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STRUCTURE-BASED DAMAGE HYPERELATIC CONSTITUTIVE MODELLING: APPLICATION TO TENDONS AND LIGAMENTS.

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Ligaments and tendons are connective tissues with a highly hierarchical structure, from collagen fibres, to fibrils and fascicules. Recent constitutive models have been developed with all parameters describing the structure of the tissue [1], with the advantage that they can be measured directly rather than being phenomenologically-derived. This is an ideal framework to model damage as its onset and propagation can be associated to change in the structure directly. In this preliminary study, models of a ligament and a tendon with fibre bundles failing progressively but not otherwise changing the structure were developed with a damage variable associated to the decrease of collagen volume fraction in the tissue.

A human anterior cruciate ligament, with fascicules forming a helix with its longitudinal axis, and a human patellar tendon, with fascicules co-aligned with its longitudinal axis, were modelled as circular cylinders using FeBio, and submitted to longitudinal uniaxial tension. The tissue elastic behaviour was modelled with a structured-based law [1], using a coupled hyperelastic model. Verification of the user-defined constitutive law was performed by replicating tests with analytical solutions [1]. Damage was accounted for using a continuum damage framework, with one damage variable having an effect on the collagen volume fraction. Damage was assumed to be linearly increasing from 0 to 1 between a stretch threshold, $\lambda_{d,}$ and a failure stretch, λ_f.

For all verification tests, the relative difference between the Finite Element predicted stress and the analytical solution converged below 0.2% as the stretch increased. Larger error (below 1%) were found at very low stretch values as boundary conditions effects increased the difference between a coupled (almost incompressible) formulation, used in the FE model, and an uncoupled (incompressible) formulation, used in the analytical solution.
Varying λ_d from its lowest value (the stretch in the fascicule direction required to tauten initially crimped fibres, λ^*) and λ_f (chosen at $10\lambda^*$) showed the model has potential to investigate damage mechanisms in ligaments and tendons.

This preliminary work studied the potential to use a structural constitutive model to describe occurrence and propagation of structural damage in an in silico model of hierarchical connective tissues such as tendon and ligaments. The initial results show using such a framework allows to clearly differentiate between different values of damage threshold for tissue with co-aligned or helical fascicules.

REFERENCES

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