Measurement of arterial plasma oxygenation in dynamic oxygen-enhanced MRI

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Introduction: There has been increasing interest in the use of oxygen as a T_1 contrast agent in MRI, primarily for lung ventilation imaging but also in other tissues [1,2]. These methods exploit the paramagnetic T_1-shortening properties of molecular oxygen dissolved in blood and tissue plasma. Quantitative work in soft tissues has focused on calculation of signal intensity ratios for breathing air and breathing oxygen rather than following signal intensity changes dynamically. Compartmental models of blood-tissue gas exchange, similar to those used in dynamic contrast-enhanced MRI, have potential for quantifying parameters describing tissue physiology. In order for such models to be applied, an input function describing the delivery of oxygen to the tissue of interest would be required. This work investigates the feasibility of measuring such a function from the aorta using oxygen-enhanced (OE) MRI data acquired in the lungs.

Methods: 24 subjects underwent dynamic OE imaging at 1.5 T. 14 (7 smokers (S), 7 never-smokers (NS)) volunteers had the aorta in the field of view and were therefore selected for further analysis. Informed consent was obtained from all subjects. A 15 mm thick coronal slice was positioned posterially with a 44.5 cm x 44.5 cm field of view (see Fig. 1). This volume was imaged using an inversion-recovery turbo field echo sequence (TR/TE 2.2/1.0 ms, flip angle 5°, acquisition matrix 128 x 256 zero filled to 256 x 256) to acquire images throughout recovery from an initial nonselective inversion pulse (25 inversion times were used, shortest 74 ms with intervals of 143 ms), permitting a measurement of T_1. The acquisition was repeated continuously for 18 minutes, giving T_1 measurements at a time resolution of 6 seconds. The volunteers breathed medical air via a Hudson mask for the first 3 mins, then the supply to the mask was switched to 100% oxygen. After a further 9 mins, the supply was switched back to air for the remainder of the acquisition. Gas was delivered at 15 l/min

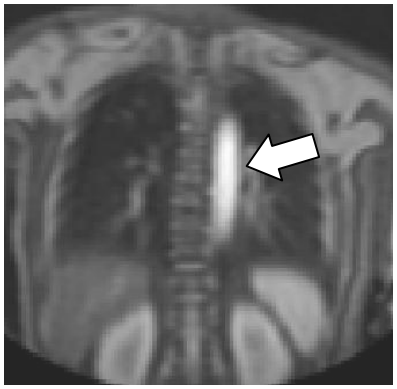

Fig. 1 – Mean of 30 images on breathing medical air with TI = 217 ms clearly showing the aorta (arrow).

A region of interest was marked for the aorta and dynamic measurements of T_1 were extracted by fitting the Look-Locker signal equation [3]. Changes in T_1 due to inhalation of oxygen were converted to changes in partial pressure of oxygen in blood plasma (ΔPO_2) using the relaxivity constant $r_1 = 2.49 \times 10^{-4}$ [4]. The mean ΔPO_2 in the plateau region of the dynamic curve (chosen as the region between 8 and 12 mins) was recorded for each subject, and a Wilcoxon rank sum test was used to compare these values for smokers and never-smokers, testing the hypothesis that S had lower plateau ΔPO_2 values than NS due to possible reduced oxygen exchange efficiency.

Results: The ROIs contained a mean of 42 ± 20 pixels. Mean baseline and plateau T_1 values were 1300 ± 200 ms and 1200 ± 100 ms for S and 1300 ± 200 ms and 1100 ± 100 ms for NS respectively. Fig. 2 shows ΔPO_2 plotted as a function of time for each subject in the two groups, smoothed using a 5-point moving average. The bold line shows the mean time course over all volunteers (unsmoothed). The mean plateau value was 350 ± 90 mmHg for S and 430 ± 40 mmHg for NS ($p=0.049$).

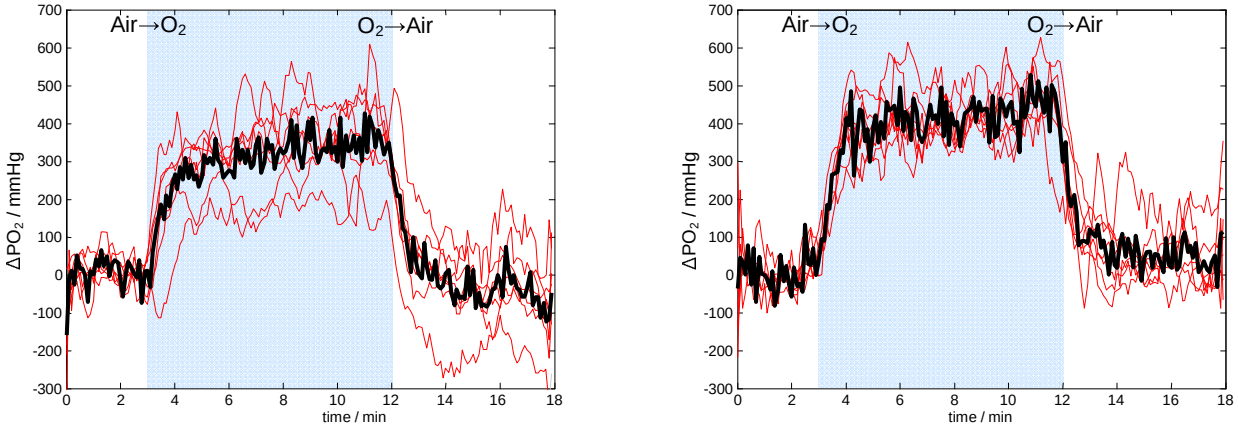

Fig. 2 – ΔPO_2 as a function of time for smokers (L) and never-smokers (R) plotted for each subject (red), with mean over all subjects in black

Discussion: In this small number of volunteers, the plateau ΔPO_2 values showed a borderline significant difference between the two groups, with S showing lower plateau ΔPO_2 values than NS. The standard deviation of the plateau ΔPO_2 in S was double that in NS. Literature values for arterial blood gas measurements of PO_2 in normal volunteers when breathing air and 100% oxygen suggest that the expected ΔPO_2 should be 490 ± 20 mmHg [5], in agreement with our findings. Direct comparison with arterial blood gas sampling would be advantageous to validate the measurement and the study of more subjects will allow stronger conclusions to be drawn regarding any difference between S and NS.

These curves show that the gas delivery system used in OE-MRI is functioning as expected, and also give an indication of global lung function by showing how well the lungs are oxygenating the blood, although they do not provide information on haemoglobin transport. These measurements of arterial plasma oxygenation could be used as an input function in compartmental modelling of oxygen uptake in tumours or other tissues, or in modelling of oxygen transfer in the lungs.

In conclusion, we have measured T_1 changes in the aorta for smokers and never-smokers due to breathing 100% oxygen, which, assuming a value for r_1, can be converted to a measurement of ΔPO_2 that is in agreement with literature values. These noninvasive measurements of ΔPO_2 have potential in modelling of oxygen uptake in a wide range of tissues and also for modelling gas exchange in the lungs.

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