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Meshless Generalized Finite Difference Method and Human Carotid Atherosclerotic Plaque Progression Simulation Using Multi-Year MRI Patient-Tracking Data

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Summary

Atherosclerotic plaques may rupture without warning and cause acute cardiovascular syndromes such as heart attack and stroke. Many victims of the disease who are apparently healthy die suddenly without prior symptoms. Noninvasive methods to assess plaque vulnerability and identify patients with high rupture risk in a near future are needed. In this paper, we combine computational modeling and magnetic resonance imaging (MRI) techniques to quantify patient-specific carotid atherosclerotic plaque growth functions and simulate plaque progression. Participating patients were scanned about every 18 months to obtain plaque progression data. Point-wise vessel wall thickness (WT) changes were used as the measure for plaque progression. Three scans (T1, T2, and T3) were used to quantify plaque growth functions where WT at T3 was fit using terms including WT and wall maximum principal stress and their time derivatives. Vessel normal tissue, calcification and lipid core were assumed to be hyperelastic, isotropic and nearly incompressible. Both linear and nonlinear elastic models were used. The multi-component 2D plaque model was discretized and solved using a meshless generalized finite difference (GFD) method. Starting from the T2 plaque geometry, the solid model was solved. Then the next-time-step plaque wall thickness at every nodal point was calculated using the plaque growth function quantified based on MRI data. The procedure was repeated until T3 time was reached. Numerically simulated plaque progression agreed very well with real MRI-obtained plaque geometry at T3. The meshless GFD method is especially suitable for the complex plaque geometry and frequent update. We believe this is the first time patient-specific plaque progression simulation was reported based on multi-year patient-tracking data. Success of this project will lead to a better and quantitative understanding of plaque progression which adds a new dimension (time) to plaque vulnerability assessment for improved accuracy and reliability. This research was supported in part by NSF DMS-0540684 and NIH R01 EB004759.

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