Airway Measurement in 3D using Dynamic Hyperpolarized He-3 Multi-Echo VIPR

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Introduction: This work presents a technique to measure the lung airways using hyperpolarized helium-3 (HPHe3) MRI using a 3D Multi-Echo-PR (ME-VIPR) acquisition [1]. The approach combines previously presented methods for airway segmentation [2-5] with newly developed algorithms for airway measurement. Inspiratory dynamics are used to isolate the He-3 signal in the airway lumen from that in the parenchyma. The time resolution needed for this approach has previously limited this technique to 2D, with a single slice typically selected to encompass the major branches of the airway tree in the coronal plane. However, accurate evaluation and measurement of the airway tree requires 3D information such as that acquired in multi-detector CT (MDCT) methods, which is the current gold standard for non-invasive airway measurement in obstructive lung disease. Measuring airways in 3D is important because a single 2D slice may obscure vital information and diminish sensitivity due to partial voluming in a similar manner to X-ray projection imaging. Moreover, quantitative airway measurements are vital for assessing changes between time points in the same individual or when seeking to better understand regional differences in lung function. Airway measurements, for example, would be useful for monitoring lung transplant and cystic fibrosis patients over time in order to determine disease progression and response to therapy. Here we present an airway measurement algorithm capable of 3D measurement in HP He-3 MR images with accuracy similar to that of 3D MDCT measurements for the large airways.

Methods: *Imaging:* Imaging was performed on two volunteers with asthma using a 1.5T clinical scanner equipped with broadband capability (GE HealthCare, Milwaukee, WI). An excite/receive vest coil tuned to ~48MHz, the resonance frequency of He-3 at 1.5T, was used (Medical Advances). A ME-VIPR acquisition was performed using a cubic 42cm FOV and ramp sampling with maximum radial distance from the center in k-space corresponded to 64 evenly spaced points on a Cartesian grid. During imaging subjects performed a 4 s inspiration maneuver followed by breath-hold of ~1L of HPHe3. Data during the inspiration were sinc interpolated to a 256^3 matrix. MDCT scans were also acquired in the same subjects at a lung volume equivalent to functional residual capacity (FRC) and total lung capacity (TLC) as part of the same experimental protocol.

Airway Segmentation and Measurement: The MRI airways were segmented (**Fig. 1d**) using an algorithm [4] which includes seeded region growing along with several constraints designed to improve the segmentation of small airways in low SNR and CNR images. After segmentation 3D skeletonization [6] was performed, which finds the centerline of the segmented airways. A simplified 2D example of skeletonization is illustrated by the dark lines inside the brighter 'airway' components in **Fig. 1e**. For HPHe3 images the airway measuring process was a multi-step procedure: 1) Assign each voxel to an airway based on the closest centerline segment. An example can be seen in **Fig. 1e** with arrows 1-3 pointing to idealized airways. 2) Sum the voxels in each airway individually and add the total number of voxels in each of the 3 regions 1-3. 3) Find the length along each individual centerline segment by following its path. 4) Calculate each airway diameter based on the volume and length of the airway segment. 5) Airway branching angles are calculated by finding the angle between the centerlines of mother and daughter branches. The branching angles for **Fig 1e** would be the angle between centerlines 2 and 3 divided by 2 to represent the individual angles for each airway. The MR measured airways were compared to airways segmented and measured from MDCT using commercial software (VIDA Diagnostics, Iowa City, IA, USA) (**Fig. 1c**).

Subject	1	1	2	2	1	2
	CT(mm)	MR(mm)	CT(mm)	MR(mm)	MR(º)	MR(º)
Trachea	12.73	12.45	15.68	14.38	42.19	36.61
RMB	10.71	12.85	13.90	15.34	45.00	41.44
LMB	7.99	10.62	11.49	14.08	38.86	52.13
RLL7	8.76	10.19	11.30	10.23	36.16	35.17
LLB6	6.64	7.64	9.67	10.10	-	37.87
RB1	3.47	6.74	-	6.19	-	-
LB1	3.37	8.72	6.35	6.51	-	-

Table 1: Comparison of typical airway diameters from MDCT and MRI of the two individuals studied. - indicates values that were not measured.

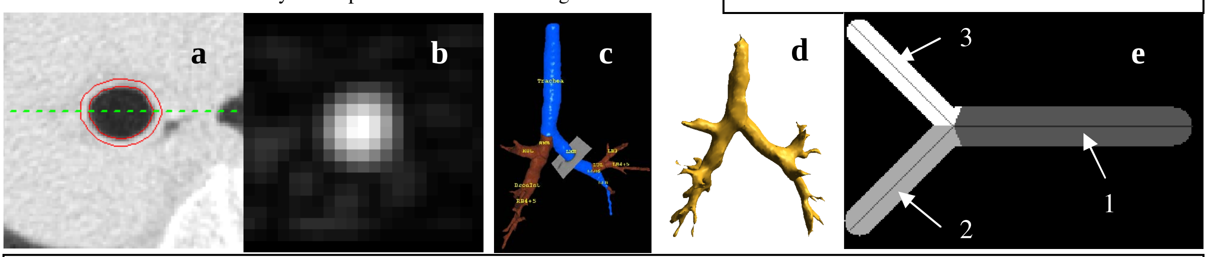

Figure 1: a) A reformatted CT image perpendicular to the airway at the location seen in panel c. b) A similar reformatted slice from the He-3 MRI near the same location as the slice in panel a. c) A rendering from CT showing the location of the perpendicular slices in panels a and b. d) A rendering of the segmented MRI airways in the same subject. e) A 2D schematic illustrating the measurement algorithm with area 1 representing a major airway, and areas 2 and 3 representing daughter branches. The shading indicates the regions that are assigned to each airway segment and the dark line in the middle represents the centerline for each branch.

Results: Measured airway diameters (**Table 1**) show comparable values for MRI and MDCT, however the smaller airways are not measured as accurately (**Fig. 2**). Branching airway angle measures on MDCT were not available for comparison to the values found in MRI, but the MRI values measured were between 30º and 50º and were near previously published values of 36.11±20.85º [7] (**Table 1**).

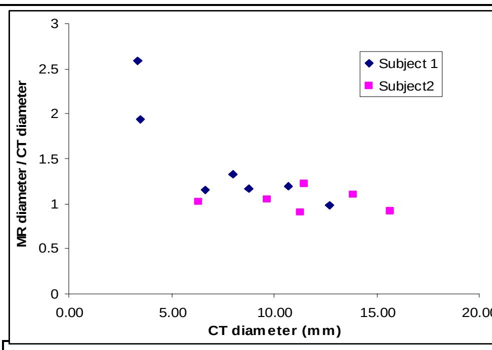

Figure 2: Plot of MDCT diameter vs MR diameter/MDCT diameter. This shows that, at present significant error results as the airway diameter falls below 6 mm.

Conclusion and Discussion: The potential of 3D HP He-3 MRI for assessing the airway tree dimensions during dynamic respiration and for repeated scans at different lung volumes is a significant advantage over MDCT methods that are limited by radiation dose burden. Although voxel sizes are isotropic for the present 3D acquisition, spatial resolution limits the current implementation. At present, the regridding algorithm causes blurring with a Full Width Half Max (FWHM) of 1.5*(voxel size) which results in an actual resolution of 4.92 mm which is approximately 8 times that of the MDCT measurements [8]. Small airways therefore pose a challenge due to the lower resolution of the MRI method compared to MDCT (**Fig. 2**). In addition, heart motion blurring, especially in the left branches near the heart (LMB, LLB6), and differences in lung volumes are additional sources of discrepancies between MDCT and MRI measures in this study. Future work will look to improve the resolution of the 3D HPHe3 MRI technique, primarily by improving the signal-to-noise with improved RF-coil design, modulated flip angle methods and improved dynamic range of the receiver. Additional future work includes direct validation of the airway measures using an anthropomorphic phantom with known 'airway' sizes suitable for both MDCT and MRI airway measurements.

References: [1] Brodsky et al. ISMRM 11:322 (2005) [2] Lewis et al. MRM 53:474–478 (2005) [3] Peterson et al. ISMRM 3342 (2006) [4] Peterson et al. ISMRM 1299 (2007) [5] Tzeng et al. MRM 57 :636-642 (2007) [6] Borgefors et al. Pattern Recognition 32 :1225-1236 (1999) [7] Tawhai et al. J Appl Physiol 97 :2310-2321 (2004) [8] Holmes et al. MRM (in press)