Computed Tomography Airway Tree Tortuosity Features Predict Functional Small Airway Disease in Chronic Obstructive Pulmonary Disease

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Introduction

• Over 1,000,000 Canadians are diagnosed with Chronic Obstructive Pulmonary Disease (COPD), and by 2020 the disease will be the third deadliest on Earth[1,2]

• Despite high prevalence, diagnosis of COPD occurs late in the disease course, after a large portion of the small airways are destroyed[3]

• Current methods to quantify small airway disease (SAD) using the Disease Probability Measure (DPM)[4] approach requires CT images acquired at full-inspiration and full-expiration, and therefore there are technical challenges and dose concerns

• Computed Tomography (CT) imaging using only a single full-inspiration CT image can be used segment the central airway tree and generate quantitative morphometric measurements

Objective & Hypothesis

Objective

• To determine if CT airway tortuosity measures can be developed and are independently associated with DPM SAD

Hypothesis

• We hypothesize that CT measurements reflecting airway tree tortuosity will be significantly correlated with DPM SAD measurements

Methods

Canadian Cohort Obstructive Lung Disease (CanCOLD)

• Cohort between 45-90 years of age identified by random digit dialing from the general population

fSAD

• CT full-inspiration and full-expiration images are registered using deformable image registration, and all voxels are classified as normal, emphysema or SAD. SAD is the percentage of voxels in the lung classified as small airway disease.[4]

Standard Quantitative CT Measurements

Pi10 was defined as the hypothetical wall thickness of an airway with 10mm internal perimeter. TAC was defined as the number of observable airway segments in the airway tree.

Tortuosity

• The Straight Distance Tortuosity was defined as the ratio between the total path length of a segment and its straight line distance between the endpoints. Deviational Tortuosity was defined as the deviation from a fully straight path.

Table 1. Subject Demographics

Parameter (±SD unless specified)	Never-Smoker (n= 29)	At Risk (n= 166)	GOLD I (n= 181)	GOLD II+ (n= 175)
Age, yrs	67 (10)	68 (9)	71 (10)	68 (9) ‡
F Sex, n (%)	66 (19) ‡	45 (75)	39 (70) *	46 (80)
Pack-years, yrs	0 (0) †‡	21 (21) *	17 (22) *	24 (24) *‡
FEV_1/FVC, %	75 (5) ‡	77 (5) ‡	64 (4) *†	58 (9) *†‡
RV/TLC, %	41 (7)	38 (8) ‡	41 (8) †	48 (11) *†‡
BMI	28(8)	28(5)	27(4)	28(5) ‡

*Significantly different from Never-smoker; †Significantly different from At Risk; ‡Significantly different from GOLD I

Results

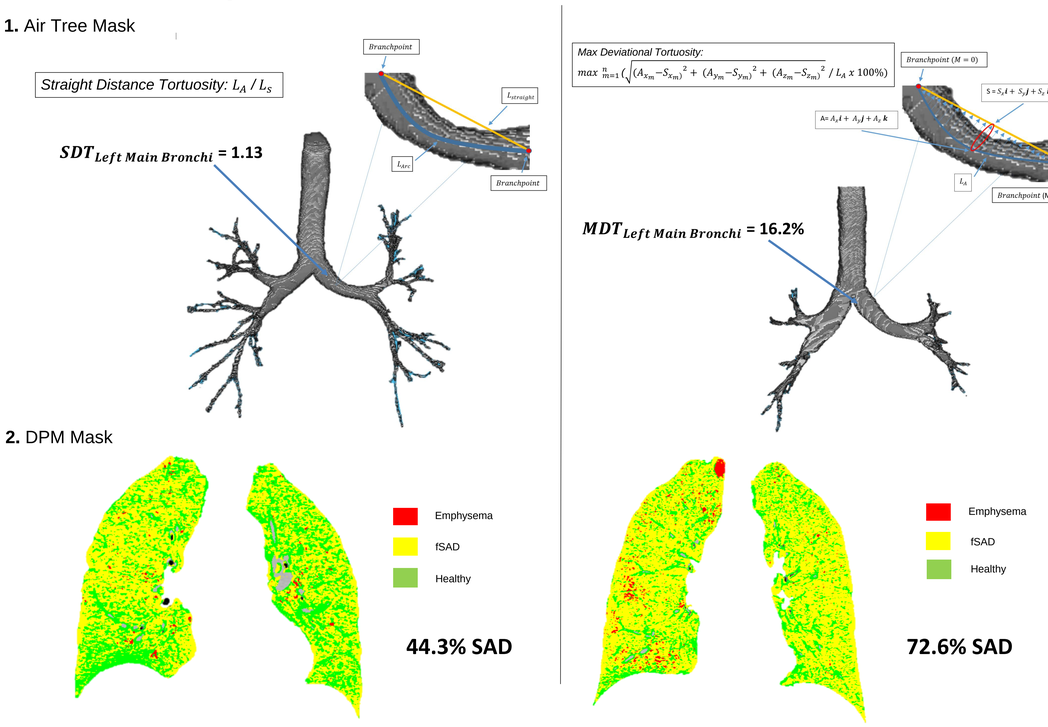

Figure 1. 3D CT Airway Tree Segmentation and DPM Map for Never-smoker and Mild COPD Subject

Table 2. Multivariable Regression Models for fSAD including Average Sub-Segmental Deviational Tortuosity

Model	All Variables		
	Standardized Estimate	P-value	Variance Inflation Factor
fSAD			
Average Sub-Segmental Deviation	0.10	0.02	1.13
Pi10	-0.08	0.17	2.14
TAC	-0.17	<0.001	1.60
Sub-Segmental Wall-Thickness	-0.012	0.89	5.00
Sub-Segmental Wall Area %	0.08	0.47	7.37
Sub-Segmental Lumen Area	-0.004	0.98	12.35

Table 3. Multivariable Regression Models for fSAD in healthy, At Risk, and with COPD including Max Sub-Segmental Deviational Tortuosity

Model	All Variables		
	Standardized Estimate	P-value	Variance Inflation Factor
fSAD			
Max Sub-Segmental Deviation	0.09	0.047	1.15
Pi10	-0.08	0.16	2.14
TAC	-0.17	<0.001	1.63
Sub-Segmental Wall-Thickness	-0.007	0.94	4.98
Sub-Segmental Wall Area %	0.08	0.48	7.38
Sub-Segmental Lumen Area	-0.008	0.95	12.37

Results Summary

• Average, and max deviational tortuosity as well as straight distance tortuosity measurements were developed and investigated at the segmental and sub-segmental airway level

• Significant associations were shown for sub-segmental average and max deviational tortuosity with DPM SAD using multivariate regression models which included standard quantitative CT airway morphological measurements

Conclusions

• CT airway tree tortuosity measurements are significantly and independently associated with small airway disease measurements in COPD

• This data supports the notion that morphometric measurements generated from the 3D airway tree segmentation can provide information related to the small airways, and therefore may replace the DPM SAD measurement

• Replacing DPM SAD would eliminate the need for both full-inspiration and full-expiration image acquisition, and therefore reduce dose to patients

Future Directions

• The tortuosity of complete lobar and sub-lobar paths can be found, and related to lobar and sub-lobar DPM SAD measurements

• Machine Learning algorithms can be applied to the extracted features to develop a model to predict likelihood of COPD development based on airway tree feature morphometry

References

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