Optimisation of Oxygen-Enhanced Imaging in the Kidney

K. F. Holliday1,2, J. H. Naish1,2, J. Tessier1, and G. J. Parker1,2
1Imaging Sciences, The University of Manchester, Manchester, United Kingdom, 2Biomedical Imaging Institute, Manchester, United Kingdom, 3Early Clinical Development, AstraZeneca, Macclesfield, United Kingdom

Introduction: Oxygen-enhanced MR imaging (OE-MRI) has been used in various studies to investigate oxygenation in arterial blood, abdominal organs and tumours by measuring a signal change upon the breathing of 100% O₂, which is due to the paramagnetic T₁-shortening properties of dissolved molecular O₂ in blood and tissue plasma [1-3]. Blood flow and oxygenation in the kidneys is known to be inhomogeneous [4] and previous oxygen-enhanced studies have shown regionally varying signal change [5]. The magnitude of oxygen-enhanced signal change is small, yet few attempts have been made to optimise any imaging sequence for this particular application and no comparisons have been made between the abilities of different sequences to demonstrate signal change in abdominal organs or tumours. In this work we have investigated the contrast to noise ratio offered by two sequences commonly used in OE-MRI: Inversion-prepared Half Fourier Turbo Spin Echo (IR-HASTE) and Spoiled Gradient Echo (SPGR), and then using simulations we have optimised both for use in OE-MRI of the kidneys. We then compared their abilities in vivo in a single subject. Finally we carried out a dynamic OE-MRI study in the kidneys of a small group of healthy volunteers and created parameter maps showing ΔPO₂ and wash-in time on a voxel-by-voxel basis. Simulations: Typical T₁ changes due to breathing 100 % O₂ for a selection of abdominal organs were taken from literature [5]. Simulations were carried out using Matlab 7.5 (The Mathworks Inc, Natick, MA, USA) to calculate the potential contrast to noise ratio using the dynamic plots for typical sequence parameters and bandwidth values, for a range of possible signal changes.

Head-to-Head Study: A head-to-head imaging session was then carried out in a single healthy volunteer at 1.5 T to compare the signal change produced by each imaging sequence after optimisation. Prior to the dynamic series, T₁ measurements were taken using both acquisition methods. For SPGR T₁ measurement, flip angles of 3°, 11° and 15° were used with a TR/TE of 5000 ms with T₁ derived using the variable flip angle method [6]. A range of inversion times (TI) from 100 to 5000 ms was used for an IR-HASTE single slice acquisition, with TR/TE = 5000+TI/3.4 ms. Both sequences were acquired coronally, centred on the kidneys, with a slice thickness of 6 mm. During gas switch-over T₁-weighted images were repeatedly taken to capture the gas uptake signal curve using optimised parameters described above. Head-to-Head Results: ROI analysis of the dynamic images was carried out to investigate the difference in CNR between the two sequences in the kidney. Mean baseline and peak values for both signal and noise were calculated in order to derive CNR values. These were CNR = 1.1 for SPGR and CNR = 2.6 for IR-HASTE. These results demonstrate that a much greater CNR was achieved using the IR-HASTE technique, in agreement with the expectations from the simulations studied, so this acquisition method was further studied. The two dynamic curves for the whole kidney are shown in Figure 2, with mean baseline and peak values for the two sequences shown with dotted lines. Further In Vivo Study: Five further healthy volunteers were then scanned using the IR-HASTE protocol described previously. Subjects breathed medical air whilst a T₁ measurement was taken. Dynamic scanning then began and the breathing gas was switched to O₂ after 20 dynamic images. A total of 80 dynamic images were taken before a second T₁ measurement was made whilst the subject continued to breathe O₂. Time series images were used to create a parametric map of the weighted 2D T₁-relaxivity body algorithm in FLIRT [7]. T₁ maps were then compared for both air and O₂ signal, then converted to ΔPO₂ using a published relaxivity constant [8]. Dynamic plots were used to initialise a sigmoid curve fitting algorithm which calculated ΔPO₂ and wash-in time for the dynamic series on a voxelwise basis. Results: A map of signal change (left – scale 0 to 16000), ΔPO₂ (centre - scale: 0 to 10 mmHg) and wash-in time (right – scale: 0 to 480 s) for one of the subjects is shown in Figure 3. Mean ΔPO₂ in the whole kidney was 53 ± 18 mmHg and in the renal cortex was 30 ± 10 mmHg across all subjects. Discussion: Although SPGR sequences have the potential for much greater CNR, when we include consideration of the temporal resolution requirements of a dynamic study we find that using IR-HASTE sequences leads to a much greater CNR. However, our IR-HASTE acquisition was only single slice, and CNR or temporal resolution sacrifices may have to be made if full volume coverage is required. Analysis of dynamic signal changes has previously been demonstrated with OE-MRI in the lungs, aorta and spleen [9, 10]. This study was able to show that through the parameterisation of the dynamic signal curve obtained during gas switch-over, it is possible to create maps which distinguish between regions in the kidney with differing oxygen delivery. It would be interesting to apply this technique in a study involving the use of diuretics, which are known to affect regional oxygenation levels and blood flow within the kidney [11]. The use of OE-MRI as an indicator of plasma-dissolved oxygen delivery to the kidneys may also be considered as a practical alternative to the use of gadolinium-based contrast media for assessment of renal health.

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