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Statistical Approach for a Continuum Description of Damage Evolution in Soft Collagenous Tissues

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Abstract

We propose a statistical approach to describe microscopic damage evolution in soft collagenous tissues such as arterial walls. The damage model extends a framework published by BALZANI *et al.* (2012), Comput. Meth. Appl. Mech. Eng., 213–216:139–151, by postulating specific damage functions that result from the fibers' microstructure. Statistical distributions of three different microscopic quantities such as proteoglycan orientation, fibril length parameters and ultimate proteoglycan stretch are considered. The resulting stress-stretch response is compared with experimental data obtained from uniaxial tension tests given in the literature. In particular, the individual statistical distributions are analyzed in regard to their ability to capture the distinct softening hysteresis observed when subjecting soft tissues to cyclic loading in the supra-physiological domain. Details regarding the algorithmic implementation are provided, and the applicability of the model within a finite element framework is shown by simulating the overexpansion of simplified atherosclerotic arteries.

1 Introduction

The mechanical behavior of soft collagenous tissues is a focus in current biomechanical research due to its significance onto the overall functioning of the cardiovascular system, in particular with a view to fatal consequences of diseased tissues such as heart attack, stroke and smoker's leg. For example, atherosclerotic degeneration may lead to arterial luminal narrowing, i.e. a stenosis. One possibility of a clinical treatment of such diseases is balloon angioplasty in combination with the insertion of a stent. Thereby a catheter is inflated to a pressure significantly higher than the blood pressure which induces damage at the fibrous level of the tissue. These supra-physiological situations need to be fully understood in order to reliably predict the outcome of such medical interventions, for example, to identify plaque ruptures. In this context computer simulations are expected to provide an important contribution.

To capture the mechanical behavior of arterial walls in the physiological loading domain various experiments have been carried out, see, for example, the reviews by FUNG [20], ABÉ *et al.* [1], HUMPHREY [33] and HOLZAPFEL & OGDEN [29]. Within experimental studies CASTANEDA-ZUNIGA *et al.* [11] showed that supra-physiological loading conditions yield remanent deformations as soon as a certain load level is exceeded. This was confirmed by OKTAY *et al.* [41] for carotid arteries of dogs, and by HOLZAPFEL *et al.* [30] for human iliac arteries. SCHULZE-BAUER *et al.* [48] performed experiments of human adventitias under physiological and supra-physiological conditions and in particular the supra-physiological domain was analyzed in detail by SOMMER *et al.* [51]. In the latter study it was found, by using cyclic tensile