ANISOTROPIC PROPERTY CHARACTERIZATION OF HUMAN CAROTID PLAQUES BY USING INVERSE FINITE ELEMENT MODELING

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Introduction

Plaque rupture occurs when the structural stresses are higher than the tissue strength [1]. Although plaques are highly heterogenous in the structural organization and hence, in the mechanical properties, our current knowledge on plaque mechanical properties are limited to global, aggregate, isotropic behavior [2]. In this study, we obtained the local anisotropic elastic properties of human carotid plaques by using inverse finite element modeling (iFEM), and used these properties to obtain local failure measures at rupture.

Methods

Nine atherosclerotic human carotid endarterectomy (CEA) samples were collected. Then, the fibrous plaques were imaged by using second harmonic generation multiphoton microscopy to obtain local structural collagen information. Subsequently, uniaxial tensile testing was performed on the samples, combined with digital image correlation (DIC) to obtain local displacements. By using the acquired local collagen information, FE models of fibrous plaques were built as fiber-embedded, anisotropic, hyper-elastic, incompressible, Holzapfel-Gasser-Ogden (HGO) solids [3]. The FE models simulated the tensile tests. The iFEM framework [4,5] was used to predict C_1, k_1 and k_2 HGO constants by iteratively running FE models until the normalized mean square error (NMSE) between the computed and experimentally measured displacements is minimized by the Deep Partitioning based Bayesian Optimization (DPTBO) [6] (Fig.1).

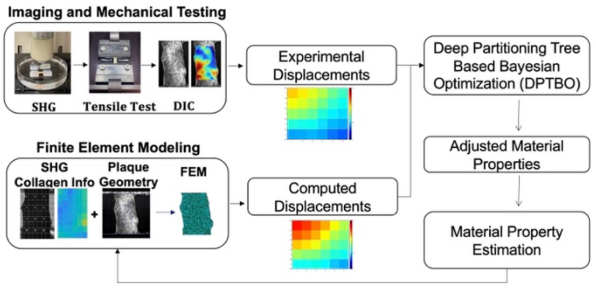

Figure 1: The DPTBO based iFEM pipeline.

Results

The iFEM approach was succesfully applied, so far, on one representative strip. The associated error of the iFEM run was NMSE=4%, and the obtained material constant values were: C_1=0.4 MPa, k_1=0.4 MPa and k_2=400. The trends were quite similar in both computational and experimental displacements with elevating levels of displacements from lower right to the top left regions (Fig.2).

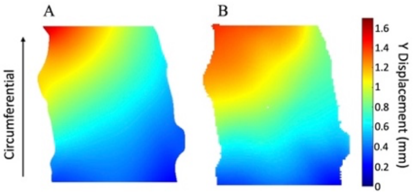

Figure 2: iFEM predicted computational (A) and experimental (B) displacement results.

The FE model (Fig.3A) was then used, with the iFEM predicted HGO constants, to compute stress distribution on the sample. Eventhough not at the highest stress region, the rupture initiation was observed at a local high stress region (Fig.3B).

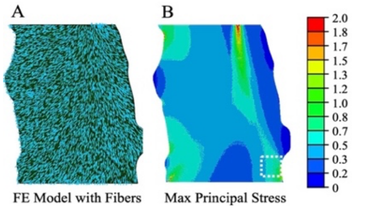

Figure 3: Fiber embedded anisotropic FE model (A), FE model stress patterns for rupture region correlation showed within white dashed square (B).

Discussion

In this study, we developed a pipeline for the characterization of local anisotropic elastic and failure properties of fibrous plaques. Preliminary assessment achieved a successful NMSE result. High stress patterns at the rupture initiation indicated that the local stress could be an important parameter for risk assessment. However, other structural metrics, i.e., collagen content or cross-linking, could be investigated as not all high stress regions ruptured. Next, the tested eight strips will be analyzed. To the best of our knowledge, this is the first study on the local assessment of anisotropic elastic properties and the failure properties of fibrous plaque tissue. Findings from this study hold the great potential in identification of stress fingerprints crucial for risk assessment tools.

References

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