High resolution CT-based characterization analysis of idiopathic pulmonary fibrosis

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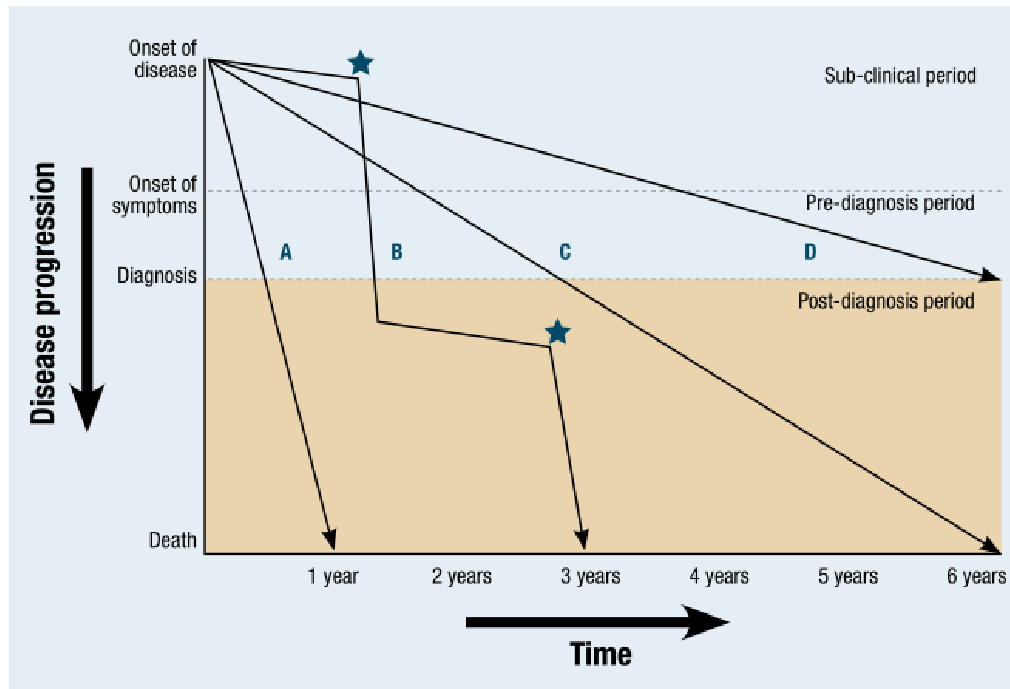
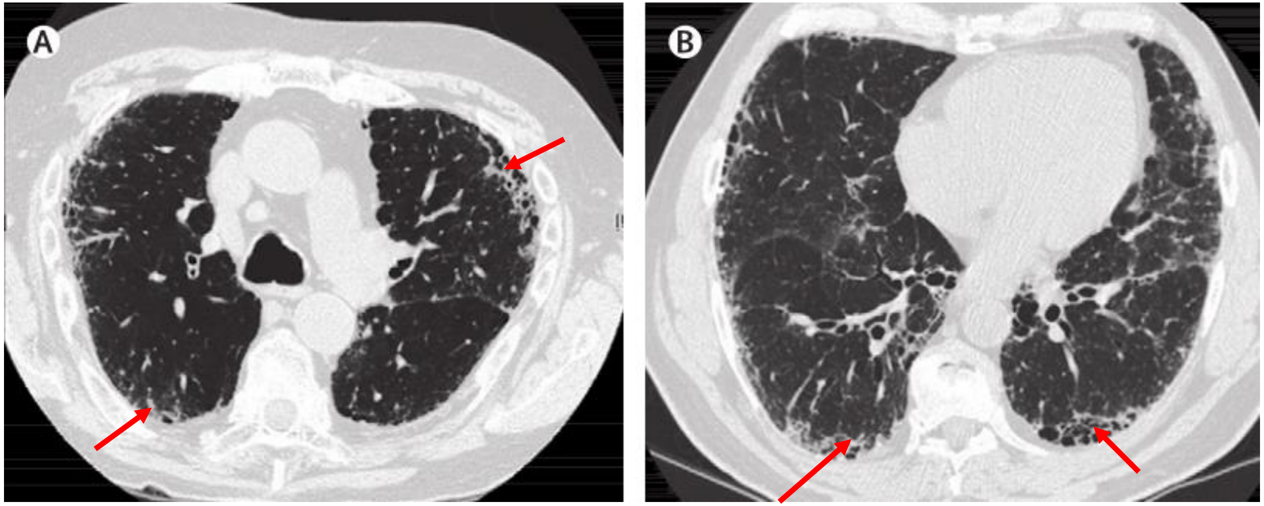
Background

- Idiopathic pulmonary fibrosis (IPF) is a chronic and life-threatening disease
- Cause is unknown
- Aetiology remains elusive
- Progression is variable and unpredictable



Background

- HRCT is an essential tool in evaluating lung disease
- Associates with the presence of a usual interstitial pneumonia (UIP) pattern on HRCT (ATS/ERS criteria)
- Honeycomb, reticular, ground-glass
- combined IPF and emphysema (CPFE)



Summary of published work

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- Radiological quantitiative analysis:
  Adaptive multiple feature method (AMFM), mean lung attenuation (MLA), texture-based computer aided diagnosis scoring system

- Clinial functional measurement:
  Pulmonary functional tests (PFTs), airway resistance/tissue compliance, ventilation/perfusion ration

Few researches involves in combining spatial distribution of abnormalities with functional data.
No established quantitative tools exist to assess the progression of IPF

Aim: Develop a new method for quantitative assessment of the IPF lung that brings together volumetric imaging, pulmonary function tests, and computational models for lung function.

Renuka et al(1999), Alan et al (2008), Wang et al (2003, 2008), Hyun et al (2010, 2011, 2015)

Imaging and clinical data

Description	
Age years	43-82
Females/Males	3/5
Slice thickness	1.25-3.00mm
Scan month interval	5-20 month
Slice resolution	512*512
Number of slice	65-160

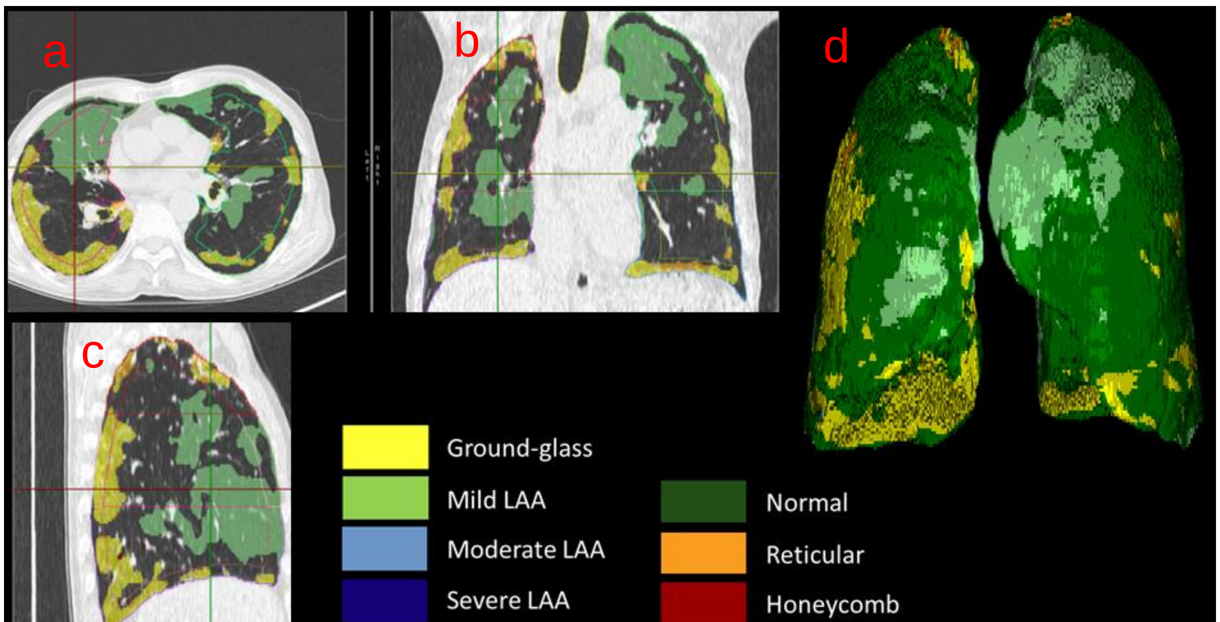
The clinical data used in this study comprised HRCT images obtained from 8 patients diagnosed with IPF at Auckland City Hospital, Auckland, New Zealand.

5 patient → 1 time point
1 patient → 2 time point
2 patient → 3 time point

Pulmonary parenchymal classification

CALIPER (Computer-Aided Lung Informatics for Pathology Evaluation and Ratings) software.
Mayo Clinic (Rochester, MN, USA)

Each parenchymal voxel was classfied into the following characteristic CT patterns: normal (N), reticular (R), honeycomb (HC), ground-glass (GG), mild low attenuation areas (LAA), moderate LAA and severe LAA. Emphysema : Hounsfield Unit is under -950.



Color labelled classification result of case 7 on IPF HRCT by CALIPER. (a) Transverse plane. (b) Coronal plane. (c) Sagittal plane. (d) 3D color labelled lung.

Normalization of classified data

- Lung mesh : bi-cubic Hermite finite element surface mesh (left lung: 35 nodes and 44 elements; right lung: 50 nodes and 62 elements)
- Statistical shape model (SSM): 30 healthy normal subjects (15 males and 15 females), principal component analysis (PCA)

Lung surface mesh fitting

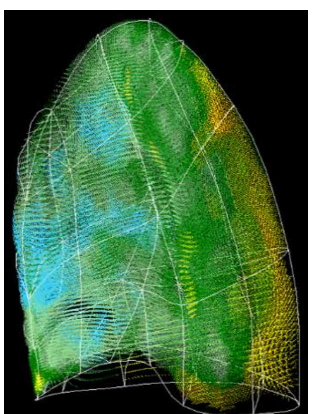
Classfied data

Calculate ξ within each element

Classfied data mapping to SSM

KNN searching

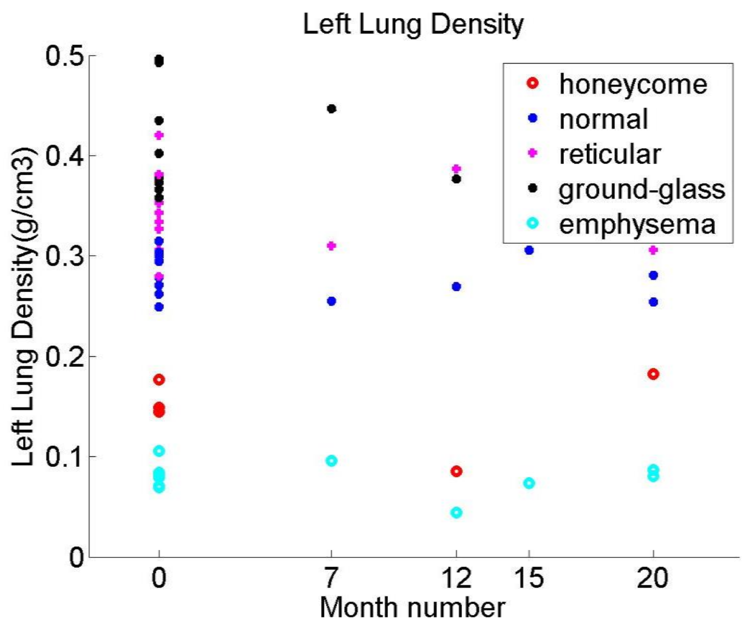
Mapped data gap filling

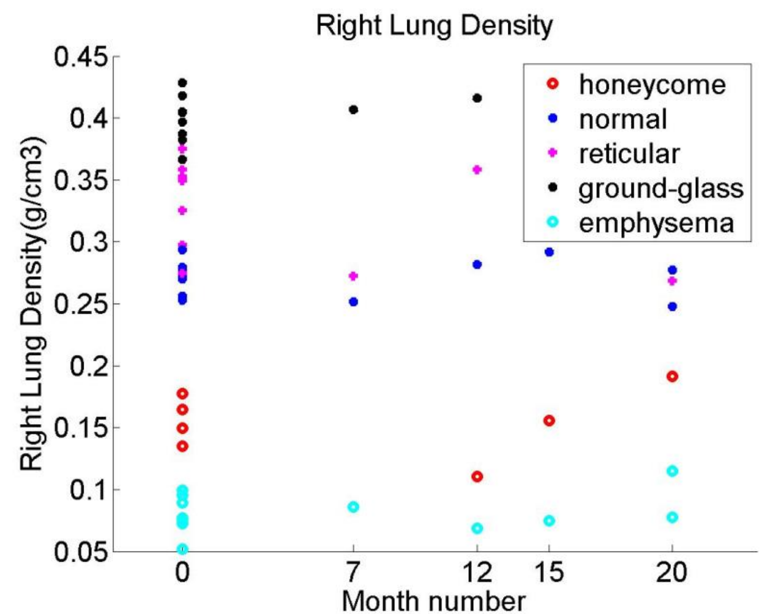


Density analysis

- Fibrosis usually has a consistently higher tissue density (0.34/0.41 for reticular/ground-glass) compared to normal tissue (0.2752) over time

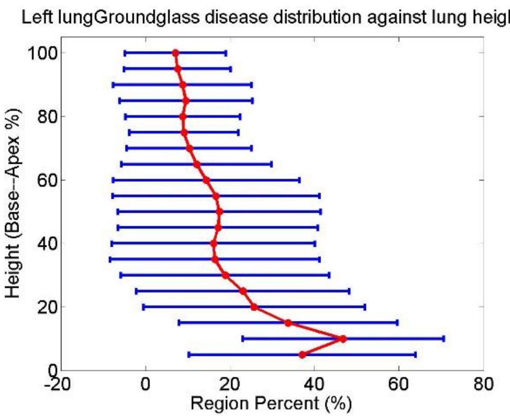
- In contrast, emphysema has lower density (0.0784)



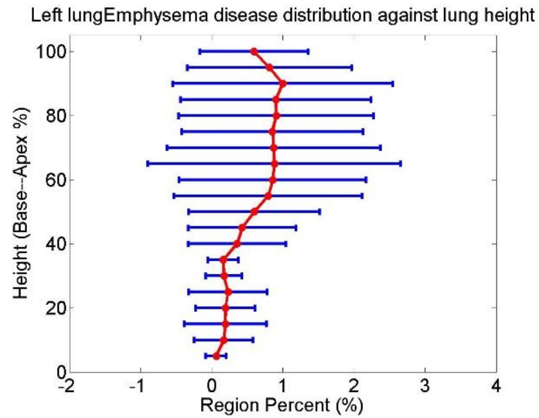


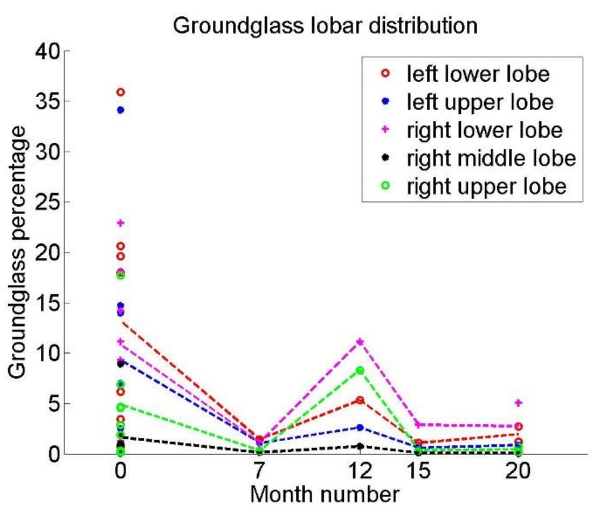
Spatial distribution analysis

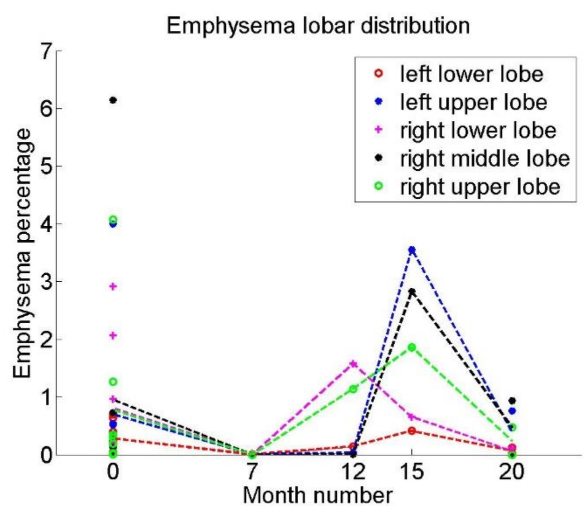
Ground-glass



Emphysema

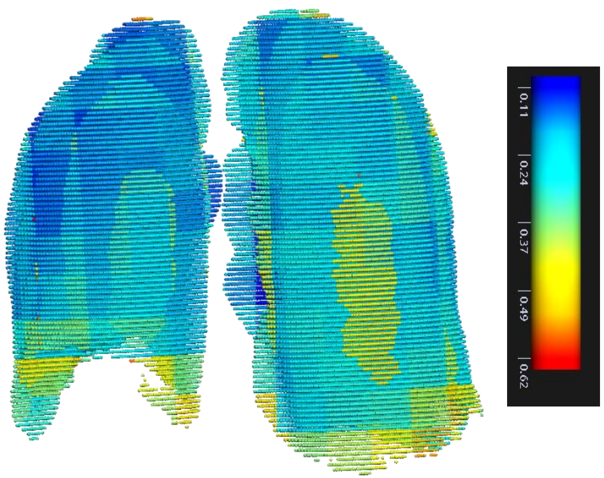




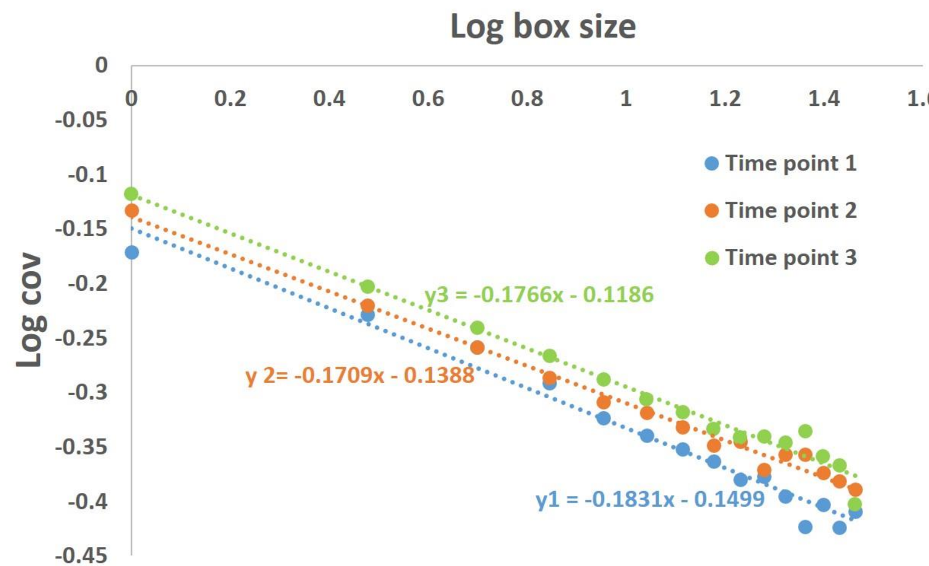


- Fibrosis mostly located in lower lobes (72%, 58%, 65% for honeycomb, reticular, ground-glass)
- Emphysema mostly located in upper lobes (73%)

Heterogeneity analysis



3D grid density visualization



- Fractal dimension for density: fitting a straight line for the relationshape between coeffient of variance (COV) and shamping window size.
- FD = 1 – gradient of log-log curve
- Hererogeneity didn’t change too much over time.

SSM based shape analysis

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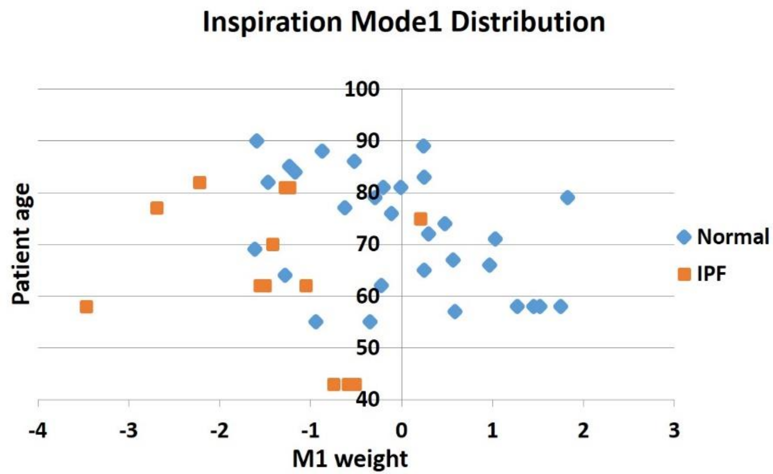
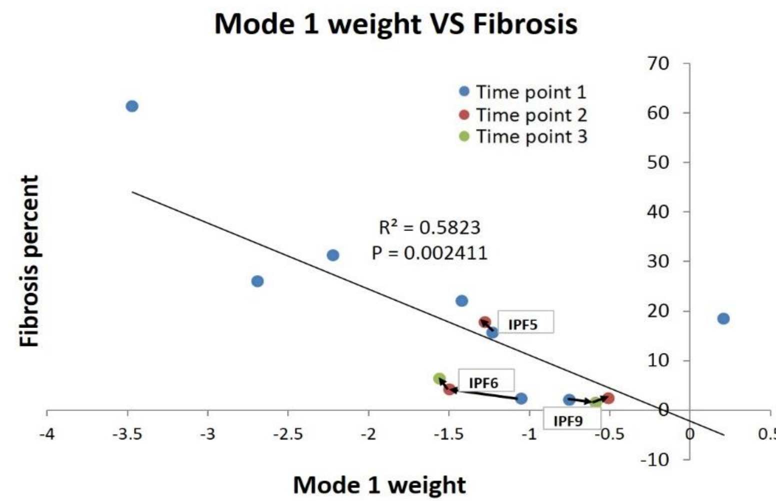
Training data collection(35 old normal) → Principle component shape feature analysis → Statistical shape model construction → Specific subject projection





- The first principal SSM mode relates to the anteroposterior diameter of the lung, and the ratio of apical and basal diameters
- The first principal SSM mode (>20% of the shape variation in normal lungs) is significantly different between IPF and normal .
- For IPF subjects, the first mode has a strong relationship with fibrosis percent.

IPF patient-specific airway tree geometry

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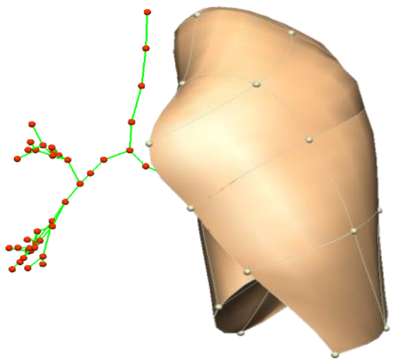
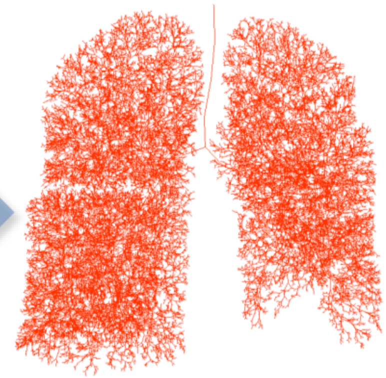
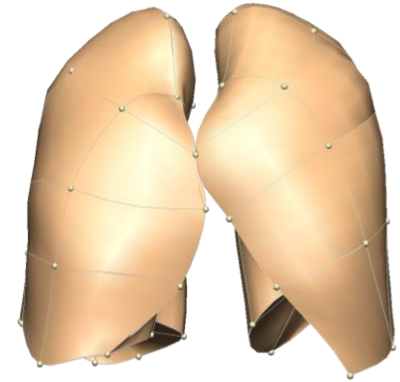


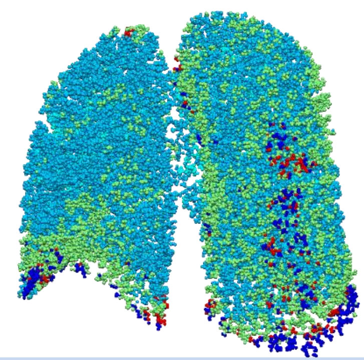
Manually digitize upper airway



Generate full airway tree of time point 1



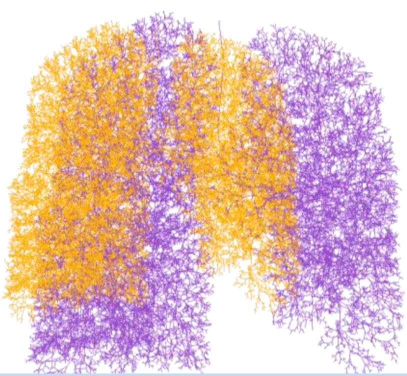
Map first airway tree to other time points



Label each terminal acinar unit with differerent CT patterns

Disease spatial distribution

Disease percentage against gravitional height



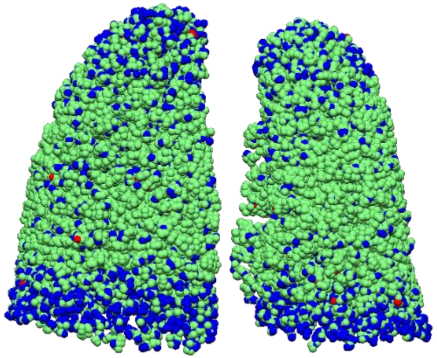
Scale the airway tree (length and radius) to FRC volume

IPF patient-specific ventilation analysis

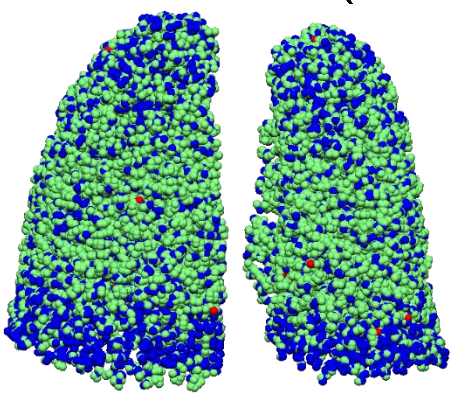
Forced inspiration

Reference FRC –TLC: set muscle pressure

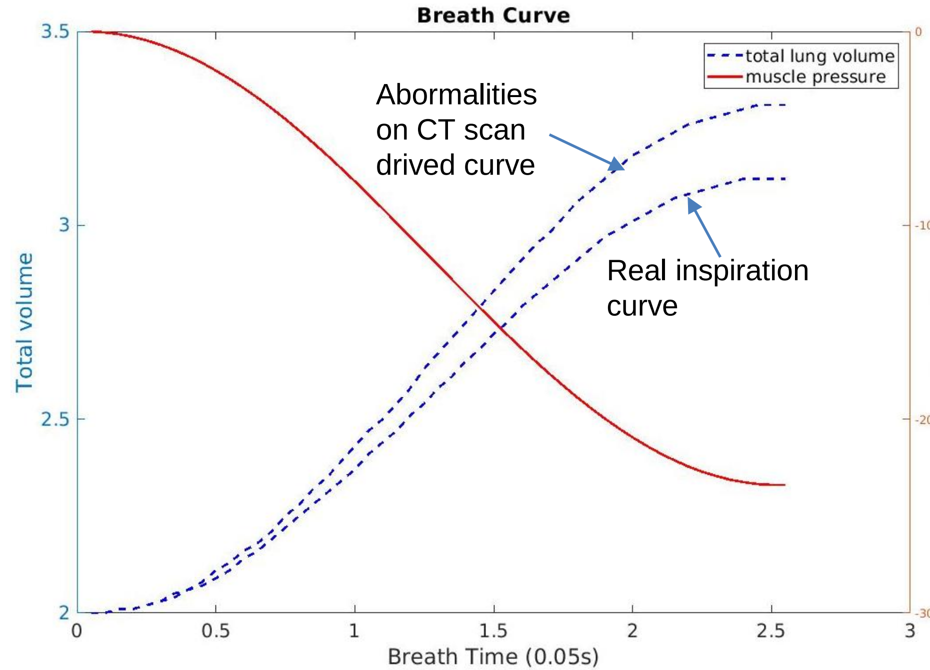
Real FRC –TLC: set real abnormality distribution



Fibrosis: 17.64%(from CT)



Fibrosis: 29.75%



- abnormalities on volumetric data are not sufficient to explain increased lung stiffness

IPF patient-specific gas exchange analysis

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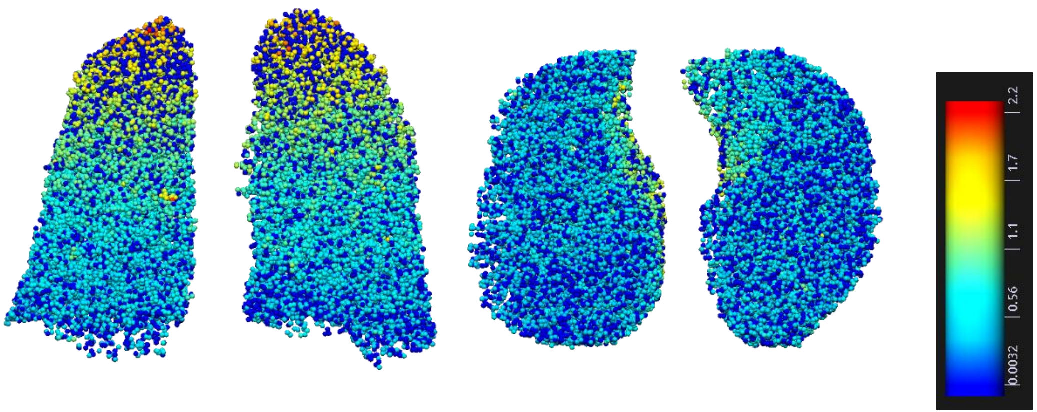
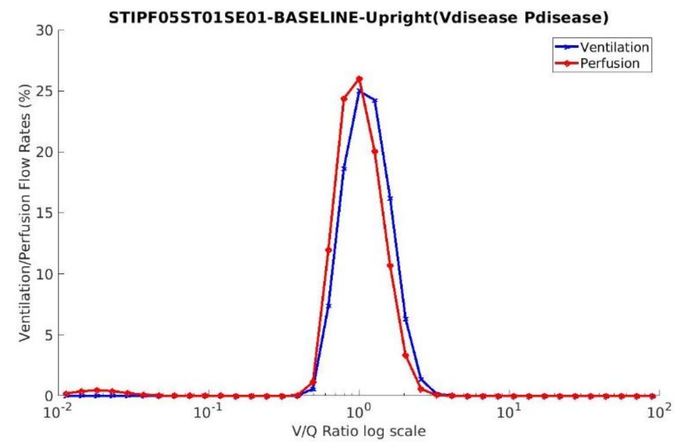
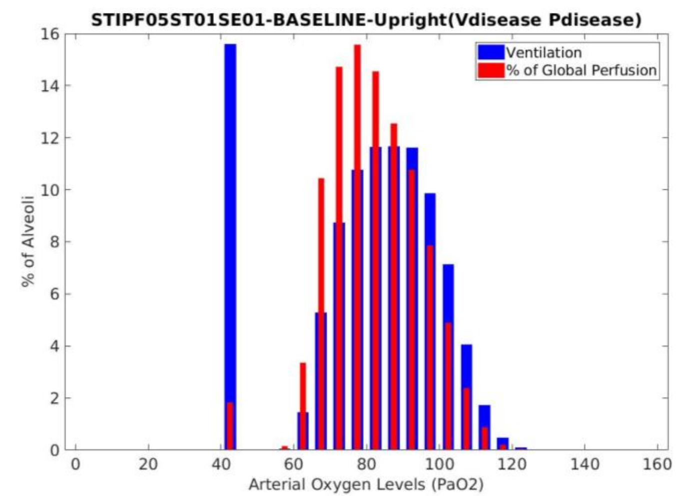
Perfusion analysis:

- parameterize the model inputs
- generate vessel geometry matching on airway tree
- reduce the vessel radius of disease labelled region



V/Q ration distribution





Future work

- Transfer factor: aveolar-capillary membrane area, thickness
- Forced expiratory model combined with FEV1, FVC results
- Tissue mechanical model combined with density and shape analysis results
- Predict IPF development at an early stage

Thank you

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