

PERSONALIZED VISCO-HYPERELASTIC FINITE ELEMENT MODELING FOR PREOPERATIVE BREAST TUMOR LOCALIZATION

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1. Introduction

Breast-conserving surgery (BCS) is the preferred treatment for non-palpable breast tumors, but accurate tumor localization during surgery is challenging due to breast deformation between preoperative (prone) MRI and the surgical (supine) position. Current methods, such as wire-guided localization, are invasive and often inaccurate. Biomechanical models, typically based on hyperelastic formulations, have been proposed to address this issue, often integrating imaging in the surgical position, such as supine MRI or optical surface scans. However, these models often fail to capture the complex mechanical behavior of soft tissue. We propose a visco-hyperelastic finite element model that localizes tumors using only surface scans. Validated across diverse anatomies, this approach offers a promising solution to enhance tumor localization and support more effective surgical planning in BCS.

2. Materials and Methods

We propose a patient-specific biomechanical model to register prone MRI to the supine surgical position for accurate breast tumor localization. The model employs a visco-hyperelastic finite element formulation to simulate large breast deformations. The dataset includes 15 retrospective breast cancer cases with prone T2 SPAIR MRI and supine CT, used to simulate the intraoperative surface and for evaluation. The breast was segmented from MRI and modeled as a homogeneous material with an added skin layer. Sliding contact was defined at the breast–chest wall interface. Subject-specific material parameters were optimized using the supine surface as target data

3. Results

The visco-hyperelastic model with sliding contact achieved a tumor localization error of 8.12 ± 4.15 mm and tumor-skin projection distance of 6.36 ± 4.66 mm. Visual results are shown in Figure 1. Performance across different breast volumes demonstrated consistent accuracy, confirming the model's robustness in tumor localization.

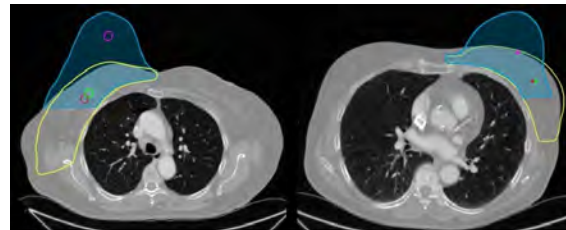


Figure 1: Results of the simulation.

4. Discussion and Conclusions

This study presents a patient-specific approach for modeling breast deformation from prone to supine using a visco-hyperelastic material model. The method optimizes mechanical properties based on individual data, achieving improved tumor localization accuracy with an average tumor distance of 8.12 ± 4.15 mm. The model outperforms previous prone-to-supine methods based on surface data [1,2]. Key innovations include using non-invasive surface data and the potential for real-time clinical applications. Further improvements could integrate this model with deep learning to generate data for training real-time models, enabling clinical applications with faster, real-time performance.

5. References

1. Eiben B, Vavourakis V, Hipwell JH, Kabus S, Buelow T, Lorenz C, et al. *Ann Biomed Eng.* 2016;44(1):154–173.
2. Duraes M, Crochet P, Pagès E, Grauby E, Lasch L, Rebel L, et al. *Breast J.* 2019;25(5):874–879.