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Inverse Estimation of 3-D Traction Stress Field of Adhered Cell based on Optimal Control Technique using Image Intensities

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Abstract: Cells adhere to a substrate and generate traction forces in focal adhesions that enable them to apprehend extracellular mechanical properties [1]. Current concerns are focused on mechanisms how the mechanical balances hold in the cell and affect the cell behavior, and therefore non-invasive measurement techniques for the cell traction forces are required. The cell traction force microscopy (TFM) generalized by Dembo and Wang [2] is an attractive approach to non-invasively estimate cell traction force fields, in which an inverse problem is solved using a mechanical model of the substrate and displacement fields from fluorescent images of immersed beads in the substrate. So far, a wide variety of TFMs has been developed [3], and the authors have also proposed a novel TFM approach, which can offer the 3-D cell traction force field using in-plane displacements on multiple slices [4]. In these TFMs, since partial information of displacement fields is used as observation data, one of the component to determine the estimation accuracy is an image processing technique to evaluate the displacement field from the observation images for fluorescent beads. In addition, if the number density of the image-based displacements is not enough, an ill-posed condition occurs in solving the inverse problem. In this study, the authors propose a novel TFM approach which directly uses image intensities as the observation data without pre-processing the beads' displacement. The 3-D traction stress field is inversely estimated by solving an optimization problem, which minimizes a L2 norm of the difference of image intensities between the numerical model and observation, by an optimal control technique. A validity of the proposed approach has been confirmed though a numerical experiment using pseudo-observation data w/ and w/o data noise.

Keywords: 3-D traction stress field; adhered cell; inverse estimation; image intensity; optimal control

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