Idiopathic pulmonary fibrosis: a study using volumetric imaging and functional data in a computational lung model

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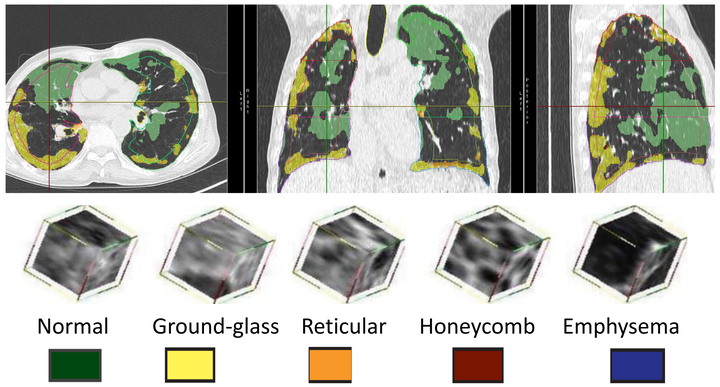
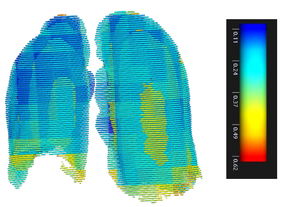
Introduction

Idiopathic pulmonary fibrosis (IPF) is an aggressive idiopathic interstitial pneumonia, and often occurs in elderly adults. In IPF, fibrosis typically develops preferentially in posterior-basal lung regions, and often co-exists with emphysema. Currently it is not clear how - or whether - the spatial distribution of tissue abnormalities in IPF (including classifications of tissue type) correlate with pulmonary function tests (PFTs) and their change over time. This work aims to develop a new quantitative tool that integrates data from volumetric imaging, PFTs, and computational models for lung function, to understand differences between IPF and normal older lungs.

Tissue classification and quantification

- **Data**- Clinical IPF CT data from Auckland City Hospital
  8 patients, 4 of them contain more than one time point scan for each
- **Pulmonary parenchyma classification** - CALIPER (Computer-Aided Lung Information for Pathology Evaluation and Ratings) classification of abnormalities based on signature mapping techniques



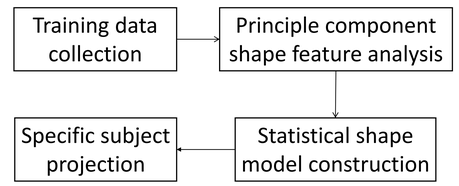


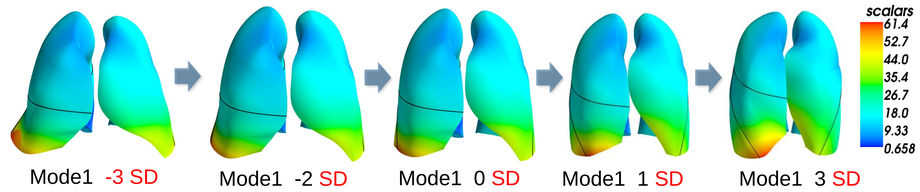
3D grid density visualization of tissue patterns

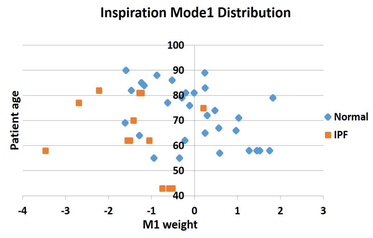
- Fibrosis has a consistently higher tissue density (0.34/0.41 for reticular/ground-glass) compared to normal tissue (0.28) over time. In contrast, emphysema has lower density (0.08)
- Fibrosis presents predominantly in lower lobes (72%, 58%, 65% for honeycomb, reticular, ground-glass). But emphysema appears predominantly in upper lobes (73%).
- The distribution of fibrosis is basal, peripheral and pathy. The disease mostly occurs in small airways which causes peribronchiolar airway constriction.

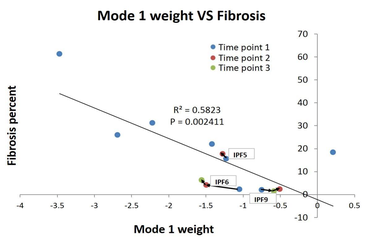
Analysis 1

Statistical shape model based shape analysis









- Mode 1 of the SSM is significantly different between IPF and normal subjects and correlates with percent of fibrosis ($p<0.01$).
- The most significant variation in shape (mode 1 of the SSM) relates to the anteroposterior diameter of the lung, and the ratio of apical and basal diameters
- There is a significant difference of right lower lobe volume and right middle lobe volume between normal old and IPF lungs ($p<0.001$, $p<0.001$ respectively).

Analysis 2

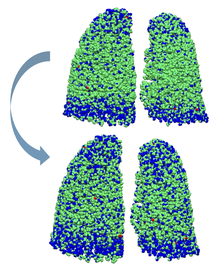
Patient-specific computational modelling of lung function

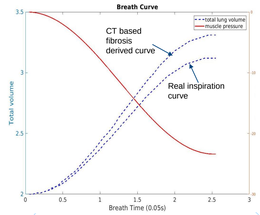
Step1: Airway and vessel tree generation with disease labeling

Maunual digitize upper airway/vessel → Map upper airway/vessel to PCA predicted mesh of old normal lung → Generate full airway/vessel tree → Map full airway/vessel back to disease lobe mesh → Label airway/vessel tree with different tissue patterns

Step 2: Ventialtion and perfusion simulation

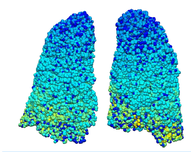
Deep inspiration using normal geometry and lung volume → Set patient-specific muscle pressure → Deep inspiration using disease geometry and lung volume → Predict model based real fibrosis distribution





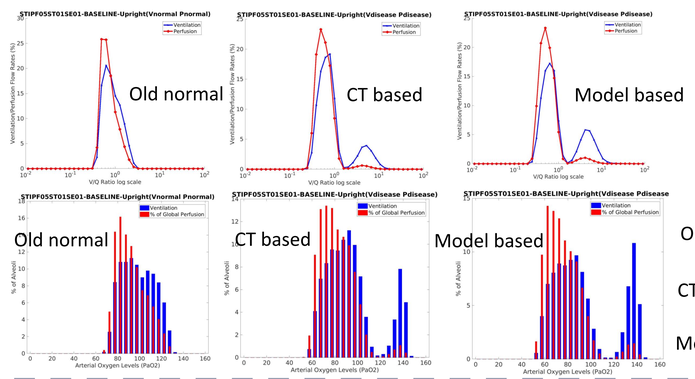
Inhale volume and pressure curve

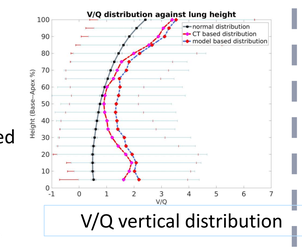
- Patient-specific perfusion
  Reduce vessel radius of fisbrosis labelled regions



Disease perfusion

Step 3: V/Q distribution (gas transfer modeling)





V/Q vertical distribution

Old normal PaO2 89.02mm Hg

CT based PaO2 is 78.11mm Hg

Model base PaO2 is 72.91mm Hg

Summary

- We classified the pulmonary parenchyma representing IPF features and performed quantitative analysis of IPF lungs.
- Statistical shape analysis suggests quantifiable differences from normal in lung shape are present in IPF.
- V/Q mismatch (impaired gas exchange) is present in 'normal' tissue as well as regions that are classified as abnormal.

Acknowledgements – Clinical data for this study was provided by Drs ML Wilsher and DG Milne, Auckland City Hospital; CALIPER analysis was conducted by Dr B Bartholmai, The Mayo Clinic.