Rapid lung volumetry with ultrafast dynamic MRI during forced vital capacity (FVC) –correlation with spirometry

A. J. Swift[1], G. H. Mills[2], N. Woodhouse[1], S. Fichele[1], J. Seidel[2], E. J. van Beek[1,3], J. M. Wild[1]

[1]Academic Radiology, University of Sheffield, Sheffield, Yorkshire, United Kingdom, [2]Anesthesiology, Sheffield Teaching Hospitals, Sheffield, Yorkshire, United Kingdom, [3]University of Iowa, Iowa, Iowa, United States

Introduction Dynamic ^{1}H MRI has been shown to be a non-invasive method of evaluating respiratory mechanics at high temporal resolution. Several studies have been performed, from assessment of chest wall and diaphragmatic motion [1-3] to the generation of pulmonary volume/time curves [4]. The purpose of this study was to investigate the feasibility of using ultrafast 2D imaging to accurately sample the volume/time curves during the Forced Vital Capacity (FVC) manoeuvre. The volume exhaled in the first second FEV1 is the most clinically useful spirometric index, as such temporal resolution of regional volume/time curves is paramount.

Theory In order to accurately calculate the rate of change of lung volume (and hence the flow) in the first second of the FVC, very high temporal resolution (< 0.2 s) is needed. 3D imaging methods [4] struggle to provide this, even with high parallel imaging reduction factors. In this work, an elliptical model of the lung was used to approximate the lung as a stack of parallel axial ellipses whose major (*a*) and minor (*b*) axes were derived from ultrafast 2D coronal and sagittal slices –see Fig.1. The elliptical model was tested for accuracy by comparing the elliptical volumes, $\Delta z \cdot \pi ab/4$, with those calculated from a stack of axial images, which were acquired at full inspiratory capacity –see Fig.2.

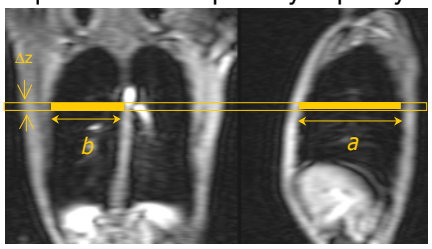


Fig. 1 Calculation of ellipse dimensions from 2D sagittal & coronal images

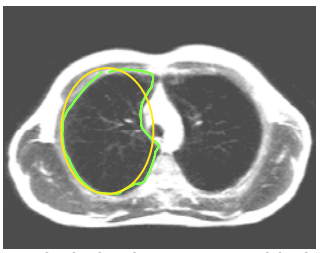


Fig. 2 Comparison of elliptical area (yellow) with actual volume – (green) from axial scan at inspiratory capacity

Methods All work was performed on a 1.5 T Philips, Infinion whole body scanner with the body TR coil. Nine healthy non-smoking volunteers underwent static breath hold MR scanning at inspiratory capacity. A single shot 2D half Fourier fast spin echo sequence was used for the static imaging with 25 axial slices of thickness 10 mm –see Fig. 2. Coronal and sagittal dynamic MR images were obtained in repeated forced vital capacity (FVC) manoeuvres. The dynamic imaging sequence was an ultrafast low resolution spoiled gradient echo, TE=1.6 ms, TR = 3 ms, 20 mm slice thickness, 125 kHz BW, 45 cm FOV, 32 phase encodes. The frame rate was just over 10/s. Volumes were calculated from the coronal and sagittal scans by assuming elliptical cross section of the lung made at 4 cm intervals in the axial direction from head to foot. Spirometry was performed in the supine position, and the spirometric indices (FEV1, FVC and FEV1/FVC) were correlated with MR findings. Statistical analysis was performed using the Spearman's sign rank test.

Results Total lung volume calculated from static MR imaging correlated well with the dynamic MR scans ($r=0.83$; $p < 0.01$). FEV1 (forced expiratory volume in 1s) and FVC showed a good correlation between the MR and conventional spirometry techniques $r = 0.95$ and $r = 0.83$ respectively. The frame rate gave a time-resolved quantitative depiction of the FVC –see Fig.4

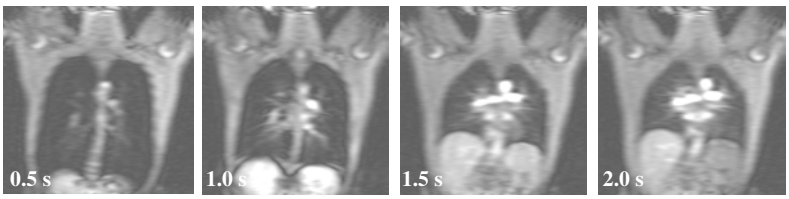
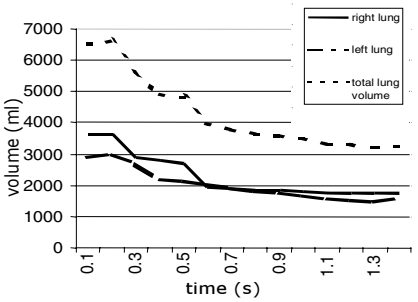


Fig. 3 Snapshots at 0.5 s intervals (every 5th frame) from a coronal FVC time series. The temporal resolution is fast enough to sample the FVC flow curve –see Fig.4

Fig. 4 (right) volume time curves calculated from the elliptical model. Shown are the curves from the left, right and both lungs sampled at 0.1 intervals



Discussion Using an elliptical model of the axial cross-section of the lungs enabled rapid volume-time curves to be derived from interleaved coronal and sagittal 2D scans. Despite showing good correlation there is an offset in Figure 5, which could be due to an underestimate of the exact position of the lung wall from our low-resolution images or inaccuracy in the elliptical model. However, these early results suggest that ultrafast 2D dynamic proton MRI could potentially be used to assess global and individual lung function as a spatially localised alternative to spirometry. These methods provide a means of sampling regional lung volume change during the rapid sub-second movements that take place during FVC manoeuvre. While 3D approaches [4] provide more accurate depiction of lung volumes at either end of the spirometry manoeuvre, their temporal resolution are not sufficient to sample the FVC –the spirometric index of most clinical use. Reproducibility of a FVC manoeuvre and supine positioning of the subject during imaging are limitations of this study. Further studies will assess the technique on a regional/lobar basis with further increases in scan speed with parallel imaging. Imaging in an upright position and MR compatible spirometry equipment would also be valuable.

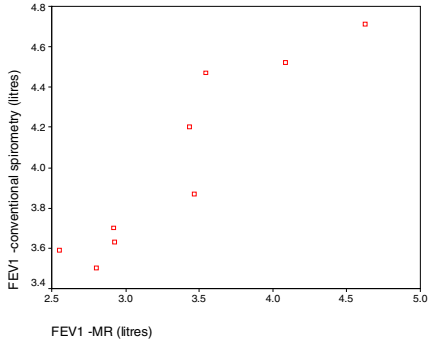


Fig. 5 Correlation of spirometry and MR volumes r=0.95 FEV1.

References [1] Gierada DS, et al. Radiology. 1995;194(3):879-84. [2] Cluzel P, et al. Radiology. 2000;215(2):574-83. [3] Suga K, et al. JMRI. 1999;10:510-5204. [4] Plathow C, et al. Invest Radiol. 2004;39(4):202-9.