

Optimal design of experiments for in-vivo identification of breast tissue mechanical properties

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Abstract

Breast cancer is the leading cause of cancer-related death in females, affecting 1 in every 10 women worldwide. Breast conserving therapy (BCT) is the most common procedure used for treating early-stage invasive breast cancers, and involves localized excision of tumorous lesions. The success of BCT procedures depends largely on the ability of a surgeon to palpate and excise lesions in their entirety to reduce the chance of local recurrence of the disease. However, palpation can be difficult, depending on the composition of the breast and the characteristics of the cancer. Furthermore, clinical imaging modalities used for diagnosing and detecting the extent of tumors (e.g. MRI), acquire information with the patient in different positions to that assumed during surgery (Turnbull et al., 2010). These represent some of the biggest challenges that surgeons face when treating the disease, which currently results in incomplete excision in 20 % to 40 % of BCT patients.

Patient-specific biomechanical models of the breast can be used to address these challenges by predicting the position of tumors during surgical procedures (Babarenda Gamage et al., 2012). Successful application of these models depends on their ability to make reliable predictions, and therefore requires robust identification of individual specific soft tissue constitutive parameters by minimizing discrepancies between model simulations and model calibration experiments. Identifying these mechanical properties is particularly challenging as they require experiments to be performed in-vivo using non-invasive methods, and therefore require simultaneous identification of all relevant model parameters. This is in contrast to conventional ex-vivo parameter identification methods, which can apply independent modes of deformation to samples of tissue to simplify and constrain the identification problem.

In this study, we present a biomechanical model of the breast for predicting the motion of tumors from their locations identified in diagnostic MRI (acquired in the prone position), to their locations in the supine position (for surgical applications, for example). We illustrate how optimal design of experimental protocols can be used to investigate approaches for identifying the constitutive parameters of the in-vivo tissue to ensure that predictions of the required precision can be achieved. This involved determining the specific orientations in which the breast could be positioned, under gravity loading, in order to elicit deformations in the tissue that provide maximal information for identifying model parameters. Methods for quantifying the identifiability of the parameters for a given experiment, and visualizing their variability due to measurement uncertainty, are also presented. While this approach is demonstrated for breast tissue parameter estimation, these techniques may be useful for a wide range of biomechanics applications.

Keywords: Soft tissues mechanics, constitutive parameter estimation, optimal design of experiments, breast biomechanics

References

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