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Advanced Arterial Pathology Assessment: A 3D Wave Propagation Modelling Approach for Elastography

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Extended Abstract

Abstract

Cardiovascular diseases represent a major global health concern, affecting millions of people worldwide every year. Accurately determining the mechanical properties of the arterial wall is therefore crucial for reliable risk assessment and early diagnosis. In this context, wave-based diagnostic techniques have shown strong potential as non-invasive methods for the detection of cardiovascular diseases, as wave dispersion characteristics and propagation velocities provide meaningful information on the health and function of the arterial tree. Existing approaches are based on guided-wave formulations, such as Lamb waves, guided axial waves, or guided circumferential waves, derived under simplifying assumptions, including homogeneous, linear-elastic arterial walls, the absence of physiological residual stresses, and idealised fluid coupling. Moreover, these models produce stiffness measures that face significant limitations when anisotropy, layering, residual stresses, fluid-structure interaction, and pathological alterations become relevant. We propose an alternative modelling strategy for arterial wave propagation, that aims to overcome the limitations of conventional guided wave approaches. The method relies on a fully three-dimensional formulation combined with Bloch wave analysis, where Bloch–Floquet boundary conditions are used to reconstruct wave propagation along the vessel. The arterial wall is represented as a fibre reinforced material through the Gasser–Ogden–Holzapfel (GOH) constitutive model, capturing its anisotropic mechanical behaviour. The geometry is discretised using brick finite elements with a hybrid formulation, which enables an accurate representation of the intima, media, and adventitia layers. Physiological residual stresses due to axial stretch and internal blood pressure are incorporated, and fluid–structure interaction with blood is accounted. Several pathological conditions are investigated, including global stiffening, layer specific degeneration, loss of interfacial integrity, and delamination. By incorporating material parameters and structural alterations reported in the literature, these scenarios reveal distinct signatures in both dispersion characteristics and wave propagation velocities. The findings show that advanced, high-frequency wave analysis is able to distinguish between pathological mechanisms that remain undetectable using conventional models. The proposed framework offers a physically consistent and computationally efficient approach for modelling arterial systems, while also providing new insights for interpreting elastography data and pulse wave measurements.

Keywords:

Wave Propagation Non-invasive Diagnostics Arterial Wall Mechanics Cardiovascular Diseases Structural Pathology Detection