ELUCIDATING THE LONGITUDINAL IMPACT OF SOLID MECHANICS ON ATHEROSCLEROTIC PLAQUE IN REAL CORONARY ARTERIES

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Introduction

In 2020 the CDC reported that 20% of deaths were attributed to cardiovascular disease (CVD) from 1999-2020 [1], [2]. In particular, coronary artery disease (CAD) accounted for roughly 55% of CVD-attributed deaths in 2020 alone, making it the leading cause of death across all CVD [2]. CAD is characterized by the formation of a fatty plaque within the walls of coronary arteries. It is known that flow-dependent low wall shear stress (WSS) contributes to plaque growth via increased inflammation [3], leukocyte infiltration [4], and low-density lipoprotein transport into the wall [5]. What is less known is how solid mechanics within the lesion impact plaque growth. Herein we investigated this relationship using longitudinal patient data and in-silico modeling to identify correlations between biomechanics and morphological features of plaque remodeling. The outcomes of this work will enhance our understanding of mechanics-driven plaque growth with implications in personalized treatment to minimize disease progression.

Methods

Currently, virtual histology intravascular ultrasound (VH-IVUS) is utilized to diagnose plaque severity and identify compositional features. We recently developed an automated meshing algorithm that uses VH-IVUS images to generate 3D volumetric meshes of coronary arteries for finite element analysis (FEA) [6]. We applied this meshing algorithm to a 16-patient dataset of paired baseline (BL) and 6-month follow-up (FU) VH-IVUS images. Quadratic tet10 elements with mean edge lengths of roughly 0.2mm were utilized with nonlinear Neo-Hookean material models. Material properties were literature derived and luminal surface pressure was patient specific. FEA was performed using FEBio and mean elemental effective stress and strain corresponding to each pair of BL and FU images was calculated. A separate script extracted image-derived features from each pair of BL and FU VH-IVUS images [**Figure 1**].

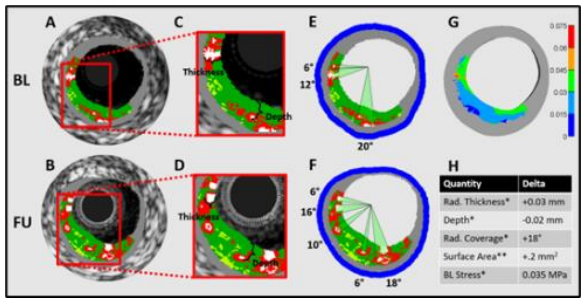

Figure 1. Image-derivable features. *A, B) Original BL and FU IVUS. C, D) Thickness and depth. E, F) Radial coverage. G) Eff. stress. H) Calculated differences.*

Results

Preliminary results using 13 of the 16 patient datasets (n = 842 images) suggest that larger changes in plaque area between BL and FU occur at low-mid eff. stresses whereas smaller changes in surface area occur at mid-high eff. stresses [**Figure 2**].

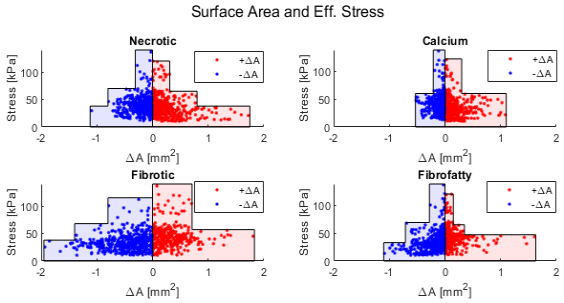

Figure 2. Mechanically mediated changes in plaque area. *Results for the global dataset, y-axis: effective stress in kPa, x-axis: change in area in mm².*

Discussion

Our preliminary results corroborate the work by Samady et al. who found that low WSS corresponded with increased plaque volume [7]. It is thought that endothelial cells lining the lumen must be in a constant state of motion to maintain healthy cell-cell connections between them and minimize transport of leukocytes or LDL into the wall. Smooth muscle cells (SMCs) inside the artery wall are similarly impacted by lower stresses, as seen during in-vivo experiments where SMCs in low stretch conditions (0-10%) proliferated less than those in large stretch conditions [8]. Further investigation is needed to quantify these relationships, but initial results point toward a mechanobiological remodeling paradigm driven by the mechanical forces felt at the cellular level.

Acknowledgments

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