Efficient Semi-Automatic Workflows for Segmenting the Lung Lobes and Lesions in CT Images of COVID-19 Patients: Application to Full Inspiration and Full Expiration

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Introduction: Coronavirus disease-19 (COVID-19) is a severe acute respiratory syndrome that has caused a deadly worldwide pandemic. Computed tomography (CT) scans of the chest are useful for diagnosis, disease management, analysis, and research on COVID-19 infected lungs. Analysis of the infected lungs requires that the lungs are isolated from surrounding tissues in the CT images using image segmentation. Manual segmentation methods are cumbersome and often irreproducible, while automatic segmentation methods are computationally costly. COVID-19-afflicted lung CT scans make segmentation more challenging due to the presence of ground-glass opacities (GGOs) and nodules in addition to motion artifacts due to coughing. Hence, efficient semi-automatic segmentation approaches using open-source software are a promising option for the analysis of COVID-19 lungs. Therefore, the objective of this study was to develop and compare two efficient semi-automatic workflows for segmenting COVID-infected lungs from low-resolution CT images at full inspiration and full expiration.

Materials and Methods: A four-dimensional computer tomography (4DCT) dataset showing the lung at different phases of breathing was obtained from a COVID-19-positive patient at Vidant Medical Center (Greenville, NC) in accordance with IRB-approved protocol. 4DCT images were imported for segmentation in 3D Slicer software (slicer.org)[1,2] and used in two separate workflows to create lung lobe and lesion segmentations. Both workflows started by using the Interactive Lobe Segmentation module of the Chest Imaging Platform to create outlines of the five lung lobes based on the interlobar fissures[3]. The additive workflow consisted of region growing of the lobes using the Margin tool and manual addition of GGOs. The subtractive workflow created a segmentation of both lungs using the Lung CT Segmenter module that includes the internal GGOs and manually added GGOs on the edges of the lungs[3]. Each segmentation method was performed on datasets taken at the end of inhalation and the end of exhalation. We then performed a volumetric analysis using the Lung CT Analyzer module (github.com/rbumm/SlicerLungCTAnalyzer/)[3].

Results and Discussion: Both workflows were successful in creating lung segmentations suitable for analysis (Figure 1). Total volume, functional volume, and COVID-affected volume (infiltrated and collapsed regions) were compared. Differences in these values ranged from 0% to 6% when comparing end-inhalation to end-exhalation segmentations, indicating similar capability for segmenting COVID lungs. It is notable that the additive workflow requires more manual intervention, so the subtractive workflow may be more suitable in the absence of a significant difference. When comparing inhalation to exhalation, a 30% reduction in functional volume and a 3-6% increase in COVID-affected volume was observed. At end-inhalation, 48% of the total lung volume was affected by COVID and at end-exhalation 59% of the lung is affected.

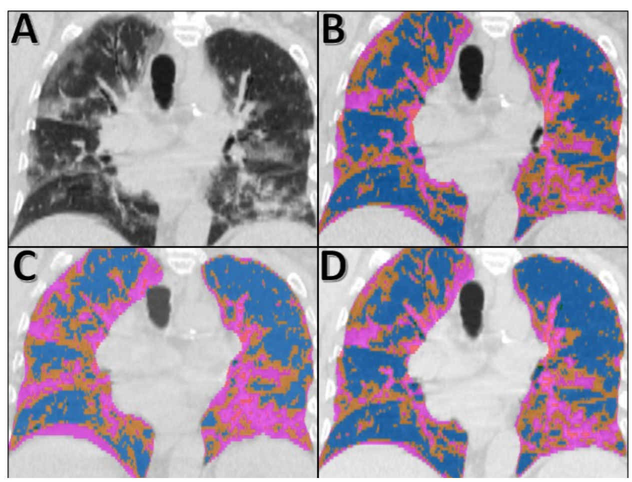

Figure 1. (A) Mid-sagittal view of the lung at end-inhalation. (B) Additive method results at end-inhalation. Blue is the inflated area, pink is the collapsed area, orange is the infiltrated area. (C) Subtractive method at end-exhalation. (D) Subtractive method at end-inhalation.

Conclusions: The results of this study demonstrate that additive and subtractive semi-automatic workflows in 3D Slicer are effective for COVID lung lobe segmentation. Results also show that inflated lung volume decreases from end-inhalation to end-exhalation while COVID-affected volume persists, resulting in the appearance of higher severity at end-exhalation than end-inhalation. This indicates that the temporal characteristics of the respiratory cycle are important to consider when segmenting COVID-19 lungs.

Acknowledgments: This material is based upon work supported by the National Science Foundation under CMMI-2034964. The funding source had no role in writing the manuscript.

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