Quantitative analysis of regional airways obstruction using dynamic hyperpolarized 3He MRI - Preliminary results in children with cystic fibrosis

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Introduction Dynamic imaging of hyperpolarized ^{3}He can provide striking cine movies of lung ventilation in humans [1] and in animal models [2]. The dynamic images are influenced by several physical factors relating to the lung environment, the breathing manoeuvre and the pulse sequence design. As a consequence there are questions regarding the inference of accurate quantitative information on lung function from the data. The aim of this study was to examine the degree of pulmonary involvement and to quantitatively evaluate patterns of gas flow in lung regions in children with CF. The results were compared with standard pulmonary function tests.

Theory The flow (dV/dt) in the airways can be derived from Poiseuille's equation: $dV/dt = \Delta P\pi r^4/8\eta l$ Where η is the viscosity of the gas inhaled, r is the radius of the airway segment, l is its length and ΔP is the pressure differential across its length. Flow rate is thus proportional to the fourth power of the radius, therefore small changes in the radius will greatly affect the flow. This model of the major airways as rigid tubes with laminar flow serves as an approximation. In a graphic demonstration of the signal measured in a ROI with the time, the slope of the curve therefore describes the flow –see schematic of Figure1. A smaller gradient corresponds to a slower flow and could indicate a greater involvement of the region with pathologic process such as obstruction.

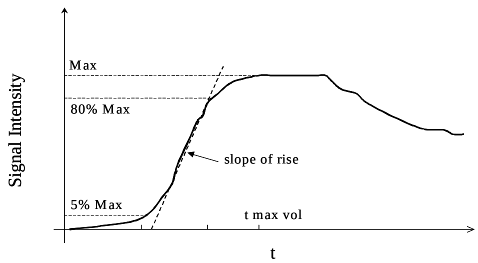

Fig. 1 Signal kinetics parameters

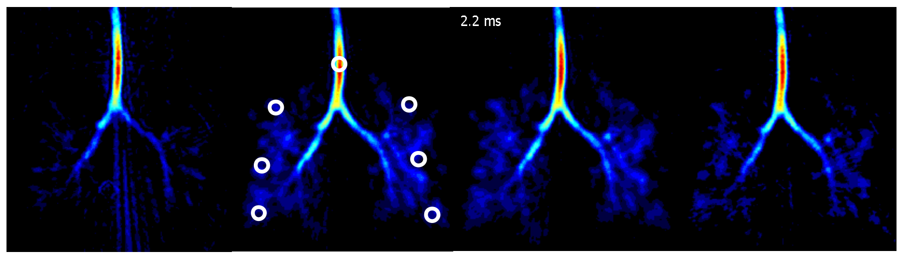

Fig. 2 Time series of images chosen at 1 s intervals note the obstruction in the upper lobes

In an effort to normalise for the effects of subject dependent factors such as the inspiratory effort or the gas delivery method, we propose to use the ratio of the slope of the curve in the area of interest to the slope of the curve in the trachea as an index of relative flow. Since all gas will pass via the trachea it seems reasonable to use the tracheal signal intensity as a form of 'input function' to normalise for input flow effects.

Materials and Methods The study population consisted of 8 children with CF aged 6-15 y (mean age 11,4y). All of them had undergone a recent spirometric evaluation. The ^{3}He gas was polarized to 30% with rubidium spin exchange apparatus. All imaging was performed during inhalation and exhalation of a dose of gas, which consisted of approximately 5 ml of ^{3}He /kg body mass. The ^{3}He was made up to a total volume of 500 ml with N_2 and delivered manually from a Tedlar bag. All imaging was performed on a 1.5T whole body MRI system using a dynmaic radial projection sequence described in [1]. After reconstruction, the images were evaluated using a pixel by pixel fitting of the spatio-temporal parameters depicted in Fig.1. The data was first normalised for the effects of RF depolarisation as described in [2]. The mean slope was defined between 5% and 80% of the maximum signal for the pixel and was calculated using a linear fit. A total of 7 ROI's were taken, three in each lung field and one in the trachea –see Fig.2. ROI measurements were then made by averaging the signal over all pixels in the ROI (30 pixels).

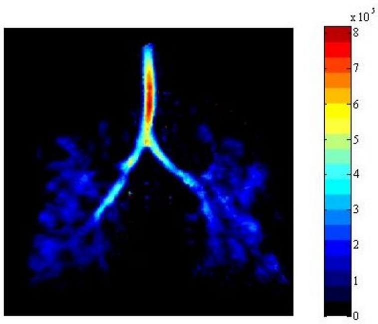

Fig3 Map of slope

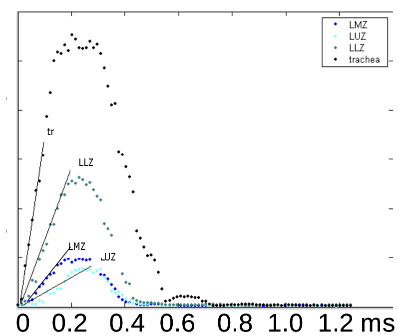

Fig.4 ROI measurements

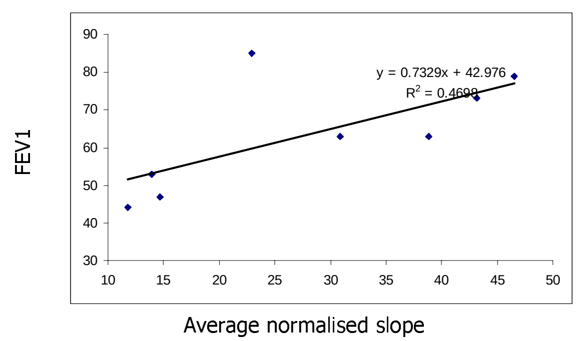

Fig. 5 Correlation with spirometry

Results Figure 3 shows the pixel-pixel map of the slope of the curve from the time series shown in Fig.2 Note the high flow rates in the airways as predicted by our model. Fig. 4 are ROI measurements made in the trachea and 3 ROI's in the left upper, middle and lower peripheral lung –see Fig.2. The low flow rate in the upper lobes was a pattern observed in all of the patients and is symptomatic with CF, which has a preferred distribution in the upper lobes. The flow measurements in the peripheral ROI's were then normalized using the tracheal flow as an 'input function'. When averaged to give an index of flow in the peripheral lung these showed a good correlation ($p<0.005$) with the forced expiratory volume (FEV1) from spirometry –see Fig.5 .

Discussion These results suggest that a quantitative measurement of localised airways obstruction may be obtained from dynamic ^{3}He MRI by using the slope of the signal rise as a measure of air flow in to the peripheral lung. When the flow curves were normalised with the flow from the major airways (as a normalising input function to account for variability in breathing manoeuvre) the results showed good correlation with spirometry.

References [1]Wild JM et al, Magn Reson Med, Jun 2003; 49: 991-7. [2] Dupuich D, et al Magn Reson Med 2003 50;777-783.

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