Modeling lung deflation during video-assisted thoracoscopy surgery for the localization of small nodules

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Introduction

Lung cancer remains as the worldwide leading cause of cancer death [1]. The disease is normally identified at late stages, where the 5-year survival rate lies between 6% and 18% [2]. However, survival opportunities might significantly increase if diagnosis and treatement are performed at early stages [3]. In this regard, screening programs have used low-dose CT to raise detections of early stage lung cancers [3]. In such scenarios, surgical resection through thoracotomy or video-assisted thoracoscopy (VATS) are the choice of treatment, the latter being a less invasive method with better and faster patient recovery [4].

One of the principal issues during a VATS resection comes from the localization of small, subsolid nodules [5]. In practice, such difficulty is addressed by physically tagging the lesions (e.g., dyes, wires, coils) through an auxiliary, preoperative CT-guided procedure [6]. However, in addition to the associated risks (e.g. bleeding, pneumothorax), these methods are not fully reliable and result in further costs and organizational burdens.

Intraoperative cone-beam CT (CBCT) has been previously used for guiding a variety of medical interventions (e.g. head and neck surgery, orthodontics). In addition, thanks to its low dose radiation and fast acquisition time, CBCT imaging might potentially guide the localization of small and subsolid nodules during a VATS procedure [7, 8]. This approach will not only eliminate the hazardous preoperative interventions, but it will also allow a safer, more deterministic method for the localization of challenging nodules. However, during the VATS intervention, the surgeon purposely creates a pneumothorax that makes him space for the comfortable manipulation of the lung. This results in a total collapse of the lung into a deflated state, which invalidates any measurement formerly calculated via preoperative CT.

This work introduces a biomechanical model of the lung that simulates its deflation process during a VATS intervention. The model can be used to predict the geometrical alterations of different lung structures, and more interestingly, the re-positioning of nodules within the parenchyma due to lung deflation. To the best of our knowledge, no previous attempt exists for the mechanical modeling of lung deflation for the localization of small, subsolid nodules during a VATS intervention.

Materials and Methods

The biomechanical model of lung deflation will be built upon a Finite Element Method (FEM) formulation. The main lung structures of concern for such model are the lobes and the initial levels of the airway tree. For the segmentation of the lobes, we have used a modified version of the Chest Imaging Platform, an open source plugin for the 3D Slicer software. In the case of the airway tree, a combination of Frangi et al. [9] vesselness measure and a 3D region growing algorithm has been

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used. These two segmentations are then used to obtain a patient-specific mesh of tetrahedral Finite Elements for the inflated lung, i.e. the lung in its preoperative state.
Although the mechanical behavior of the lung is extremely complex (e.g. very flexible tissue, very large deformations, influence of residual air, plasticity), in this preliminary work we have assumed linear-elasticity in the constitutive equation. Material properties for each Finite Element are estimated by merging information extracted from the preoperative image and information from previous works on the behaviour of lung tissue [10, 11]. Segmentations from the intraoperative CBCT are used to constraint the model using Lagrangian Multipliers. This FEM formulation is solved by using a co-rotational approach, whose efficiency allows us to comply with clinical requirements of time. Finally, the obtained deformation field is applied to preoperative nodule information to obtain the updated, intraoperative position of the nodule.
The validation of our proposed approach will be performed using retrospective data of 4 patients that underwent a VATS intervention. This study will allow us to identify the influence of different factors (e.g. gravity, elasticity, boundary conditions) to take into account for an accurate modeling of the lung deflation. We intend to continue our research by using a more reliable constitutive equation. Our final goal in the long term is to develop an application for intraoperative model-driven localization of lung nodules.

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