Automated Respiratory Pattern Analysis for Dynamic MRI of the Lung with Post COVID-19 at 0.55T

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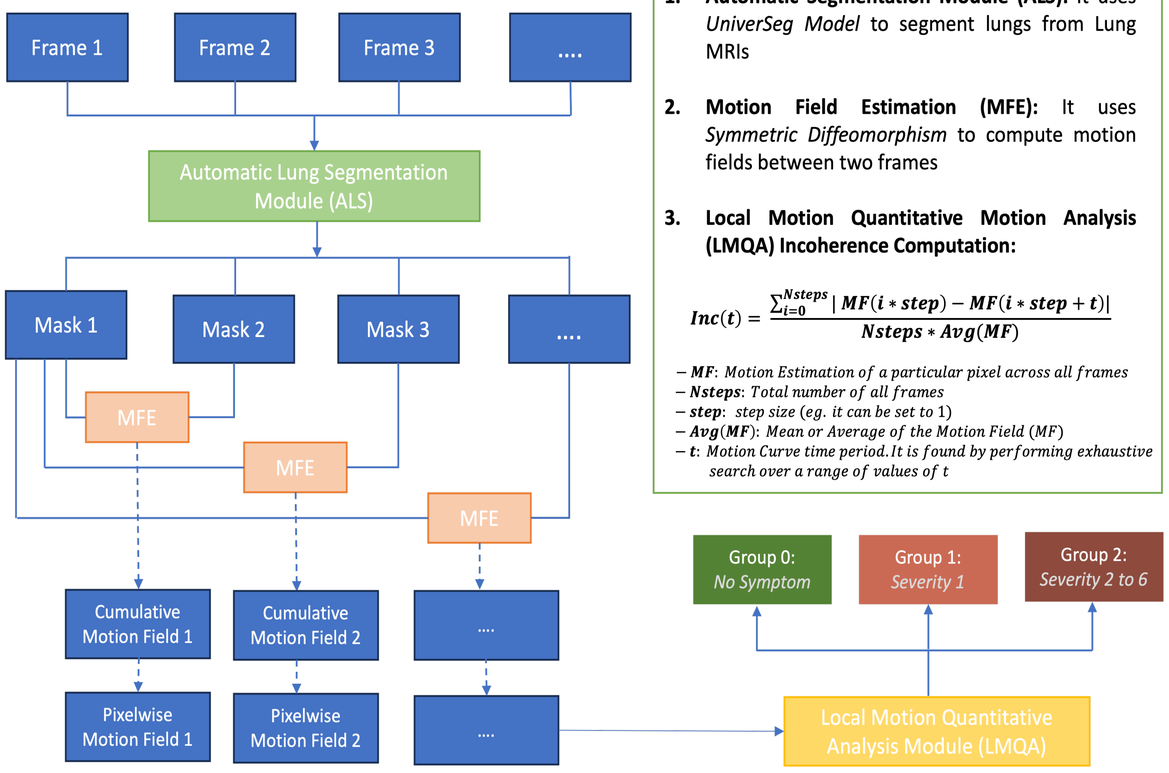
INTRODUCTION

- **Post COVID-19, some patients experienced long COVID demonstrating respiratory symptoms, including but not limited to breathlessness. Currently, there is a lack of non-invasive approaches for quantitatively describing the patterns of respiration in such patients.**
- **This research introduces a deep learning-assisted framework named "Automated Detection of Localized Motion in Lung MRI" which centers on the analysis of motion fields for individual pixels within distinct local regions of lung MRIs.**
- **The findings of this analysis can be subsequently leveraged to categorize post covid-19 patients as either having Long COVID or exhibiting no symptoms through the examination of these localized motion fields.**

METHODS

Pipeline for Automated Respiratory Pattern Analysis for Dynamic Lung MRI



1. **Automatic Segmentation Module (ALS):** It uses *UniverSeg Model* to segment lungs from Lung MRIs
2. **Motion Field Estimation (MFE):** It uses *Symmetric Diffeomorphism* to compute motion fields between two frames
3. **Local Motion Quantitative Motion Analysis (LMQA) Incoherence Computation:**

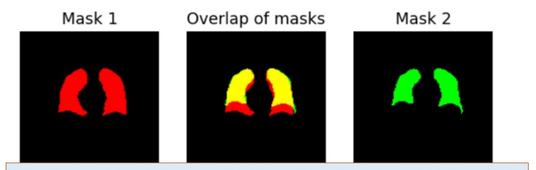
$$Inc(t) = \frac{\sum_{i=0}^{Nsteps} |\, MF(i*step) - MF(i*step+t)|}{Nsteps * Avg(MF)}$$

- MF: *Motion Estimation of a particular pixel across all frames*
- $Nsteps$: *Total number of all frames*
- $step$: *step size (eg. it can be set to 1)*
- $Avg(MF)$: *Mean or Average of the Motion Field (MF)*
- t: *Motion Curve time period. It is found by performing exhaustive search over a range of values of t*

- **The framework comprises three primary modules: *the Automatic Lung Segmentation module (ALS), the Motion Field Estimation module (MFE), Local Motion Quantitative Analysis module (LMQA).***
- **In the ALS module, a fine-tuned UniverSeg: Universal Medical Image Segmentation model is employed. UniverSeg is a pre-trained model capable of executing medical image segmentation tasks on various organs by utilizing limited support images and labels without any training on the current dataset.**
- **In the MFE module, Symmetric Diffeomorphism was utilized to estimate the motion field for each pixel within the reference frame. This estimation was achieved by computing the cumulative motion field between the lung mask of frame 1 and the lung masks of subsequent frames (frame 2, 3, and so forth). Additionally, each pixel in the mask is tracked throughout all frames, and the pixel-wise motion field is computed using cumulative motion fields generated previously.**
- **In the LMQA module, the incoherence of the motion of every pixel of the mask across all frames is computed. As depicted in the pipeline diagram above, *incoherence* gauges how far a specific curve is from being periodic.**
- **Through the computation of pixelwise incoherence within the motion curve, the outcomes can reveal whether the patients are displaying no symptoms or are undergoing a bout of long COVID.**
- **It should be noted that patients were divided into three groups for the respiratory analysis: Group 0 included patients with no symptoms, Group 1 included patients with severity level 1, and Group 2 included patients with severity level 2 to 6.**

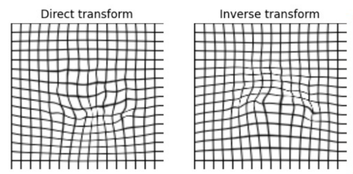
RESULTS

Results: Motion Field Estimation

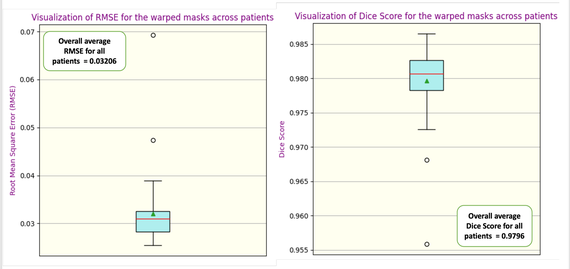


Mask 1 and Mask 2 are passed to registration algorithm. Overlap of masks shows the difference between the two masks.

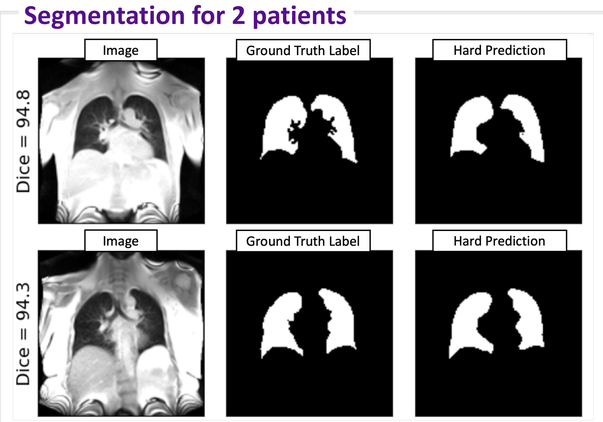
Warped Mask is the output of the registration algorithm. It should equal Mask 2. Note that both masks are overlapping correctly.



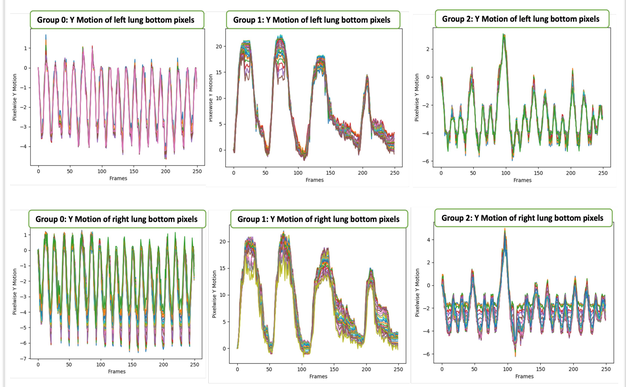
Mappings generated by the algorithm. Direct transform converts Mask 2 to Mask 1. Inverse transforms Mask 1 to Mask 2.



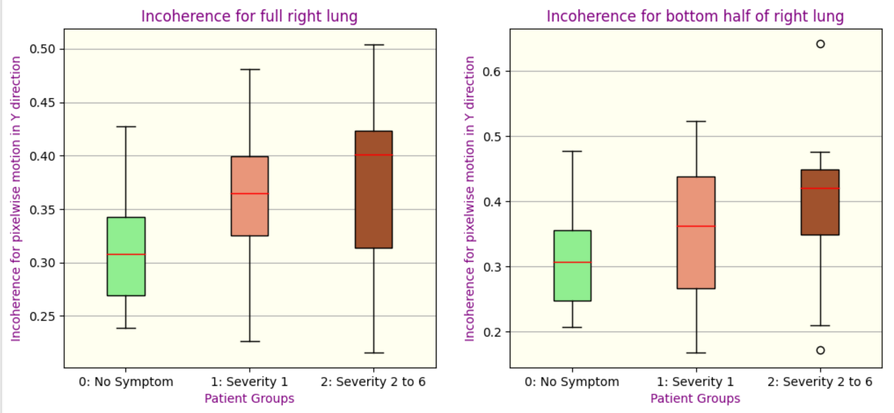
Results: Automatic Segmentation for 2 patients



Results: Pixelwise Y Motion visualization for patients from different groups



Results: Incoherence Computation for Right Lung

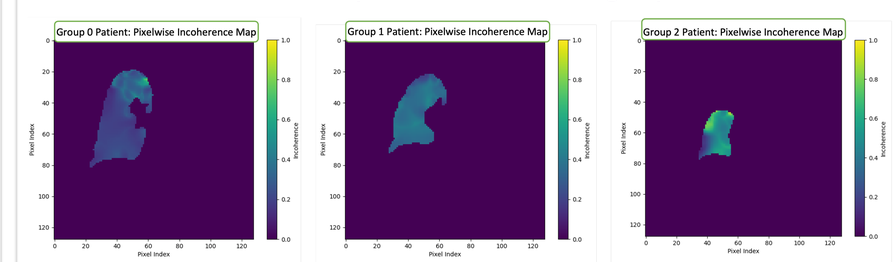


Dataset Summary	
Total Number of Patients in Group 0	10
Total Number of Patients in Group 1	14
Total Number of Patients in Group 2	12
Total Number of Patients	36
Total MRI frames per patient	250

Full Right Lung Incoherence Results	
Average Incoherence Group 0	0.31568
Average Incoherence Group 1	0.35936
Average Incoherence Group 2	0.37359

Bottom Half Right Lung Incoherence Results	
Average Incoherence Group 0	0.31636
Average Incoherence Group 1	0.35442
Average Incoherence Group 2	0.39333

Incoherence visualization for patients from different groups



Full Right Lung Incoherence Results	
Average Incoherence Group 0	0.23901
Average Incoherence Group 1	0.36048
Average Incoherence Group 2	0.47571

Bottom Half Right Lung Incoherence Results	
Average Incoherence Group 0	0.20718
Average Incoherence Group 1	0.37260
Average Incoherence Group 2	0.40567

DISCUSSION & CONCLUSION

This study proposed a novel motion detection framework named "Automated Detection of Localized Motion in Lung MRI." This fully automated pipeline differentiates between patients with Long COVID and those displaying No Symptoms by scrutinizing the motion fields of individual pixels of the lungs.

REFERENCES

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2. Avants, Brian B., et al. "Symmetric diffeomorphic image registration with cross-correlation: evaluating automated labeling of elderly and neurodegenerative brain." *Medical image analysis* 12.1 (2008): 26-41.
3. Quantitative Characterization of Respiratory Pattern on Dynamic High Temporal Resolution MRI to Stratify Patients by Cardiopulmonary Symptom Severity. *Journal of Magnetic Resonance Imaging. Under Review.*

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