A Framework for Human Coronary Plaque Vulnerability Assessment Based on Patient-Specific Intravascular Ultrasound (IVUS) Imaging, Computational Modeling and Planar Biaxial Artery Material Properties

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Atherosclerotic plaques may rupture without warning and cause acute cardiovascular syndromes such as heart attack and stroke. It is commonly believed that plaque rupture may be linked to critical stress/strain conditions. Image-based computational models have been developed by several groups combining mechanical analysis with image technology aiming to identify critical flow and stress/strain conditions which may be related to possible plaque rupture. However, existing in vivo 3D plaque models are mostly for carotid plaques based on magnetic resonance imaging (MRI) data. Similar models for coronary plaques based on in vivo image data is lacking in the current literature because clinical recognition of vulnerable coronary plaques has remained challenging and beyond the capability of non-invasive diagnostic imaging such as MRI and CT coronary angiography. Coronary imaging is more difficult because: a) coronary arteries move with the pumping heart constantly; b) coronary artery has smaller dimensions compared to carotid arteries; c) coronary arteries are not as accessible as carotid arteries; and d) plaque components are not reliably delineated as in carotid arteries. Intravascular ultrasound (IVUS) imaging with tissue characterization represents the most promising and potentially clinically relevant technique for recognition of vulnerable plaques in vivo in patients.

The objective of this project is to combine anisotropic computational modeling with *in vivo* intravascular ultrasound (IVUS), angiography, *ex vivo* Magnetic Resonance Imaging (MRI), mechanical testing, and histopathological analysis to analyze vulnerable atherosclerotic coronary plaques and identify critical blood flow and plaque stress/strain indicators for quantitative coronary plaque vulnerability assessment. The long term goals are: a) develop computational mechanical image analysis tools for more accurate plaque assessment and possible quantitative improvement to the current American Heart Association (AHA) plaque classification schemes; b) identify critical flow and stress/strain plaque vulnerability risk indicators for possible early prediction, diagnosis, treatment, and prevention of related cardiovascular diseases.

A modeling approach is proposed to develop 3D in vivo IVUS-based models with fluid-structure interactions (FSI), cyclic bending and anisotropic properties to perform mechanical analysis for human coronary atherosclerotic plaques. The framework includes a) IVUS acquisition of coronary plaque morphology and blood flow and pressure information; b) CT coronary angiography and 3D reconstruction for coronary motion and curvature; c) biaxial mechanical testing of coronary plaque material properties; d) 3D computational modeling based on data acquired in a)-c). Cyclic bending represents the bending caused by cardiac motion and is included in the FSI model to evaluate its impact on stress conditions in coronary plaques.