further develops a 2D biphasic fiber-reinforced isotropic model of the Achilles tendon considering all the main components: water, collagen fibers and matrix.

To simulate the mechanical behaviour of a realistic geometry of the Achilles tendon, necessary is to have a model able to analyse 3D geometries. Moreover, the existing model was predicting an inward non-physiological direction of fluid flow. Therefore, the model was reformulated for 3D analyses and a transversely isotropic model was used instead for the matrix. The latter was chosen because it allows to a higher Poisson ratio.

Experimental data were used to validate the model. These consisted of measured reaction forces over time of 9 rat Achilles tendons under cyclic tensile loading. The calculated average behaviour was used (Fig.1).

The difference between simulated and measured reaction forces was minimized to obtain the optimal set of material parameters describing the model.

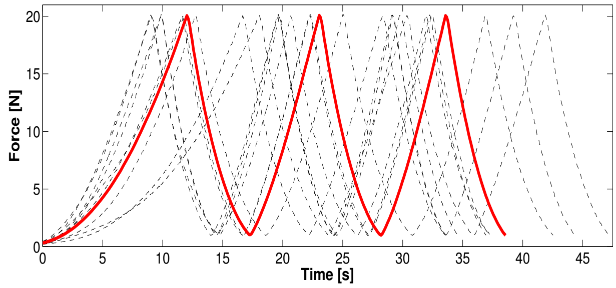

Figure 1: Average tendon reaction forces over time behavior (red).

The results showed that the reformulation of the model for 3D analysis influenced insignificantly the prediction of the behaviour obtained with the previous 2D model. Also modeling the matrix as a transversely isotropic material yielded an outward physiological fluid flow (Fig.2). The ability to represent of the experimental data remained very good as with the previous model.

Further developments could investigate the model predictions of viscous behaviours characteristic of soft biological tissues. Moreover, the fluid behaviour could be validate with specific experimental measurements and fiber recruitment could be modeled.

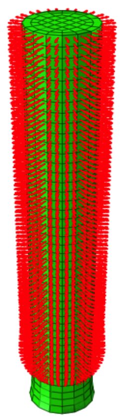

Figure 2: Outward fluid flow predicted by the 3D transversely isotropic model.