Quantitative analysis of idiopathic pulmonary fibrosis abnormality from CT imaging

Yuwen Zhang

Supervised by : Prof. Merryn Tawhai

Dr. Alys Clark

Dr. Haribalan Kumar

THE UNIVERSITY OF AUCKLAND
Te Whare Wānanga o Tāmaki Makaurau
NEW ZEALAND

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Background

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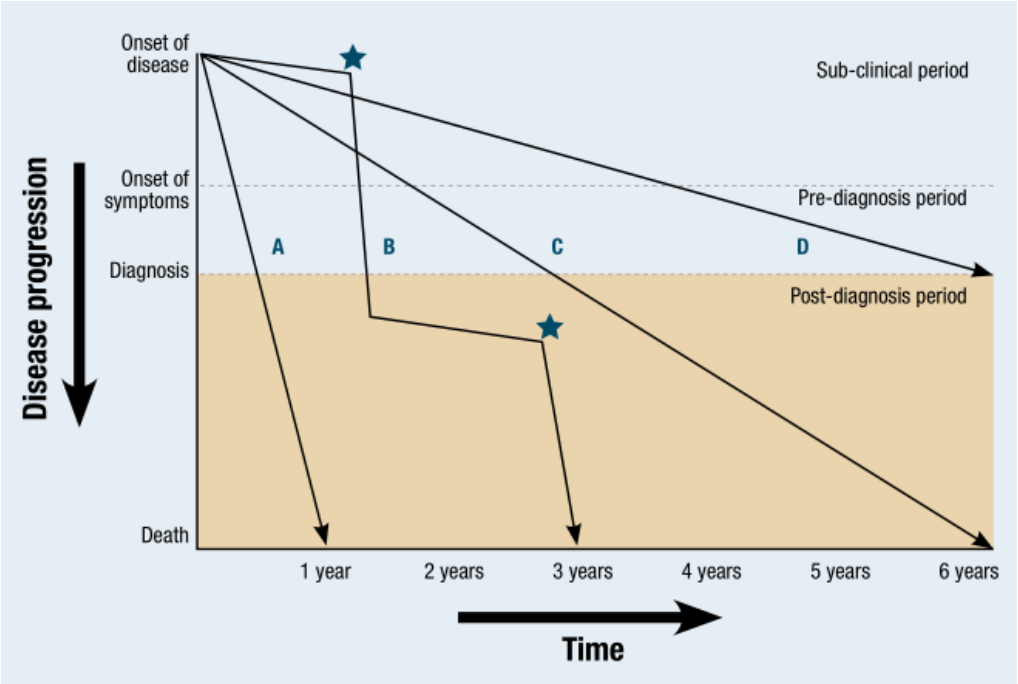
- Idiopathic pulmonary fibrosis (IPF) is a chronic and life-threatening disease
- Cause is unknown
- Aetiology remains elusive
- Progression is variable and unpredictable



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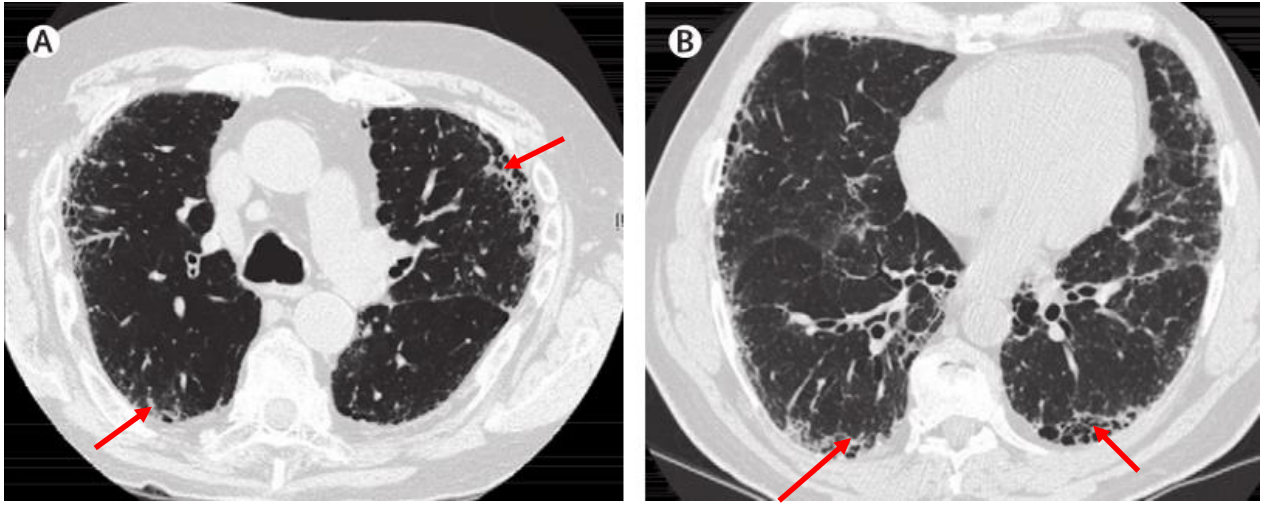
- HRCT is an essential tool in evaluating lung disease
- Associates with the presence of a usual interstitial pneumonia (UIP) pattern on HRCT (ATS/ERS criteria)
- Honeycomb, reticular, ground-glass
- combined IPF and emphysema (CPFE)



Summary of published work

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- Adaptive multiple feature method (AMFM) : combined statistical texture measures and a fractal measure (Renuka et al)
- Mean lung attenuation (MLA): skewness (asymmetry) and kurtosis (peakedness) (Alan et al)
- Texture-based computer aided diagnosis scoring system :lung disease severity (Hyun et al)

Few researches involves in spatial distribution analysis of abnormalities and disease change over time.

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

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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

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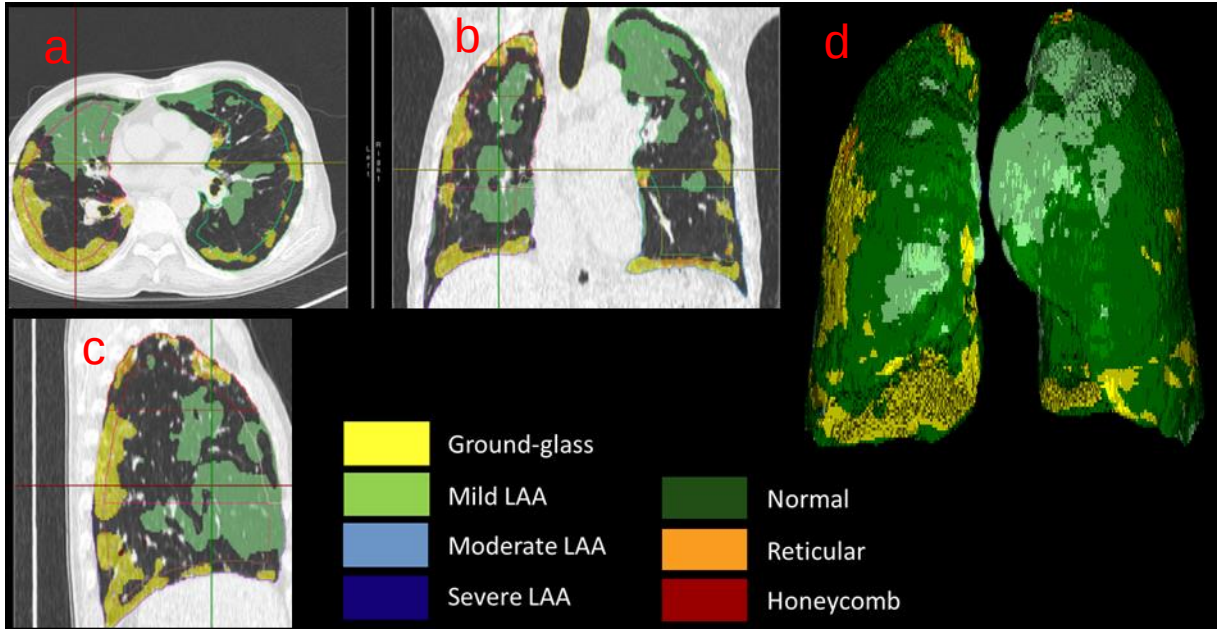
CALIPER (Computer-Aided Lung Informatics for Pathology Evaluation and Ratings) software. Mayo Clinic (Rochester, MN, USA)

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

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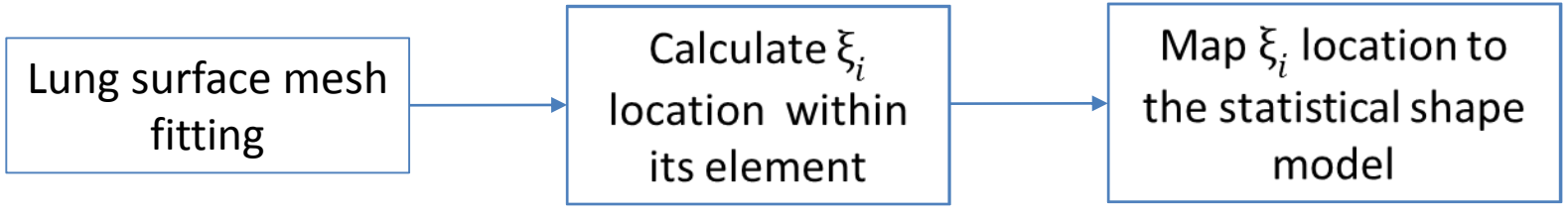
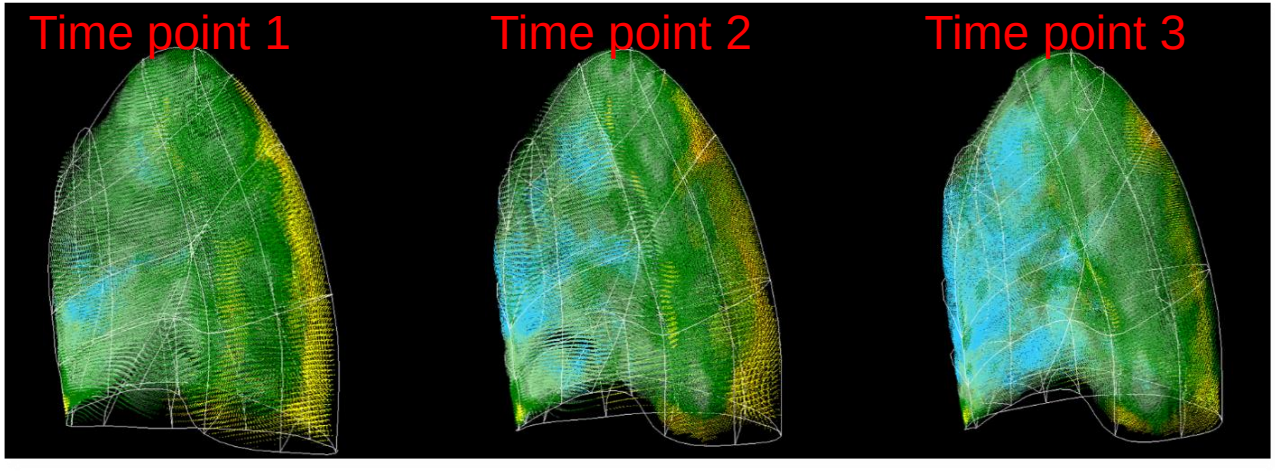
- Lung mesh : bi-cubic Hermite finite element surface mesh (left lung: 35 nodes and 44 elements; right lung: 50 nodes and 62 elements)
- Statistical shape model (SSM): 30 healthy normal subjects (15 males and 15 females), principal component analysis (PCA)





Normalization of classified data

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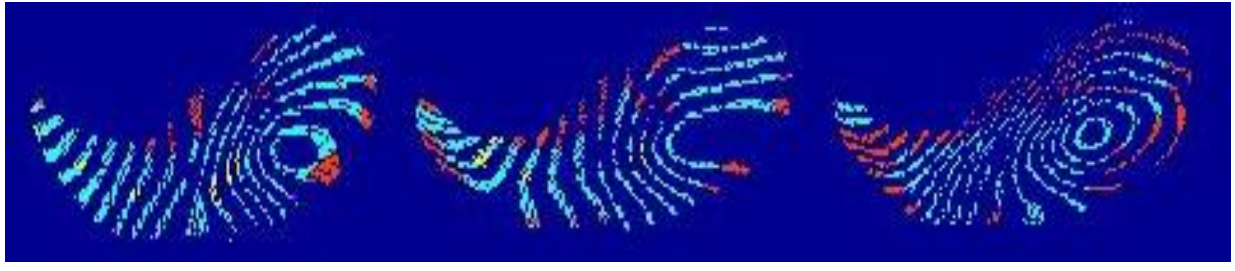
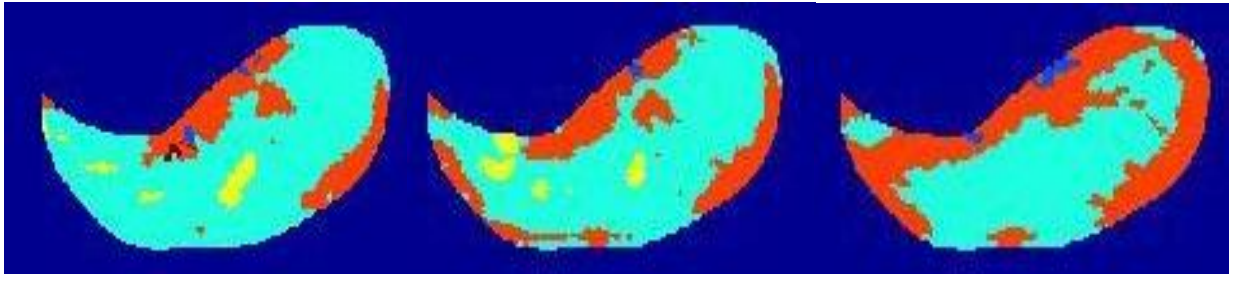
Project the mapped data into cross section slice → Use SSM to get continuous lung boundary → Fill the gaps using KNN searching



Time point 1 Time point 2 Time point 3



Density analysis

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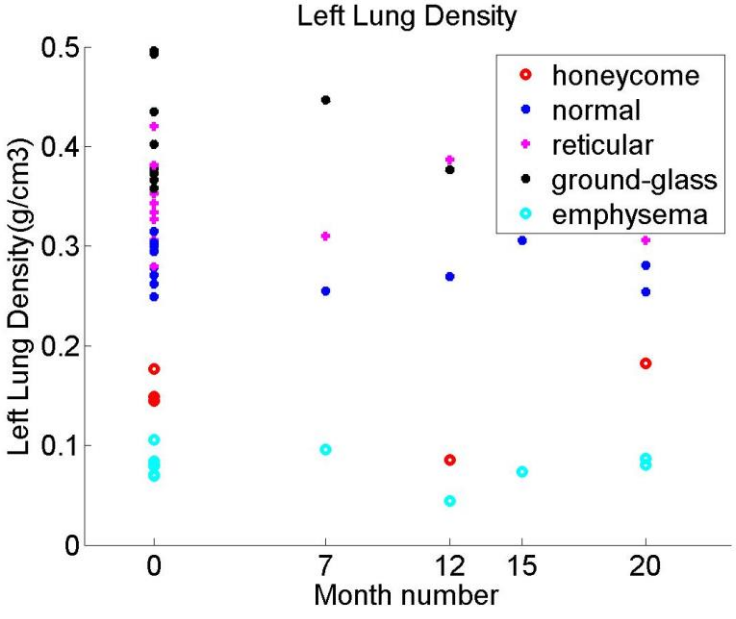
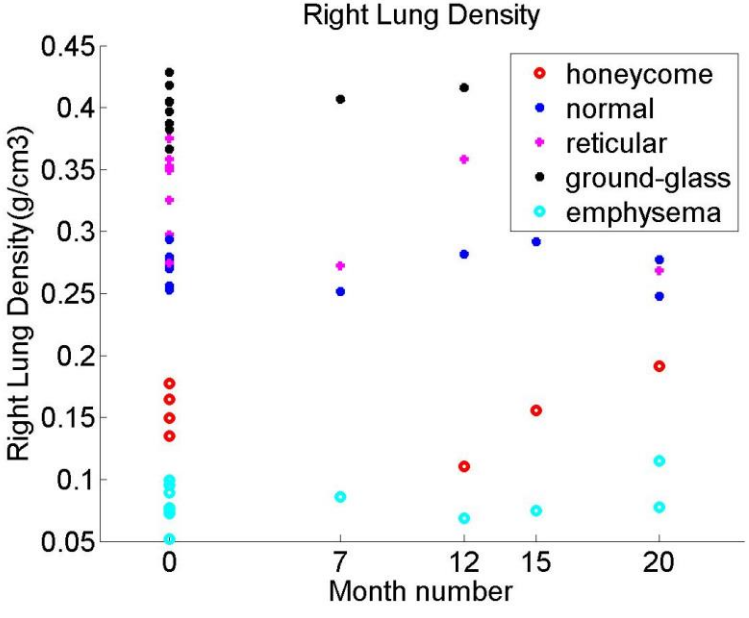
- Average density for each CT pattern remains stable over time.
- Fibrosis usually has a consistently higher tissue density (0.34/0.41 for reticular/ground-glass) compared to normal tissue (0.2752) over time
- In contrast, emphysema has lower density (0.0784)





Volume analysis

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Sub No.	Time point	Date	Left Lung	Right Lung
IPF5	Time pint1	0 month	4.3124	3.7212
	Time point2	12 month	3.9457	3.2861
IPF6	Time point1	0 month	2.4357	3.5879
	Time point2	15 month	2.1505	3.0536
	Time point3	20 month	2.0637	3.0962
IPF9	Time point1	0 month	3.3798	3.7271
	Time point2	7 month	3.0507	3.5815
	Time point3	20 month	3.0814	3.8328

- The lung volume of IPF patient keeps an overall decreasing over time (11.85% off averagely).

Spatial distribution analysis

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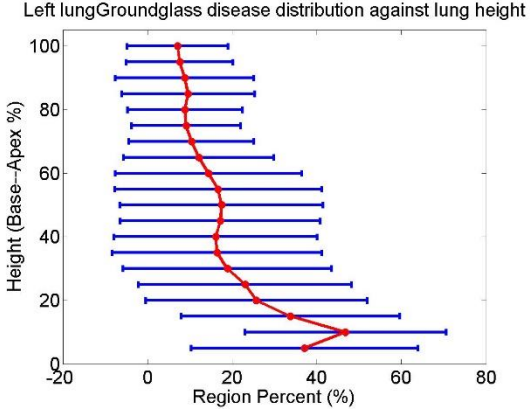
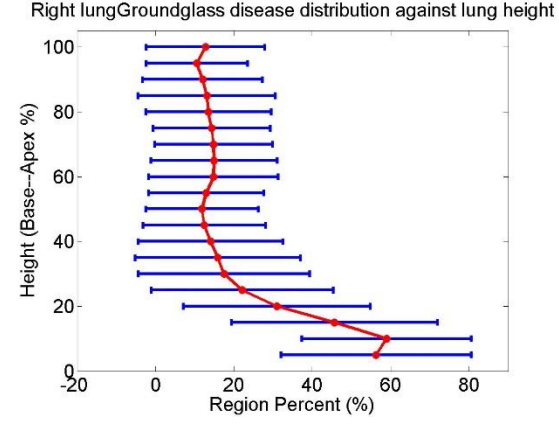
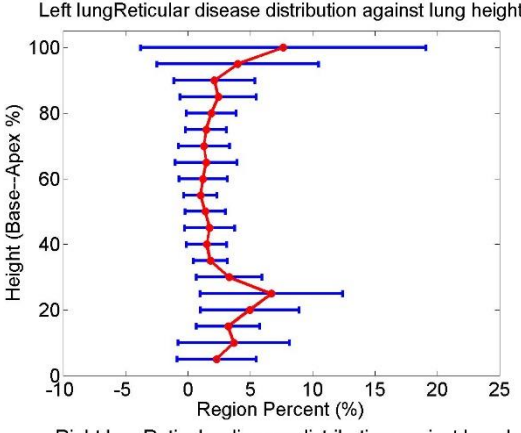
Basal-to apical analysis

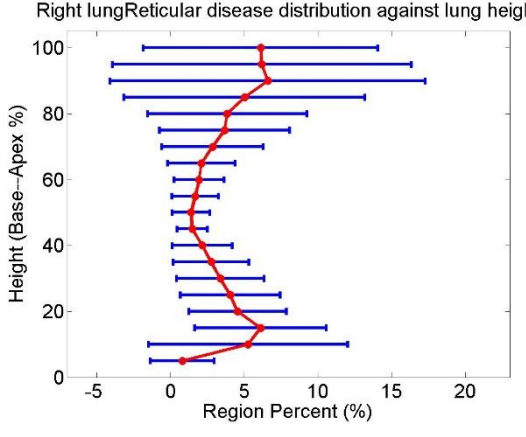
Ground-glass



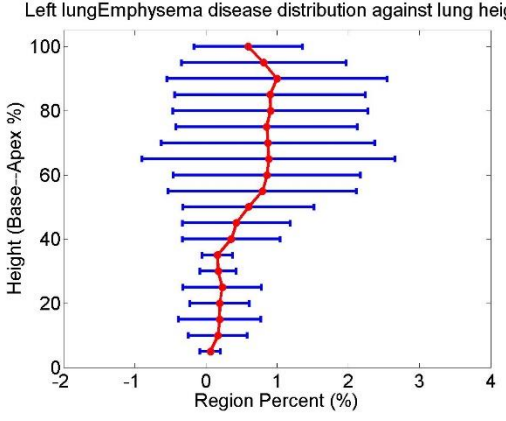


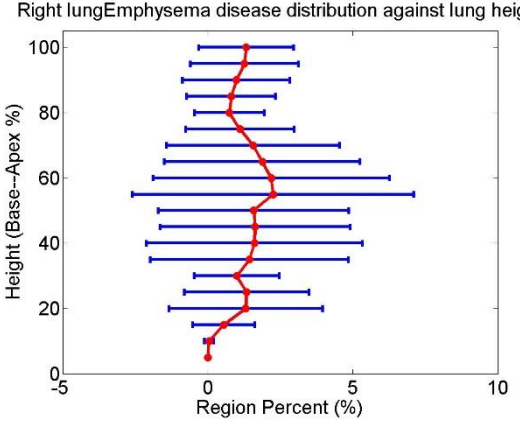
Reticular





Emphysema





Spatial distribution analysis

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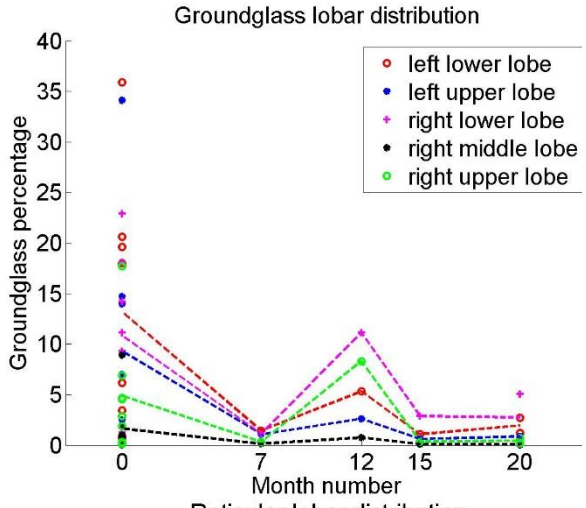
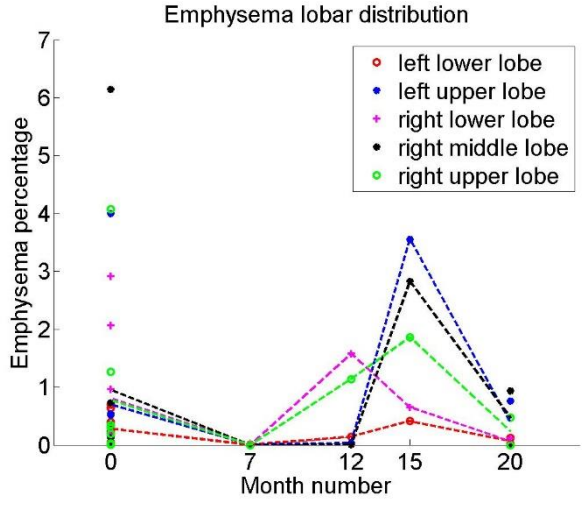
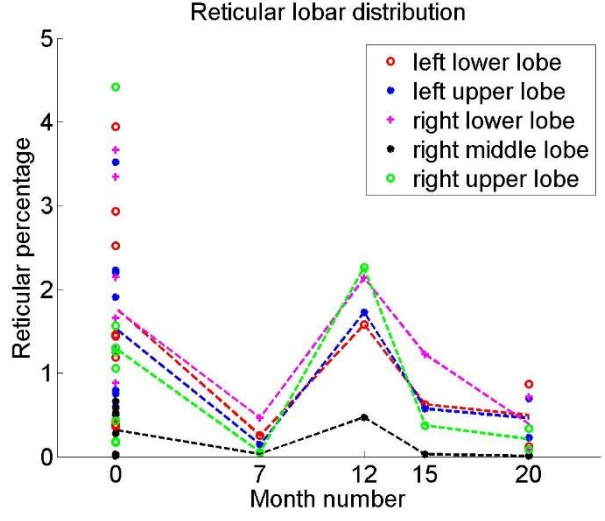
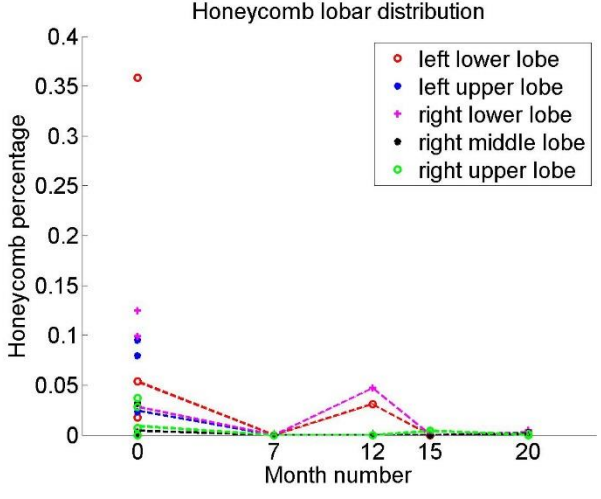
Lobar distribution

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









Subplerual-to-internal analysis

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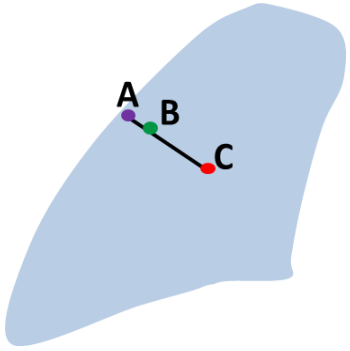
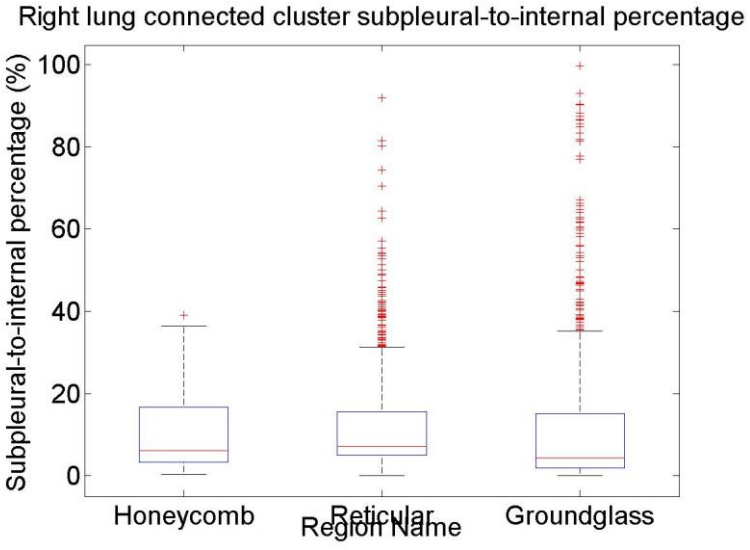
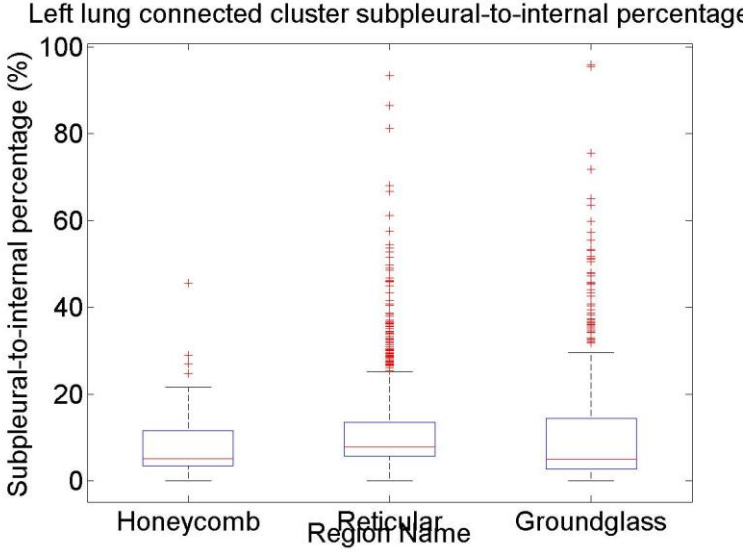


A: Lung boundary point
B: Central point of connected region cluster
C: Lung central point

$$\text{Subpleural-to-internal percentage} = = \frac{AB}{AC} \times 100$$





- The subpleural-to-internal percentage of most disease clusters are under 20%

Disease change over time

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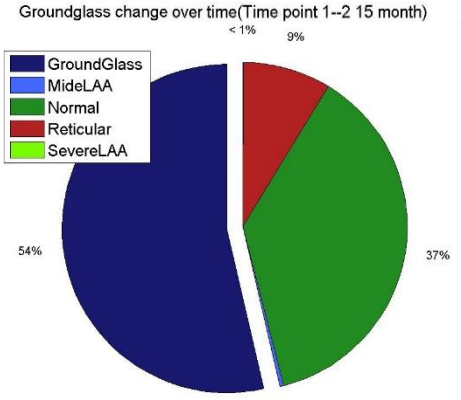

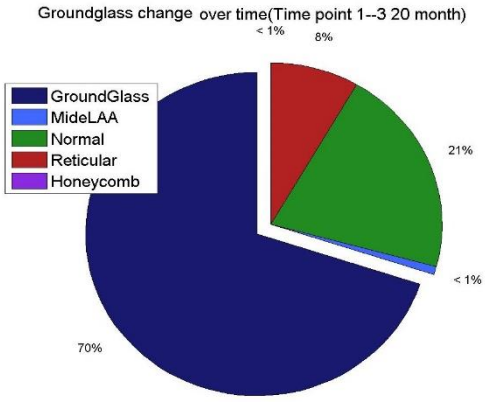

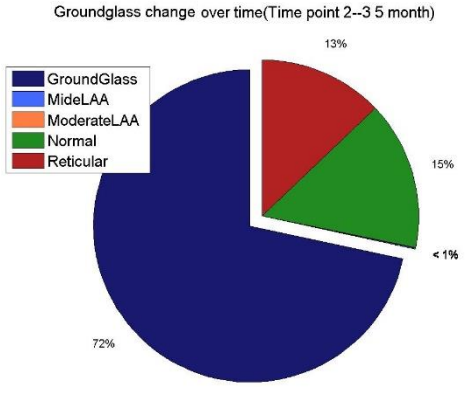

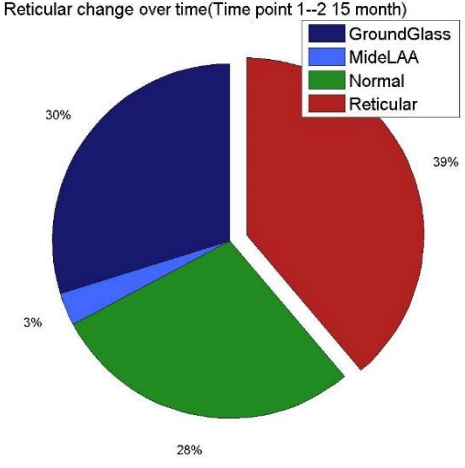

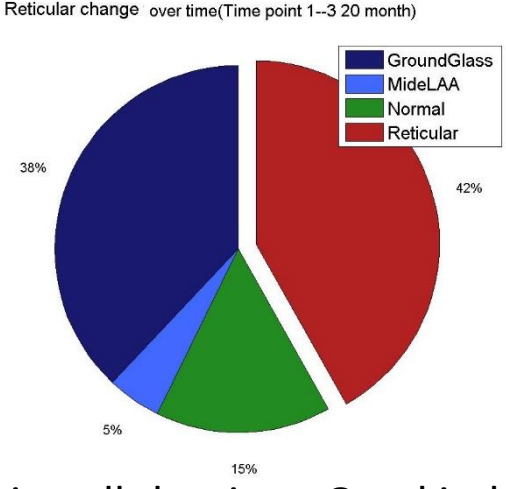

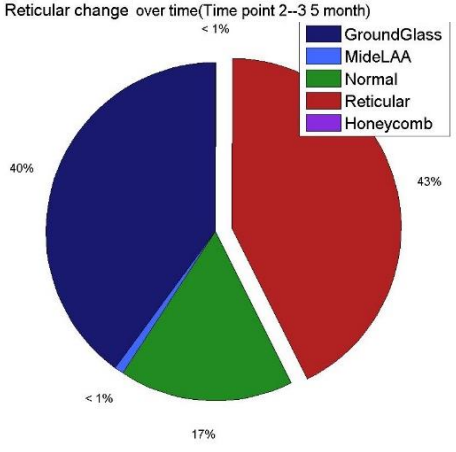

- IPF disease area is changing all the time. One kind of disease pattern may change to other pattern, and some disease area may even change to a normal area.

Image-level biomarker drived ventilation analysis

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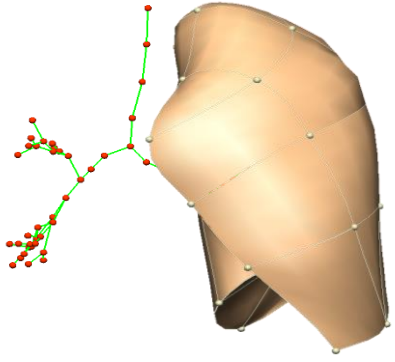
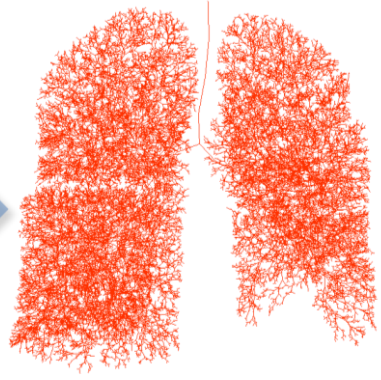
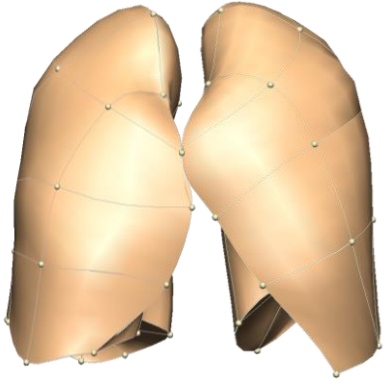


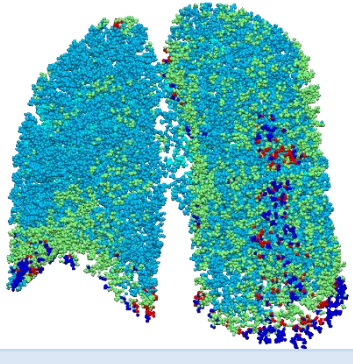
Manually digitize upper airway



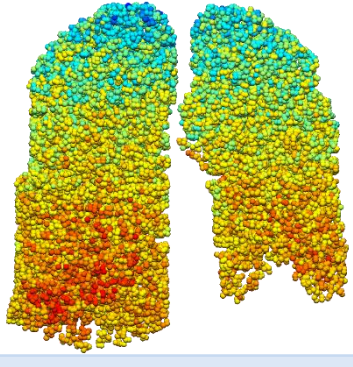
Generate full airway tree of time point 1



Map first airway tree to other time points



Label each terminal acinar unit with differerent CT patterns



Use disease distribution to conduct a patient-specific ventilation analysis

To be continued . . .

Summary

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- We classified the pulmonary parenchyma representing IPF features, mapped the classified data to a PCA-based statistical shape model and performed quantitative analysis including density analysis, volume analysis, spatial distribution analysis and disease change over time.
- The results shows fibrosis usually has a consistently higher tissue density, whereas emphysema has lower density. The distribution of fibrosis is basal and peripheral (subplerual), though often patchy, while emphysema appears predominantly in upper lobes. The spatical location of disease keeps changing over time.
- This work could help to guide a future model based analysis, and point to new biomarkers as a clinical index for diagnosis and treatment planning.

Thank you