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A multiscale model of mineralized fibril bundles - a homogenization approach

Modeling complex biological tissues like musculoskeletal mineralized tissues (e.g bone or tendon) is a challenging task. These tissues are characterized by one common building block, the so called mineralized collagen fibril (MCF). Depending on the tissue type the fibrils are organized in different pattern across many length scales. One important aim is to predict the elastic behavior of the tissue at a coarser length scale (effective stiffness) based on the structure and the material properties at a finer scale. This can be achieved using homogenization.

Most homogenization methods estimate the effective stiffness based on different structural assumptions at the finer scale and achieve hence different estimates. The choice of these methods is therefore a crucial part of the model definition. We analyze the influence of different homogenization methods, i.e. self-consistent method, Mori-Tanaka and asymptotic homogenization, on the effective stiffness estimates using a simple collagen-mineral material. Based on these results we build up a multiscale model for mineralized fibril bundles as present in mineralized tendon. In these fibril bundles the MCFs are aligned in parallel and additional stiffness is achieved by extrafibrillar mineralization. We apply this model to experimental data from circumferential tissue of the mineralized turkey leg tendon (MTLT) assessed by Scanning Acoustic Microscopy.

Our stiffness estimates are in very good agreement with the experimental data. The experimental studies of the MTLT also revealed that this tissue exhibits (besides circumferential tissue) another fine structure: loosely packed fibril bundles with high porosity (interstitial tissue). Its specific porous structure needs to be incorporated in the model through a further homogenization step.