

3D Quantification of Wall Shear Stress and Oscillatory Shear Index Using a Finite-Element Method in 3D CINE PC-MRI Data of the Thoracic Aorta

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Abstract

Several 2D methods have been proposed to estimate WSS and OSI from PC-MRI, neglecting the longitudinal velocity gradients that typically arise in cardiovascular flow, particularly on vessel geometries whose cross section and centerline orientation strongly vary in the axial direction. Thus, the contribution of longitudinal velocity gradients remains understudied. In this work, we propose a 3D finite-element method for the quantification of WSS and OSI from 3D-CINE PC-MRI that accounts for both in-plane and longitudinal velocity gradients. We demonstrate the convergence and robustness of the method on cylindrical geometries using a synthetic phantom based on the Poiseuille flow equation. We also show that, in the presence of noise, the method is both stable and accurate. Using computational fluid dynamics simulations, we show that the proposed 3D method results in more accurate WSS estimates than those obtained from a 2D analysis not considering out-of-plane velocity gradients. Further, we conclude that for irregular geometries the accurate prediction of WSS requires the consideration of longitudinal gradients in the velocity field. Additionally, we compute 3D maps of WSS and OSI for 3D-CINE PC-MRI data sets from an aortic phantom and sixteen healthy volunteers and two patients. The OSI values show a greater dispersion than WSS, which is strongly dependent on the PC-MRI resolution. We envision that the proposed 3D method will improve the estimation of WSS and OSI from 3D-CINE PC-MRI images, allowing for more accurate estimates in vessels with pathologies that induce high longitudinal velocity gradients, such as coarctations and aneurisms..

Keywords

Three-dimensional displays, Stress, Finite element analysis, Biomedical imaging, Open systems, Interpolation, Geometry.