# MODELING LUNG TISSUE MOTIONS AND DEFORMATIONS: APPLICATIONS IN TUMOR ABLATIVE PROCEDURES

by

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# Abstract

Various types of motion and deformation the lung undergoes during minimally invasive tumor ablative procedures, *e.g.* Low Dose Rate (LDR) brachytherapy, have been investigated and modeled in this dissertation. Modeling such motions and deformations are highly necessary for enhancing the accuracy of lung's Minimally Invasive Surgery (MIS). This necessity stems from the fact that due to its porous structure, which is associated with its millions of tiny alveoli, the lung is the most deformable organ in the body. As such, the lung undergoes continuous large deformation during respiration. This deformation can greatly affect the pre-planned outcome of the operation. For example, it may result in targeting an area far away from the aimed region and/or lead to significant areas of over- and/or under-radiation dosage. The first type of major deformation involved in a target lung throughout a minimally invasive tumor ablative procedure is the one encountered in procedures where the lung is totally deflated before starting the operation. A consequence of this deflation is that pre-operative images, *e.g.* Computed Tomography (CT), acquired while the lung was partially inflated become inaccurate for targeting the tumor. Another issue is that MIS procedures usually employ intra-operative Ultra-Sound (US) imaging for guidance. However, US images of the deflated lung have a very poor quality due to the small amount of air remaining in the deflated lung. To address challenges associated with deflating the lung, a novel construction technique has been proposed in this thesis to obtain CT image of the totally deflated lung. This technique processes the lung's 4D-CT respiratory image sequence acquired pre-operatively. It consists of a deformable registration/air volume estimation/extrapolation pipeline. The pipeline does not require any external marker, as it is capable of estimating the lung's air volume from the CT images automatically using a newly developed segmentation approach introduced in this thesis. The constructed CT image can be used for both pre- and intra-operative tasks such as treatment planning, tumor localization, and surgical navigation. To deal with the US image poor quality issue, a novel registration strategy has been introduced to enhance the quality of the lung's intra-operative US image by employing the constructed high quality CT image. Several experiments conducted throughout this research demonstrate favorable accuracy of the proposed techniques used to estimate the lung's air volume, construct CT image of the totally deflated lung, and enhance the quality of the lung's intra-operative US images. The second major type of lung deformation tackled in this thesis is the one due to respiratory anatomical contact forces as well as needle insertion which can be characterized using tissue biomechanical models. Two major prerequisites of developing such models are realistic biomechanical parameters of the lung soft tissue, and proper lung tissue discretization for which inevitable yet reasonable geometry simplification should be incorporated. Measuring the lung's tissue hyperelastic properties and assessing the effects of simplifying the deflated lung's geometry on its biomechanical model's accuracy have been investigated in the last two parts of this thesis. Indentation experiments conducted on dozens of lung tissue samples followed by inverse finite element simulations performed led to accurate measurement of lung tissue hyperelastic parameters. Tests were performed to validate the results which demonstrated the uniqueness and accuracy of the obtained parameters. Studies conducted in the last part of this thesis on geometry simplification effects suggested that the tumor displacement due to surface contact forces estimated by the Finite Element Method (FEM) is not very sensitive to the geometry simplification of omitting airways as long as the airways size does not exceed the tumor size. The results reported in these parts paved the way for the lung's accurate biomechanical modeling for predicting tissue deformation resulting from contact forces and needle insertion in future studies.

## Keywords

Lung Cancer, Respiratory Motion, Lung Deformation, Tumor Ablative Procedures, Brachytherapy, Respiratory Sequence, 4D-CT, Modeling, Deformable Models, Image Registration, Lung's Air Estimation, Image Segmentation, Ultrasound Image Enhancement, Lung Tissue Properties, Hyperelastic Parameters, Geometry Simplification, Omitting Lung's Airways.