Pulmonary strain and compliance mapping in COPD: Investigating reproducibility and correlation with CT and spirometry

Alexandra R Morgan[1,2], Geoff JM Parker[1,2], Penny L Hubbard[1], Weijuan Zhang[1], David Singh[3], Jørgen Vestbo[3], Simon S Young[4], Lars Wigström[5], Marietta LJ Scott[4], and Josephine H Naish[1]

[1]*Centre for Imaging Sciences, Biomedical Imaging Institute, University of Manchester, Manchester, United Kingdom,* [2]*BiOxyDyn Ltd, Manchester, United Kingdom,* [3]*Airway Pharmacology Group, School of Translational Medicine, University Hospital of South Manchester, Manchester, United Kingdom,* [4]*AstraZeneca, Alderley Park, Macclesfield, United Kingdom,* [5]*AstraZeneca, Mölndal, Sweden*

TARGET AUDIENCE This abstract would be of interest to respiratory physicians and lung imaging physicists.

PURPOSE We present a method for extracting measures of strain from free-breathing proton MRI data using mesh-based image registration methods. These methods, as well as previously developed relative regional compliance (C_{rel}) calculations[1], were applied in a reproducibility study in a cohort of COPD (chronic obstructive pulmonary disease) patients and healthy volunteers (HV) to assess potential utility in assessment of lung disease. Correlation with gold standard measures of lung function – computed tomography (CT) and spirometry FEV_1 (forced expiratory volume in 1 s) - was also investigated.

METHODS 23 COPD patients and 11 HV each underwent two MRI scans, a week apart, on a 1.5 T Philips Achieva scanner (Philips Medical Systems, Best, the Netherlands). A half-Fourier acquired single-shot turbo spin-echo sequence was used to acquire structural images during breathing, as described previously[1]. Mesh-based group-wise affine image registration[2] was applied to images, allowing vector fields of motion to be calculated. Mechanical properties of the lung were extracted from these data by calculating the strain tensor from the deformation gradient of vector displacement fields. The two components of 2D strain, E_1 and E_2, dilation (D), and C_{rel} were calculated. Fig.1 shows example parameter maps. Head-foot gradients in compliance, dilation and principal strain (C_{grad}, D_{grad}, $E_{1,grad}$) were calculated to characterise mechanical heterogeneity within the lung for quantitative comparison between groups, as well as for assessment of reproducibility. Subjects carried out spirometry, allowing separation by FEV_1 % predicted according to GOLD spirometric criteria: 30–49% = severe COPD (S-COPD), 50–79% = moderate COPD (M-COPD). Only patients underwent CT. Percentage of low attenuation areas (%LAA) in slice-matched CT was calculated, with %LAA<2% indicating no emphysema (NE-COPD) in the slice, and %LAA>2% for E-COPD (emphysematous COPD). Two-tailed t-statistics were calculated to ascertain significance in group differences. Correlation with gold standard was assessed with Pearson product-moment correlation. No corrections were made for multiple comparisons.

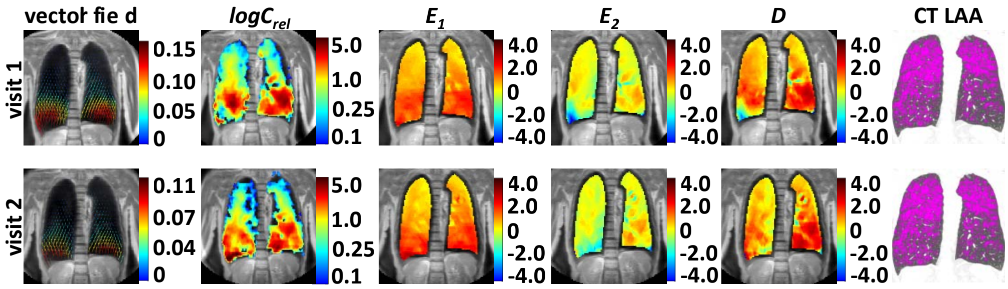

Figure 1: Vector field, relative compliance and strain maps for 1 patient alongside slice-matched CT with LAA highlighted. Data is shown for both visits. (all units arbitrary)

RESULTS & DISCUSSION Higher mean values were seen in C_{grad}, D_{grad} and $E_{1,grad}$ for patients compared to HV (Table 1). Differences were significant for all parameters when comparing S-COPD and E-COPD with HV. However, only C_{grad} and $E_{1,grad}$ were significantly different between HV and M-COPD, as well as NE-COPD. Significant correlations were found between all parameters and FEV_1, whereas correlations with %LAA were only significant in E-COPD in C_{grad}. A good inter-visit agreement was observed for C_{grad}, with a clear separation of HV and COPD patients (Fig. 2). $E_{1,grad}$ showed good agreement, but with a broader range. D_{grad} had a poorer reproducibility, perhaps explaining the lower significance in observed group differences.

Table 1: Parameter statistics for COPD patients and HV. (* = p<0.05, ** = p<0.01)

Gradient parameter	Mean (standard deviation) (group n given)			Significance of difference (p)			Correlation (r (p))
	S-COPD (11)	M-COPD (12)	HV (11)	S-COPD – HV	M-COPD – HV	S-COPD – M-COPD	with FEV_1
C_{grad}	1.14 (0.44)	0.79 (0.54)	0.31 (0.50)	<0.001**	0.04*	0.10	-0.53 (<0.001**)
D_{grad}	0.73 (0.50)	0.57 (0.80)	0.13 (0.62)	0.02*	0.16	0.56	-0.37 (0.03*)
$E_{1,grad}$	0.14 (0.07)	0.12 (0.06)	0.05 (0.07)	0.007**	0.01*	0.46	-0.51 (0.002**)
	E-COPD (15)	NE-COPD (8)	HV (11)	E-COPD – HV	NE-COPD – HV	E-COPD – NE-COPD	with %LAA (E-COPD)
C_{grad}	0.99 (0.56)	0.90 (0.47)	0.31 (0.50)	0.003**	0.02*	0.683	0.53 (0.04*)
D_{grad}	0.69 (0.69)	0.55 (0.66)	0.13 (0.62)	0.04*	0.17	0.639	0.16 (0.57)
$E_{1,grad}$	0.13 (0.07)	0.13 (0.05)	0.05 (0.07)	0.008**	0.01**	0.943	0.49 (0.07)

CONCLUSIONS Novel methods examined local relative compliance and strain in the lung in COPD patients and HV. We observed significant differences between COPD and HV, as well as fair inter-visit reproducibility. Significant correlation of compliance and strain with gold standard measures was shown, suggesting clinically useful observations can be made using these methods.

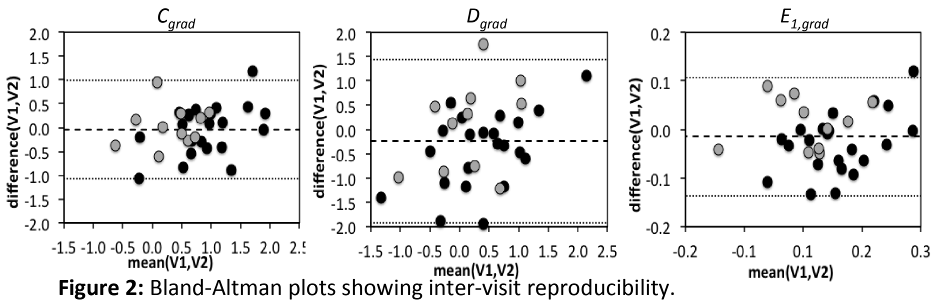

Figure 2: Bland-Altman plots showing inter-visit reproducibility. Black circles = patients, grey circles = HV. -- = mean, … = 95% confidence intervals.

ACKNOWLEDGEMENTS This work was supported by the BBSRC and AstraZeneca.

REFERENCES 1. Morgan, A.R. et al. *Assessment of Relative Regional Lung Compliance in Patients with Chronic Obstructive Pulmonary Disease* Proc Intl Soc Mag Reson Med 19 2011; 543. 2. Cootes, T.F. et al. *Computing Accurate Correspondences across Groups of Images* IEEE PAMI Vol.32 2010; 11: 1994-2005