Towards real-time patient-specific breast simulations: from full-field information to surrogate model

Introduction

In breast cancer treatment, surgery is one of the most common practices [DeSantis et al., 2019]. The surgery involves a complex pipeline, principally due to the difference between the imaging and the surgical posture [Mazier et al., 2021]. Indeed, because of the stance difference, the surgeon has to rely on radioactive or invasive markers to predict the tumor position in the surgical setup. Biomechanical simulations could predict such complex tumor displacements but often require patient-specific data (material properties, organs geometries, or loading and boundary conditions). Full-field acquisitions coupled with landmark identifications allow obtaining relative deformation between the different configurations. Having this information and assuming a finite element model, an identification procedure of the model parameters can be carried out. Finally, finding a suitable computational model allowing for a compromise between accuracy and speed, one may consider surrogate models for real-time simulations (20 to 50 FPS).

Methods

In this work, we obtained the patient-specific geometry through micro-computed tomography in 8 different configurations, including 15 bio-markers. Assessing the displacement of the bio-markers enabled us to infer the relative strains between the different configurations. A heterogeneous neo-Hookean model was assumed for simulating soft tissue behavior. Based on the displacements and the position of the biomarkers, model parameters identification was performed to calibrate the experimental data with the finite element method results. To overcome speed performance issues, Convolutional Neural Network (CNN) trained with a synthetic simulation-based dataset generated by applying different gravity directions is used.

Results

Preliminary results show that CNN can predict the displacement of anatomical landmarks to millimetric precision and is 100 times faster than the finite element method, satisfying our real-time objective. Plus, the use of Bayesian inferences involves a longer prediction time but allows a 95% confidence interval of the biomarkers' displacements.

Discussion

For a given precision, contrary to CNNs, optimization methods are computationally expensive and depend on an initialization point. Although CNNs require new training for each patient, optimization algorithms can be applied regardless of the patient's geometry. Through this study, we observed that material properties were playing an essential role but not as much as the anatomical structures e.g. infra-mammary or Copper's ligaments.

Acknowledgments

This study was supported by the European Union's Horizon 2020 grant agreement No 811099 and Marie Sklodowska-Curie No. 764644. The medical images were obtained from Hospital Arnaud de Villeneuve with Pr. Guillaume Captier and the company AnatoScope.

References

DeSantis et al., 2019, Breast cancer statistics, CA Cancer J. Clin, https://doi.org/10.3322/caac.21583.

Mazier et al., 2021, A rigged model of the breast for preoperative surgical planning, Journal of Biomechanics, https://doi.org/10.1016/j.jbiomech.2021.110645.