Computational Modelling of Arterial MRE through Atherosclerotic Plaque: A Feasibility Study

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Summary: Hooke's law states that the strain in a linearly elastic material is proportional to the applied load. Magnetic Resonance Elastography (MRE) uses this principle to deduce tissue stiffness by measuring the deformation created by externally generated waves, albeit using more complicated algorithms. Computational modelling can be used to demonstrate the feasibility of arterial MRE by showing the disruption of shear waves through a healthy vessel and an idealised fibrous and lipid plaque.

Aim: To determine whether shear waves at MRE interrogation frequencies can detect idealised atherosclerotic plaques.

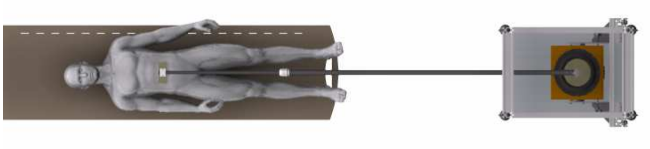


Figure [1]: Experimental MRE set-up

Introduction: Plaque composition and stiffness may be more clinically relevant than lumen reduction. Magnetic Resonance Elastography (MRE) is a method for determining tissue stiffness which may, in principle, be applied to arteries. An external actuator induces shear waves, whose displacement or wave speed within the tissue is measured using phase contrast MRI. Wave inversion algorithms are then used to estimate the tissue stiffness. A diagram of the experimental MRE set-up may be seen in figure [1]. The applications of MRE to the circulatory system to date are in the heart and aorta [1].

Method: A healthy vessel and two vessels containing either an idealised fibrous or lipid stenosis were created using a solid modelling software package (ABAQUS). Figure [2] shows the stenosis geometry. A hyperelastic, anisotropic constitutive model was used based on the properties published by Holzapfel [2]. The vessel was constrained in axial motion and a 100Hz torsion load applied at one end.

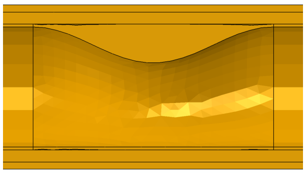
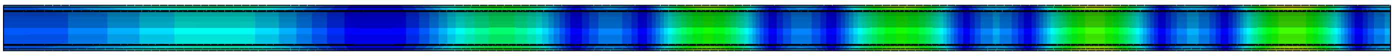


Figure [2]: Stenosis Geometry

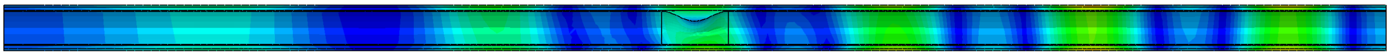
Results: Figure [3]; a cross sectional view of the shear wave propagating through an a) healthy vessel, b) fibrous and c) lipid stenosis at time step t= 6.0e-02 seconds. The presence of a stenosis causes disruption to the wave propagation; figure [3b] shows reduced displacement in the fibrous stenosis and figure [3c] shows areas of much greater displacement in the low stiffness lipid stenosis. Future work will be concerned with analysis of the shear wave patterns to determine overall plaque stiffness and improving the realism of the loading and plaque geometry.

Conclusion: A computational feasibility study has demonstrated that shear waves at MRE frequencies are disrupted by idealised atherosclerotic plaques, and that there are differences between the wave patterns through fibrotic and lipid-rich plaques. This suggests that the technique may have potential for use as a clinical tool to predict plaque rupture.

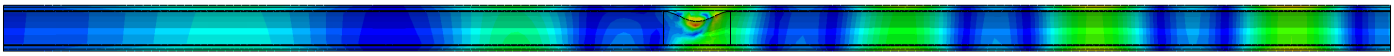
a) Healthy Vessel



b) Fibrous Stenosis



c) Lipid Stenosis



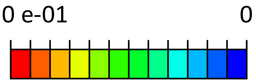


Figure [3] Cross Sectional View of Results

Magnitude, U (mm)

References:
[1] Kolipaka, Proc Joint Annual Meeting ISMRM-ESMRMB 2010
[2] Holzapfel, Ann Biomed Eng 2002; 30: 753-767