An adversarial machine learning framework and biomechanical model guided approach for generating 3D lung tissue elasticity from low dose end-exhalation CT

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Background

- Characterization of lung tissue elasticity is currently limited to 4D scans and other imaging modalities, while most diagnostic imaging uses low dose CT scans.
- The purpose of this study is to develop a method for predicting lung elasticity distribution using only a single low dose CT scan, enabling elasticity distributions to be widely employed in diagnostic and research applications.
- Such a process opens new avenues of research in the field of diagnostic imaging where the use of elasticity as a biomarker can be effective in characterizing diseases such as COPD.

Methods

- First, developed a machine learning based approach to predict a 3D lung tissue elasticity distribution given only a low dose breath-hold CT scan.
- 10 patient low-dose free breathing CT (FBCT) datasets were used to simulate ultra low-dose equivalents, which were in turn used to generate low-dose 5DCT motion models and end-inhalation and end-exhalation CT scans.
- Tissue elasticity was then estimated with a biomechanically guided inverse elasticity approach.
- A machine learning process (constrained Generalized Adversarial Neural Network (cGAN)) learned the lung tissue elasticity in a supervised manner for the simulated low dose end-expiration CT.
- Finally, cGAN estimated elasticity distributions were validated using:

a) Direct comparison with the 5DCT-based elasticity data via an L2-norm

b) Regenerating synthetic 4DCTs and comparing with ground-truth 4DCTs using 3 image similarity metrics: Mutual Information (MI), Structured Similarity Index (SSIM), and Normalized Cross Correlation (NCC).

Results

- For the training data set consisting of 8 low dose CT scans, we obtained a learning accuracy of 0.6 kPa.
- For the validation dataset consisting of 2 scans, we achieved an accuracy of 0.9 kPa.
- To demonstrate the ability of our learning process to account for patient variation and disease complexity we present the elasticity distribution for a lung cancer patient with severe COPD
- Fig 1 (a & b) shows a comparison of the ground truth elasticity and the cGAN generated elasticity for a subject with both lung tumor and severe COPD prevalence, respectively.
- Fig 1c shows the difference between the two estimations.

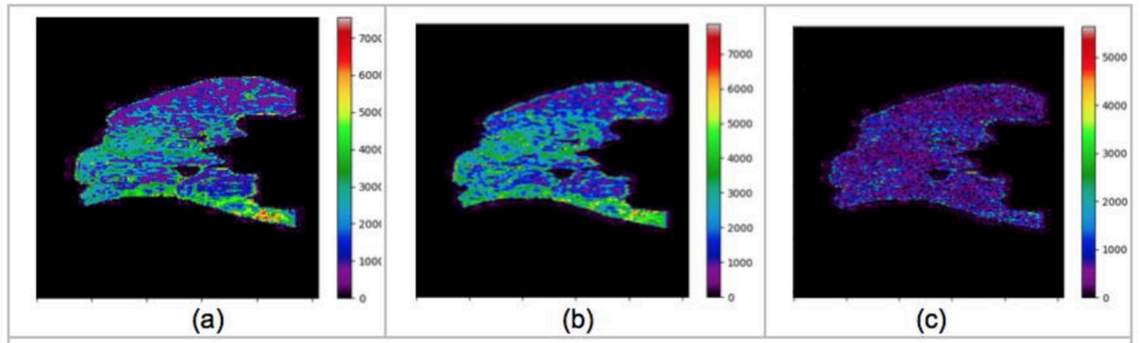

Figure 1. (a) Lung tissue elasticity estimated from the biomechanical model guided estimation for COPD patients (b) Lung tissue elasticity distribution estimated from the cGAN (c) The resulting differences in the elasticity. The units are Pascals for all images.

Conclusions

- cGAN generated lung tissue elasticity can be effectively estimated given a low dose end-expiration CT image with clinically acceptable accuracies.
- Variations in patient geometry and disease pathophysiology can be represented by the machine learning approach.
- This framework opens research avenues, where CT-based elastography can be used in a diagnostic setup for characterizing and phenotypic lung diseases.

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