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Recovery of Cellular Traction in Three-Dimensional Nonlinear Hyperelastic Matrices

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Abstract

The traction exerted by a cell on the extra-cellular matrix (ECM) is critical to understanding and manipulating important biological processes such as stem cell differentiation, cancer cell metastasis, and embryonic morphogenesis. This traction is typically quantified through traction force microscopy (TFM). In TFM, the displacement of select markers inside the ECM is tracked, and is used in conjunction with an elasticity problem to reconstruct the traction field. Most applications of this technique thus far have assumed that the matrix behaves as a linear elastic solid that undergoes small deformation and infinitesimal strains. In this manuscript, we develop and implement a robust and efficient TFM methodology that overcomes these limitations by accounting for geometric and material nonlinearities in the ECM. We pose the TFM problem as an inverse problem and develop efficient adjoint-based minimization techniques to solve it. We test the effect of measurement noise on the proposed method, and examine the error incurred by not including nonlinear effects when solving the TFM problem. We present these results for *in-silico* traction fields that are applied to realistic geometric models of microglial and neuronal cells.

Keywords: Cell traction force microscopy, Material nonlinearity, Geometric nonlinearity, Stabilized finite element formulation, Inverse problem, Adjoint equations

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