Regional comparison of vascular volume measured on CT with ventilation defect percent on hyperpolarized helium-3 MRI in asthma

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Introduction

- **Asthma: an obstructive lung disease** characterized by chronic, partially reversible airway obstruction.
- **Ventilation defects** have been observed in asthma patients using the distribution of hyperpolarized helium-3 (HP ^{3}He) MRI and quantified as a local marker of airway obstruction using the segmental ventilation defect percent (SVDP). [1]
- **Vasculature** can be modeled from CT based on the automatic extraction of the lung intraparenchymal vasculature with scale-space particles. [2]

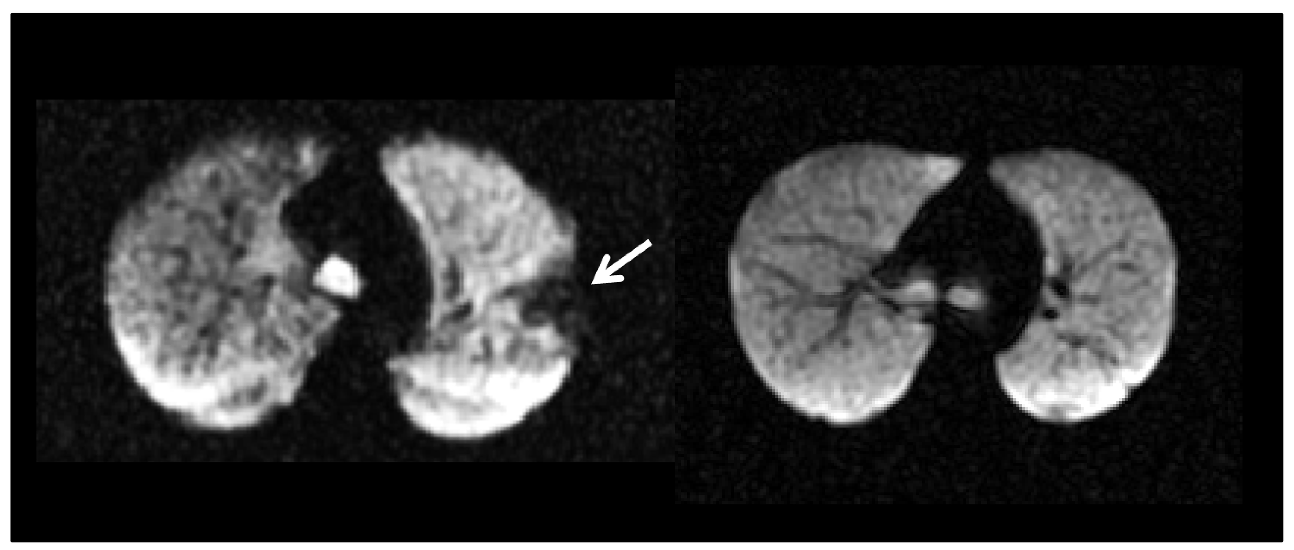

Figure. *Example from HP-MRI of typical ventilation defect (left, arrow) compared to healthy lung (right).*

Establishing **regional associations of airway obstruction with vascular volume** is of interest in characterizing the temporospatial patterns of ventilation/perfusion matching in asthma.

Materials and Methods

Population Demographics	
Total N	**= 26**
Gender	8M 18F
Age	50.2 ± 12.0 years
Asthma Severity	5 mild (19.2%) 4 moderate (15.4%) 17 severe (65.4%)

CT, HP ^{3}He MRI, Proton MRI of the lungs performed on all 26 asthma subjects

Imaging performed under **stable conditions** (subjects excluded if within 6 weeks of asthma exacerbation or respiratory complications).

Imaging performed after administration of bronchodilator (albuterol).

Materials and Methods (cont.)

Segmental Ventilation Defect Percent (SVDP)

$$SVDP = \frac{\text{Segmental Ventilation Defect Volume (HP } ^3\text{He MRI)}}{\text{Segment Volume}} \cdot 100\%$$

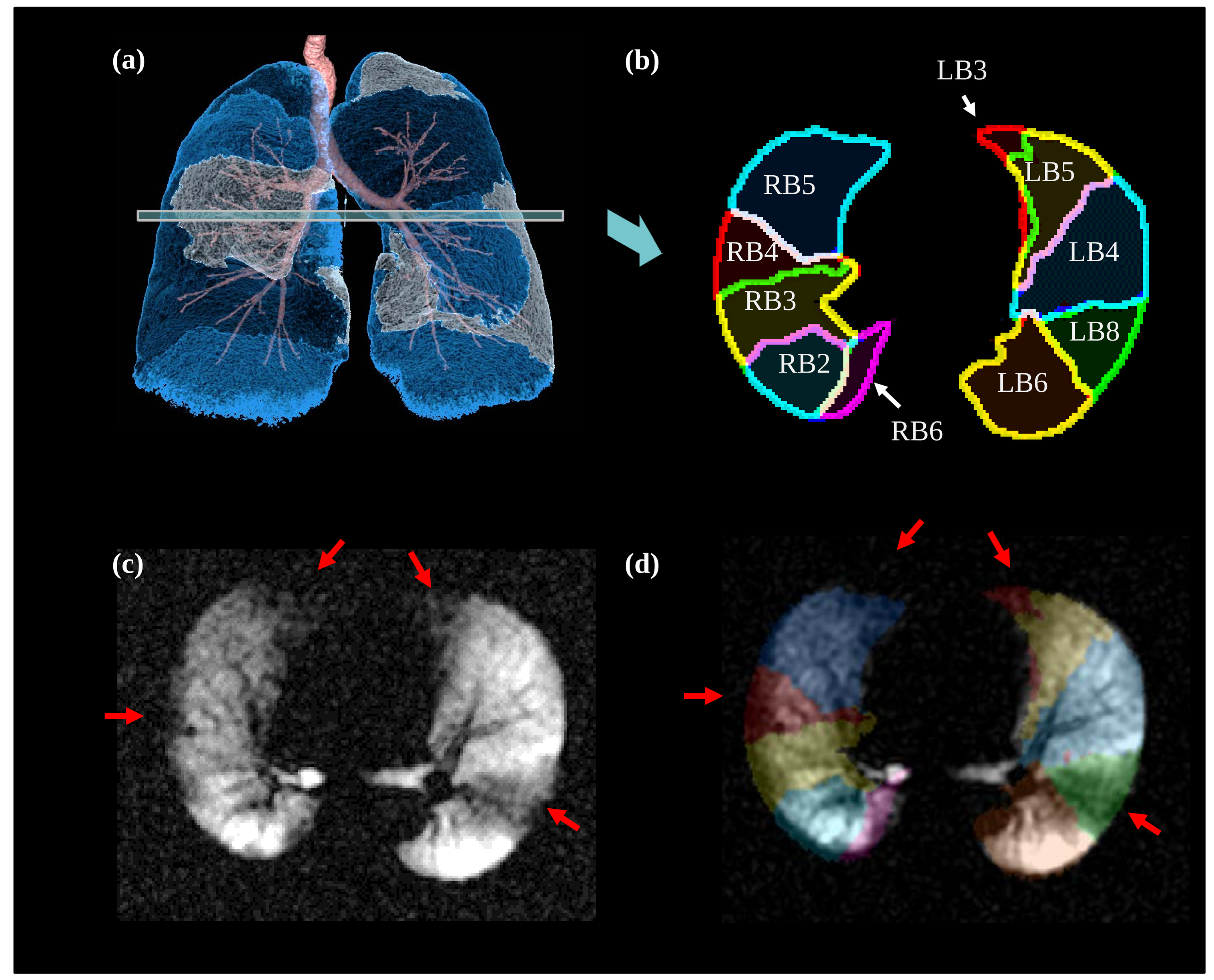

Figure. *Identification of segmental volumes on CT in (a) allows for axial segment mask shown in (b) [3]. This mask can be overlaid on HP ^{3}He MRI image (c) to identify spatial distribution of ventilation defects and calculate segmental VDP (SVDP). RB2-3 are segments of RUL, RB4-5 of RML, and RB6 of RLL; LB3-5 are segments of LUL, LB6 and LB8 of LLL. Note spatial overlap of prominent ventilation defect (red arrows) with segment LB8.*

Segmental Small-Vessel Percent

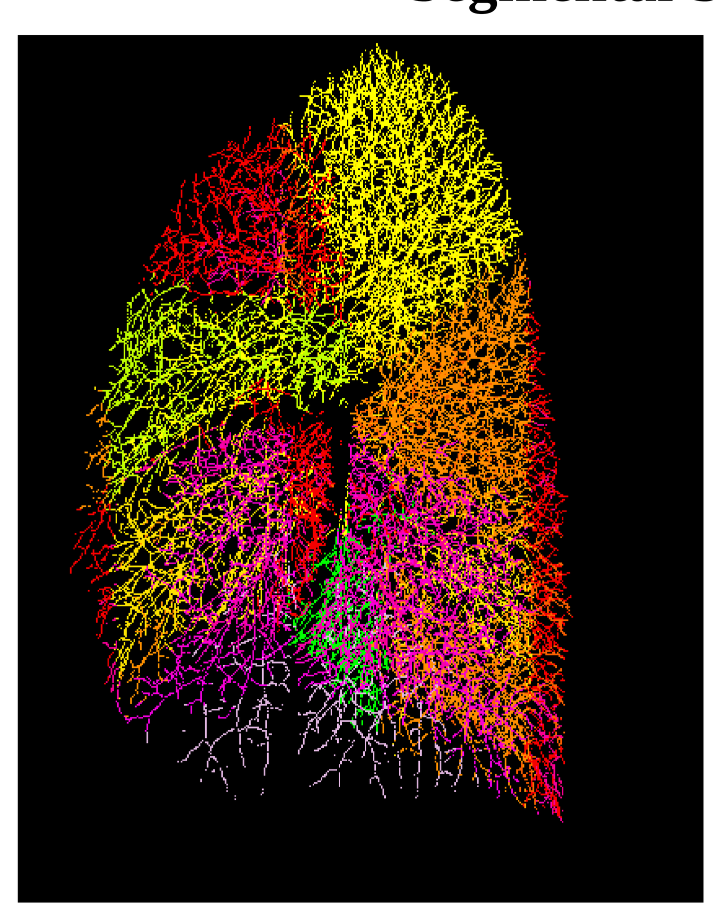

Figure. *Example of 3D vasculature mask in right lung derived from CT [3], color-coded by lung segment.*

Vasculature is extracted from CT using scale-space particles [2]. Example mask is shown at left, color-coded by lung segment.

Vessel mask was then restricted to small vessels (lumen area < 5 mm^2) to reflect vasculature most closely associated with regions of gas exchange

Small-vessel vasculature percent was calculated by dividing the **small-vessel volume** by **segmental volume:**

$$\frac{\text{Small-vessel Segmental Vasculature Volume}}{\text{Segment Volume}} \cdot 100\%$$

Statistical Model

Correlation between SVDP and segmental small-vessel percent was determined using the Spearman's rank correlation coefficient.

A linear mixed-effects model was used to model segmental small-vessel percent with SVDP, body-mass index (BMI), age, gender, and segment ID as fixed effects, and subject ID as a random effect

Results

Median [first quartile, third quartile]:

SVDP: 1.3 [0.0, 6.0]

Segmental small-vessel percent: 9.0 [7.8, 10.3]

Spearman Correlation

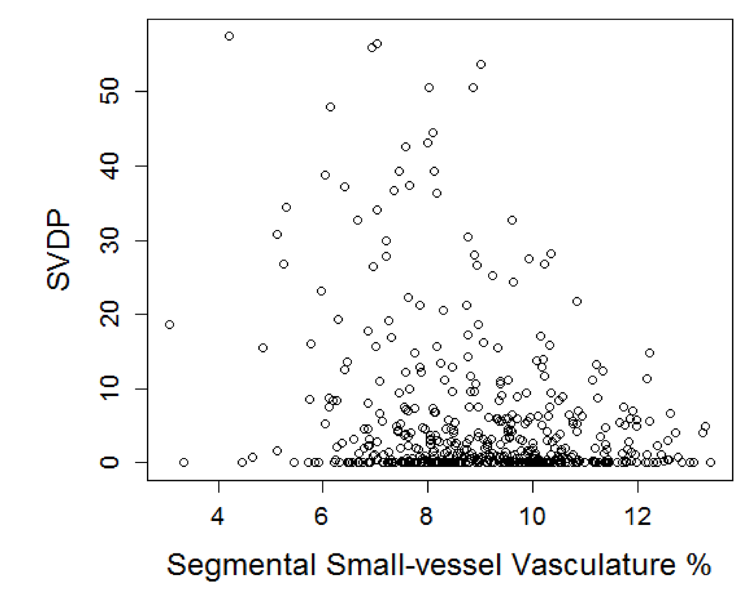

Figure. *Scatterplot (above) illustrating negative correlation between segmental ventilation defect percent (SVDP) and segmental small-vessel vasculature percent (Spearman's r = -0.15, p = 0.00078).*

Linear Mixed Effects Model

Parameter Estimates

Outcome: Segmental small-vessel percent

Parameter	Value	Std. Error	p-value
VDP	-0.018	0.0056	**0.0010**
BMI	-0.059	0.043	0.18
Age	-0.0019	0.017	0.91
Sex	1.01	0.50	0.058
LB3	-0.58	0.26	0.023
LB4	-1.2	0.25	< 0.0001
LB5	-2.68	0.25	< 0.0001
LB8	-1.8	0.25	< 0.0001
LB9	-0.94	0.25	< 0.001
LB10	-0.92	0.25	< 0.001
RB1	0.67	0.25	0.0090
RB2	0.92	0.25	< 0.001
RB5	-1.8	0.26	< 0.0001
RB6	0.63	0.25	0.013
RB7	-1.1	0.25	< 0.0001

Reference segment is LB1.

Segments not shown had p-values > 0.05.

SVDP was negatively correlated with small-vessel percent (Spearman's r = -0.15, p = 0.00078). **In the linear mixed-effects model, greater SVDP was associated with reduced segmental small-vessel percent (p=0.001).**

Discussion and Conclusion

Regional ventilation and perfusion are physiologically interrelated, with changes in one often prompting a homeostatic response in the other [4]. **These preliminary results suggest that multimodal functional imaging may provide a means of assessing spatially correlated measures of both ventilation and small-vessel volume.**

This technique could provide useful insights into patterns of small-vessel heterogeneity in the context of temporospatial characteristics of ventilation defects in asthma.

In a population of asthmatic subjects, SVDP on HP ^{3}He MRI was negatively associated with small vessel volume percent for the same segmental volume on CT.

Further research in this area will explore the use of SVDP and small vessel volume as a possible surrogate measure of ventilation/perfusion matching in asthma.

References

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