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

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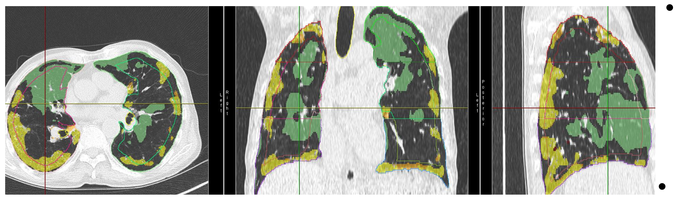
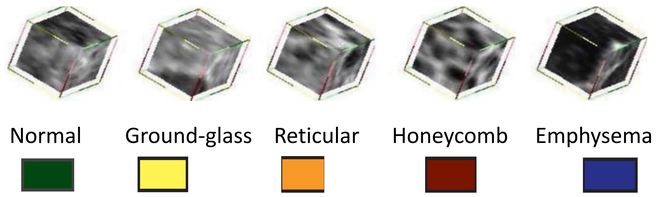
Introduction

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.

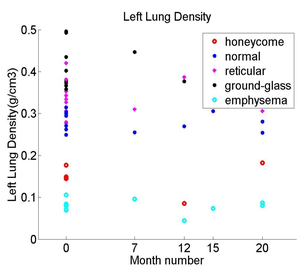
Tissue classfication



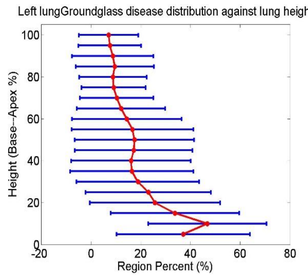


- **Data**- Clinical IPF CT data from Auckland City Hospital 8 patients, 4 of them contain more than one time point scan for each
- **Pulmonary parenchyma classification** - CALIPER (Computer-Aided Lung Information for Pathology Evaluation and Ratings) classification of abnormalities based on signature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

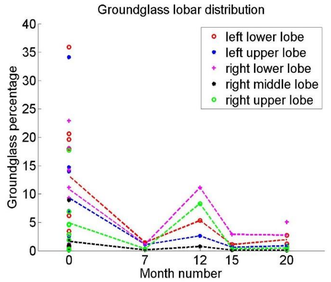
Analysis — *Qantitative* analysis of disease from classified data



- 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)



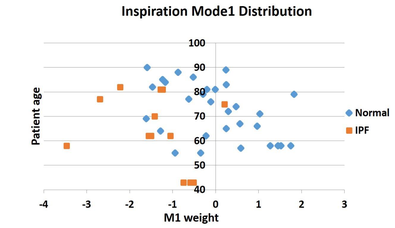
- The percentage of ground-glass decreases gradually with increasing lung height in the cranial-caudal axis. In contrast, the percentage of emphysema increases with lung height.

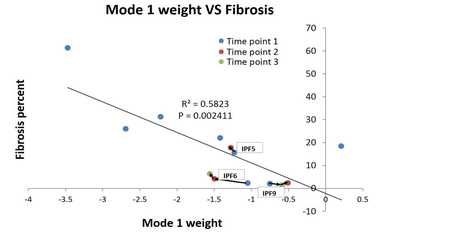


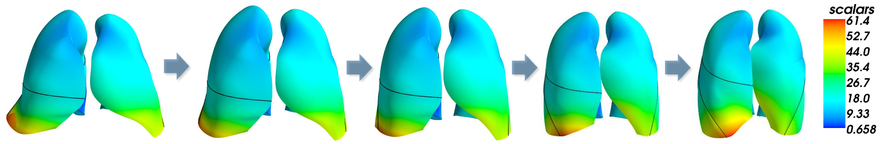
- Fibrosis presents predominantly in lower lobes (72%, 58%, 65% for honeycomb, reticular, ground-glass). But emphysema appears predominantly in upper lobes (73%).

Analysis 2 — *Statistical shape model based shape analysis*

Training data collection → Principle component shape feature analysis → Statistical shape model construction → Specific subject projection







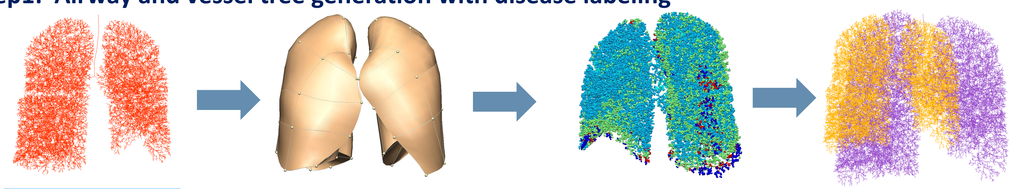
- The variation in shape of the lungs in the cohort can be assessed via a statistical shape model (SSM).
- The most significant variation in shape (mode 1 of the SSM) relates to the anteroposterior diameter of the lung, and the ratio of apical and basal diameters
- Mode 1 of the SSM is significantly different between IPF and normal subjects and correlates with percent of fibrosis ($p<0.01$).
- There is a significant difference of right lower lobe volume and right middle lobe volume between normal old and IPF lungs (p=0.008168, 7.54E-07 respectively).

Analysis 3 — *Patient-specific computational modelling of lung function*

PFT results: FRC, TLC, DLCO, FEV1.

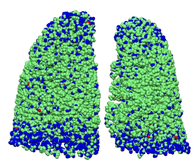
Paramiterize modeling

Step1: Airway and vessel tree generation with disease labeling

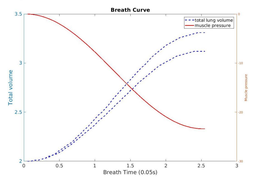


Tree generation → Tree mapping → Tree disease labelling → Tree scaling

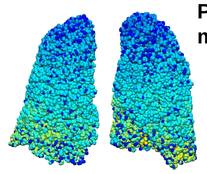
Step 2: Ventialtion and perfusion simulation



Simulated firbrosis distribution



Inhale volume and pressure curve

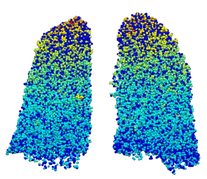


Disease perfusion distributiond

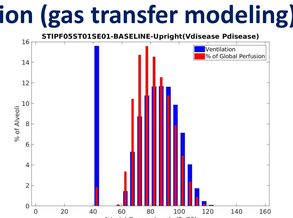
Parameterize modeling

Physiological knowledge of IPF patients: increased airway volume and vessel volume, decreased dead space, lung compliance and diffusion capacity

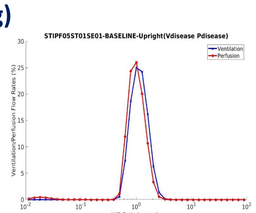
Step 3: V/Q distribution (gas transfer modeling)



V/Q distrubution



PaO_2 distribution



MIGET plot

Summary

- We **classified the pulmonary parenchyma** representing IPF features and performed **quantitative analysis** of IPF lungs.
- Quantitative analysis combined with **PFTs** were used to drive a **patient-specific computational modelling of lung function**.
- A future work is to explore the relationship between **V/Q mismatching and disease distribution**

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.