Computational modeling of the Achilles tendon

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Tendons connect muscles to bone and transfer muscle forces to produce joint movement. They also act as shock absorbers and energy storage sites to make the motion efficient. The Achilles tendon is the largest tendon is the body and it connects the calf muscle to the heel bone, see figure 1. It is essential for walking and jumping. The Achilles tendon is the most frequently ruptured tendon in humans and there is no agreement today on what is the best treatment. To improve the treatments for injured tendons and to be able to predict tendon ruptures, more information about tendon mechanics is needed.

Figure 1: The Achilles tendon.
Picture taken from
http://www.arthroscopy.com/sp09009.htm

Tendons consist of strong almost parallel collagen fibres embedded in a weaker matrix. Up to 80 % of the tissue is water and the collagen fibres make up 65-80 % of the dry weight.

Most of what is known about the mechanical behaviour of tendons comes from mechanical tests and measurements in the lab. One of the most common tests is the *tensile test*, where the tendon is fixated in one end and pulled in the other. During the test, a machine measures the tendon extension and the applied force. Tendons have very complex mechanical properties. For example, the stiffness of a tendon depends on how fast the load is applied and it gets stiffer the more it is extended. Moreover, loading and unloading of a tendon leads to energy losses due to internal friction and a constant force applied to a tendon will gradually increase the tendon's length over time.

Computational models are another way of investigating tissues' mechanical behaviour. Material models consist of mathematical equations that are developed to describe and predict the deformation of a material (e.g. tissues) caused by different loads. This project developed a material model for the Achilles tendon. To describe a biological tendon, the mechanical properties of the main components (collagen fibres, matrix and water) were represented separately in the material model. The model contained material parameters that specified how stiff the collagen fibres and the matrix were and how easily the water could flow through the tissue.

For a material model to be useful, it needs to capture the mechanical behaviour measured in experiments. Therefore, the tendon model was compared to experimental data. The material parameters were calibrated against measurements done on rat Achilles tendons subjected to tensile loading and unloading, so called cyclic loading. The difference between experimental and numerical (model) data was minimized in order to determine suitable material parameters. The result is shown in figure 2, where the red circles are the measured force values from the experiment and the blue line is the force from the computational model. The model fits the experimental data very well.

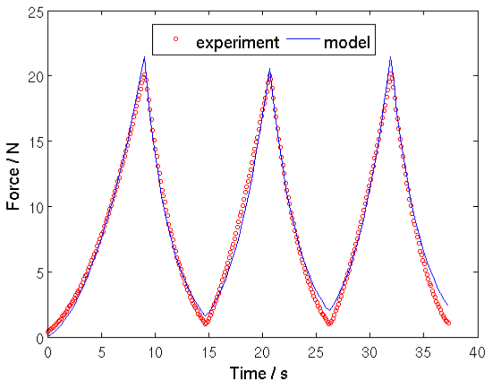

Figure 2: Force plot with experimental and model data.

In conclusion, this material model can describe the mechanical behaviour of rat Achilles tendons subjected to cyclic loading. The model can also be used to predict the mechanical response from other similar load cases.

The long term goal is to apply this model on human tendons. It can be developed to include information about tendon ruptures and the healing process and hopefully lead to better treatments of injured tendons in the future.