Reconstruction of the Stress-free Hyperelastic Parameters of Breast Tissue: Machine Learning Based Inverse Problem Technique

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I. Introduction

A critical aspect of simulating breast deformation using the finite element method (FEM) lies in incorporating accurately parameters of the tissue mechanical properties. Mechanics of breast tissue, which is known to undergo substantial deformation during medical interventions, is best characterized by hyperelastic parameters. Traditional mechanical testing techniques often overlook the significant deformation caused by gravity loading during the preloading phase which is associated to initial stress before primary loading is applied. This preloading leads to imprecise estimations of the breast tissue hyperelastic parameters and consequently affecting breast deformation predictions. Such inaccuracies may result in erroneous diagnoses or suboptimal interventions within the realm of computer-assisted medical applications. To address this issue, a robust method is essential for estimating stress-free hyperelastic parameters based on those acquired under gravity loading.

II. Methods

Here, we propose a machine-learning based inverse-problem solution to convert hyperelastic parameters of the breast obtained from conventional mechanical testing [1,2] to their stress-free counterparts. In this study we investigated this conversion for the Yeoh and 1st order Ogden models. The concept of the proposed technique relies on generating two spaces corresponding to stress-free hyperelastic parameters and their preloaded counterparts. For this purpose, each hyperelastic parameter reported in the literature was scaled incrementally down to 50% of its value. These two spaces are then fitted using a neural network (NN). To construct the data space of the stress-free parameters, various combinations of the scaled-down parameters were formed after checking the Drucker Stability condition, leading to over 800 points. For each point in this space, a uniaxial test was simulated using FEM where the gravity preloading was included, to obtain simulated stress-strain data. This data was fitted in accordance with the hyperelastic model to estimate the corresponding hyperelastic parameters under gravity preloading conditions. This led to the required two data spaces. To map the latter space to the former, we constructed a NN that contains three layers with ~80 hidden neurons in each layer. Once this NN is trained, it can be used to convert any breast tissue hypereleastic parameter set obtained in traditional mechanical testing to its stress-free state counterpart.

III. Results

We calculated the distance between predicted and true unloaded hyperelastic parameter points and used the r^2 parameter to measure the accuracy of results obtained from the NN. For the two independent models: Yeoh and 1st Ogden, the best predicted accuracy was obtained at 0.91 and 0.86, respectively. Using reverse simulation, we validated the obtained parameters by comparing the breast model configuration with its ground truth, demonstrating strong consistency. Details of this evaluation are omitted due to space limitation.

IV. Conclusions

The proposed method is capable of predicting the stress-free hyperelastic of the breast tissue using their loaded counterpart with high accuracy. To the best of our knowledge, this is the first work that employs a machine learning-based approach to estimate stress-free hyperelastic parameters. A more comprehensive and in-depth literature review is necessary to contextualize our work in the broader field of breast tissue simulation and mechanical property estimation. While only two hyperelastic models were investigated, the method can be adapted with other models and to other types of tissues (e.g brain and liver).

KEYWORDS: BREAST TISSUE, STRESS-FREE STATE, HYPERELASTCI PARAMETERS, INVERSE PROBLEM, NEURAL NETWORK

References

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