PATIENT-SPECIFIC BIOMECHANICAL MODELS FOR COMPUTER-ASSISTED MINIMALLY INVASIVE SURGERY

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ABSTRACT

During minimally invasive surgical procedures, interactions between surgical tool and soft tissue cause motion of the tissue and the intended target (e.g. a tumor). This may result in subsequent misplacement of the surgical tool. Realistic biomechanical models of tissue deformation could improve planning of the procedure [1]. Therefore, the objective of this study was to develop patient-specific models to predict motion of tissue and targets. This was achieved using a combination of magnetic resonance imaging (MRI), ultrasound elastography, and finite element (FE) modeling.

To validate the FE models, ultrasound elastography [2] was used to obtain strain images after mechanical compression of tissue mimicking phantoms with stiff inclusions to represent lesions. FE analyses with large deflection theory were performed to reconstruct the Young's modulus distribution in a region of interest from the strain images. The resulting distribution was also used to predict deformations upon application of different loading and boundary conditions, such as indentation and needle insertion. In addition to phantoms with simple geometry, we used a three-dimensional (3D) printing technique to create a more realistic phantom in the shape of a breast. MRI was used to reconstruct the geometry of the breast, which was used as an additional input for the biomechanical FE model.

Ultrasound elastography was capable of visualizing the stiff inclusions in the phantoms. Quantitatively, the distribution of elasticity in the phantoms as measured with elastography agreed well with results from dynamic material testing. Under different boundary and loading conditions (indentation and needle insertion), the FE model predicted target motions that were consistent with ultrasound measurements of displacements. Elastography-based FE models incorporating realistic geometry obtained by MRI were successfully applied to breast-shaped gels with inclusions.

We conclude that it is feasible to employ a combination of non-invasive imaging and FE models for accurate prediction of tissue and tumor motion. In future, this technique could be used to develop pre-operative models for minimally invasive surgical procedures.

REFERENCES

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