Toward a Patient-Specific Image Data-Driven Predictive Modeling Framework for Guiding Microwave Ablative Therapy

Michael I. Miga[a], Jarrod A. Collins[a], Jon S. Heiselman[a], and Daniel B. Brown[b]

[a]Vanderbilt University, Department of Biomedical Engineering, Nashville, TN 37235
[b]Vanderbilt University Medical Center, Department of Radiology, Nashville, TN 37232

Abstract: In this work, we report on a preliminary effort toward a novel multi-physics framework that combines computational approaches in soft-tissue biomechanics, and biotransport to create a patient-specific, image-data driven, guidance platform to improve localization and predict thermal dose delivery for microwave thermal ablation. More specifically, the approach begins with the use of standard preoperative magnetic resonance imaging that allows for the modeling of patient-specific organ shape followed by the acquisition of an additional fat quantification sequence (mDixon Quant) which allows for the establishment of patient-specific dielectric and thermal properties. With bioelectric and bioheat patient-specific planning models established, accurate predictions of thermal dose can be created. With dose prediction capabilities realized, the process moves on to an image-guided approach for delivery. In order to translate preoperative dose estimates to guide procedures, it is important to be able to deliver a microwave antenna to the appropriate position determined by planning. Within open, laparoscopic, or percutaneous ablative procedures, often deformation of soft-tissue organs during the procedure can compromise guidance accuracy. As part of this multiphysics framework, a soft-tissue biomechanical model is then used in combination with sparse geometric digitization data to account for deformation and provide an accurate image-to-physical registration.

To investigate, we demonstrate the novel framework in realistic liver phantoms. Briefly, phantoms were created with varying fat content between 0-10%, a range quite similar to that found in fatty liver disease. Microwave ablations were then created physically and in silico with the latter being 'tuned' by previously acquired fat quantification images. To evaluate, overlap of the physical ablation and computationally predicted were measured. The model-predicted ablation zones showed compelling overlap with observed ablations in both the validation phantoms (93.4 ± 2.2%) and the leave-one-out cross validation study (86.6 ± 5.3%). With respect to localization, our biomechanically-driven image-to-physical registration methodology to correct for deformation has been equally encouraging. In the case of partial surface availability for registration, the average target registration error was 6.0 ± 2.3 *mm* and 3.7 ± 1.4 *mm* for rigid, and nonrigid registration. When the full surface of the liver could be used, the average target registration error was 5.6 ± 2.3 *mm* and 2.5 ± 1.1 *mm* for rigid, and nonrigid registration (see Figure 1). Similarly, when comparing the predicted ablation relative to ground truth, the volumetric overlap was 67.0 ± 11.8%, and 85.6 ± 5.0% for rigid, and nonrigid registration, respectively. This multiphysics framework demonstrates, as a proof-of-concept, that physical modeling parameters can be linked with quantitative medical imaging to improve the utility of predictive procedural modeling for microwave ablation as well as improve localization.

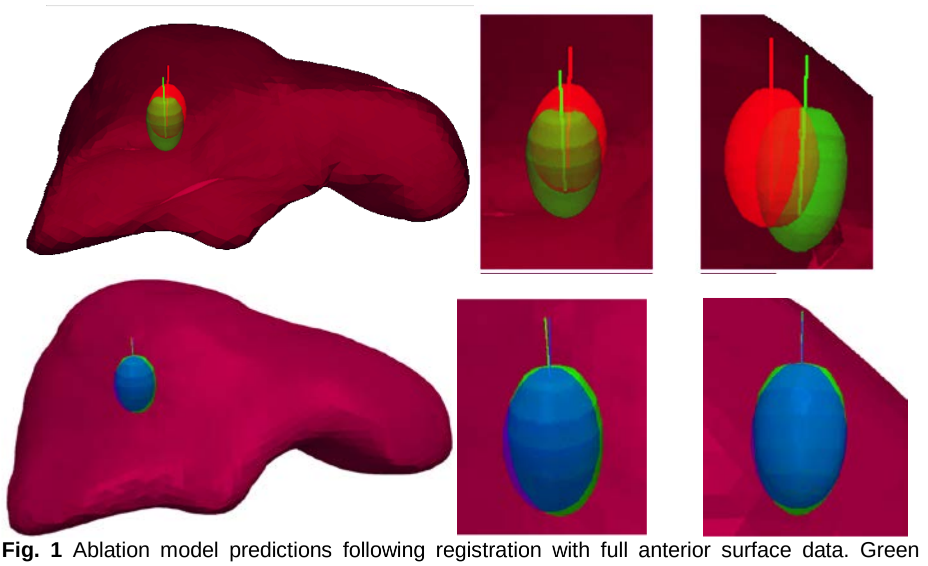

Fig. 1 Ablation model predictions following registration with full anterior surface data. Green represents ground truth ablation. The rigidly registered ablation model is presented in the top panels (red). The registered ablation model following deformation correction is presented in the lower panels (blue). Additionally, in each panel the registered ablation antenna indicated by lines with color corresponding to the registration method.

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