Improved quantitative regional oxygen-enhanced MR imaging of the lung using image registration

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Introduction

Oxygen-enhanced MR imaging of the lung was first demonstrated in 1996 [1] and has recently been shown to provide information on regional delivery of oxygen within the lung [2]. In this study we use a simple image registration method to determine regional oxygen induced changes in both T_1 and dynamic signal intensity.

Methods

Imaging was performed on 5 normal volunteers using a 1.5T Philips MR system using a HASTE sequence (128x128 matrix, 68 phase-encoding steps, inter-echo spacing 4ms, coronal section thickness 10mm). Subjects breathed medical air or oxygen through an MR compatible Bain breathing system. T_1 maps were produced using a saturation recovery HASTE sequence with nine saturation times between 100ms and 3.5s. Five images were collected for each saturation time. Saturation recovery was chosen in preference to inversion recovery because of the reduction in total imaging time (approx 2.5 minutes for the set of 45 images). Dynamic images were acquired every 3.5 seconds using an inversion recovery HASTE sequence with an inversion time of 720ms. Subjects breathed medical air for the first 10 images, then 100% oxygen at a flow rate of 10 l/min for a further 48 images. T_1 maps were collected before and after the dynamic sequence. A second dynamic sequence was then performed with the subject breathing 100% oxygen for the first 10 images before switching to medical air for the remaining 48 images.

In order to obtain regional information the images were registered spatially. For the T_1 maps, 10 points were manually marked along the diaphragm of each image. These were resampled at 10 equidistant points using an Akima spline interpolation. A further 12 points were manually marked at corresponding points along the remaining lung outline. As the diaphragm moves the lung is stretched mainly in the vertical direction. The set of 45 images were registered to a reference image (chosen from the set) by stretching individual columns of pixels. Linear interpolation was used to sample the signal at fractional pixel locations and the signal intensity was rescaled according to the magnitude of the stretch (assuming the total proton density is independent of lung volume). T_1 maps were calculated on a pixel-by-pixel basis by fitting. Each set of 116 dynamic images was registered in a similar way, except that only the first 10 images in a set were manually marked up. An Active Shape Model [3] was built using this set of 10 marked images and used to locate corresponding points in the complete set of 116 images thus reducing considerably the user input. Oxygen uptake and washout times were calculated by fitting an exponential to the dynamic signal intensity, both in large regions of interest and on a pixel-by-pixel basis in a smoothed (disk filter, radius 4 pixels) set of images.

Results and discussion

Example T_1 maps for a volunteer breathing air and oxygen are presented in figure 1 and compared to a map calculated by retrospectively respiratory gating i.e. by selecting images for which the right diaphragm matched to within 2 pixels. The T_1 maps calculated using the registered images show a clearer structure and a reduction in breathing artefacts. A reduction in T_1 on breathing 100% oxygen is demonstrated. T_1 values averaged within the lung breathing air and oxygen are 1.27s and 1.08s respectively and are consistent with previously published values [4].

Signal intensity time courses are presented in figure 2 for both oxygen uptake and washout. A small improvement (reduction in noise) is observed for a region of interest in the upper half of the right lung when comparing registered with non-registered images; a much larger improvement is seen for a region of interest in the lower half of the lung. Registration thus improves regional determination of oxygen uptake and hence regional ventilation in the lung. Table 1 lists average oxygen uptake and washout times found by fitting in a region of interest encompassing the whole of the left or right lung and in figure 3 we present an example regional uptake time map. These uptake times are longer than those quoted by Ohno et al [2] who used a similar fitting function; this may be due to the different breathing apparatus used.

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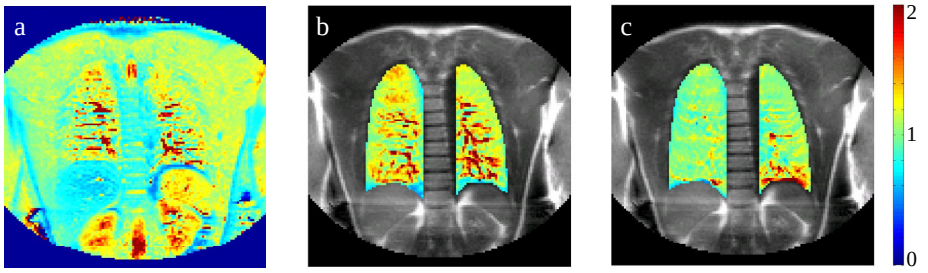

Figure 1: example T1 maps a) calculated by selecting images in which right diaphragm position matches to within 2 pixels b) & c) calculated using full set of registered images while breathing medical air (a & b) and 100% oxygen (c). The scale is in units of s.

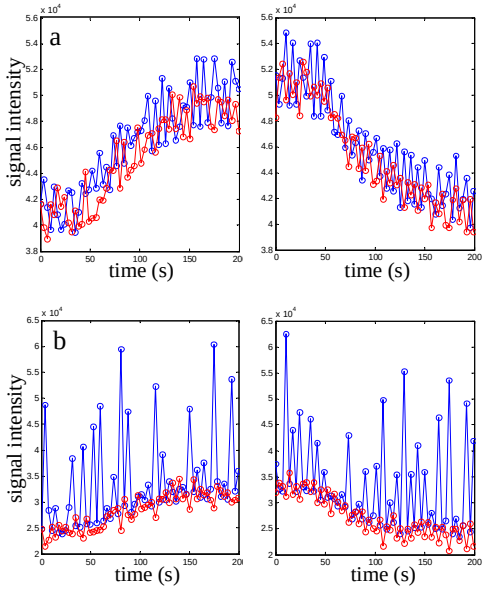

Figure 2: example dynamic wash-in and wash out curves for a region of interest in a) the upper half of the right lung and b) the lower half of the right lung. The blue lines are for raw images and the red lines are for registered images.

subject	uptake		washout	
	right	left	right	left
1	53.7	46.9	31.8	34.0
2	58.7	21.9	27.0	37.7
3	65.1	50.4	40.9	31.0
4	54.5	50.6	61.5	61.2
5	53.2	62.1	29.7	27.0
mean(sd)	57(5)	46(14)	38(14)	38(13)

Table 1: average uptake/washout times (s)

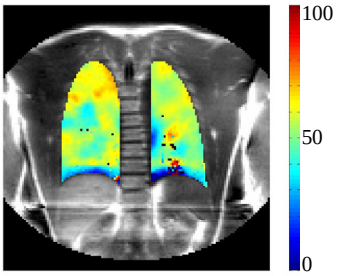

Figure 3: example regional uptake time map. The scale is in units of s.

References

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