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. In 2016, nearly one-half of patients with early-stage (Stage I or II) breast cancer underwent breast-conserving surgery [DeSantis et al., 2019]. The surgery is part of 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 [Duraes et al., 2019]. Biomechanical simulations are a powerful tool capable of predicting such complex tumor displacements. Nevertheless, to run those simulations, patient-specific data are often required, such as material properties or organs geometries. Full-image acquisition (micro-computer tomography, magnetic resonance imaging…) coupled to digital volume correlation allows one to achieve relative deformation between configurations in vivo [Palenca et al., 2016]. Having this information and assuming a finite element model, an identification procedure of the model parameters can then be carried out. Finally, an additional constraint is to find a suitable computational model allowing for a compromise between accuracy and speed, one may consider surrogate models for real-time simulations.

Methods

In this work, we obtained the patient-specific geometry through micro-computer tomography in 8 different configurations with a 0.34 mm resolution. Digital volume correlation between the configurations was computed to achieve the relative deformations between them. Hyper-elasticity with residual strains was assumed as a material model of the soft tissue. 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 can be used.

Results

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

Discussion

Strengths and weaknesses arise among the 2 methods. Optimization techniques can usually achieve the same accuracy but are less computationally efficient and highly depend on the initial guess for the algorithm. CNNs will have to be trained again for each patient. It is a generic algorithm and 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 research and innovation program under grant agreement No 811099 and the Marie Sklodowska-Curie, Luxembourg grant agreement No. 764644. The medical images used in the present study were obtained from Hopital Arnaud de Villeneuve, Département de Gynécologie Obstétrique in collaboration with Pr. Guillaume Captier and the company AnatoScope.

References

DeSantis, C.E., Ma, J., Gaudet, M.M., Newman, L.A., Miller, K.D., Goding, S., Ann, J., Ahmedin, S., Rebecca, L., 2019. Breast cancer statistics, 2019. CA Cancer J. Clin. 69 (6), 438–451.

Duraes, M., Crochet, P., Pages, E., Grauby, E., Lasch, L., Rebel, L., Van Meer, F., Rathat, G., 2019. Surgery of nonpalpable breast cancer: First step to a virtual per-operative localization? First step to virtual breast cancer localization. Breast J. 25 (5), 874–879.

Mazier, A., Ribes, S., Gilles, B., Bordas, S.P.A., A rigged model of the breast for preoperative surgical planning. Journal of Biomechanics 128, 110645.

Mendizabal, A., Tagliabue, E., Brunet, J-N., Dall’Alba, D., Fiorini, P., Cotin, S., 2019. Physics-based Deep Neural Network for Real-Time Lesion Tracking in Ultrasound-guided Breast Biopsy. Computational Biomechanics for Medicine XIV, Oct 2019, Shenzhen, China.

Palanca, M., Tozzi, G., Cristofolini, L., 2016. The use of digital image correlation in the biomechanical area: a review, International Biomechanics, 3:1, 1-21.