Constitutive modeling of soft biological tissues with emphasis on the vasculature

T.Christian Gasser

†Department of Solid Mechanics, Royal Institute of Technology (KTH)
Osquars Backe 1, SE-100 44 Stockholm, Sweden
tg@hallf.kth.se

Key words: Structure, Anisotropy, Collagen, fibrous tissue, Finite Strain, Finite Element Method

ABSTRACT

Biomechanical simulations can effectively assist and improve clinical interventions, provide diagnostic information and be of potential aid in tissue engineering. The reliability of such simulations largely depends on the underlying constitutive descriptions, and hence, constitutive modeling of soft biological tissues became an active field of research within the last few decades [1]. Continuum based constitutive relations describe the gross behavior that results from the internal constitution and allow the investigation of structural and functional interrelation in response to mechanical loading. This knowledge is crucial for the predictive capability of constitutive models and to gain insights into the physiological and the pathological load carrying mechanisms of soft biological tissues, i.e. to understand the interplay of mechanical load and cell signaling [1].

The vascular wall is a composite of cellular and extracellular constituents, where collagen type I is the most abundant protein that confers mechanical stability, strength and toughness. In details, triple helical protein chains, i.e. tropocollagen (1.5 nm in diameter; 300 nm in length) are parallel staggered into fibrils (thickness ranging from 50 nm to a few hundred nm), which in turn form more complex hierarchical structures like bundles of collagen fibrils.

The arrangement of collagen is thought to determine the macroscopic mechanical properties of vascular tissue, and this paper discusses different approaches to incorporate the collagen structure into macroscopic constitutive models. In particular, anisotropic hyper-elastic formulations for fibrous tissues are developed within the frame of finite strain continuum mechanics [2]. Constitutive models have been implemented in Finite Element software and polarized light microscopy and in-vitro mechanical testing has been used to identify structural and material parameters from of tissue samples, respectively. Finally, structural simulations aim at demonstrating the feasibility of the proposed approaches and emphasize advantages of biomechanical field variables as diagnostic determinants, e.g., to assess the rupture risk of Abdominal Aortic Aneurysm.

References

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