3D-EPI ASL at Ultra High Field

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Introduction: 3D arterial spin labelling (ASL) perfusion methods provide a method of simultaneous sampling of the imaging volume, eliminating slice dependent variation in perfusion signal due to differences in acquisition delays that occurs in 2D multi-slice methods. Further, 3D methods are of particular benefit to background suppressed ASL [1] as the static signal is attenuated to an equal extent across all slices. To date, 3D ASL methods are based on the acquisition of spin-echo trains refocused by large flip angle pulses, using 3D-GRASE [2] or 3D-FSE [3, 4]. However, the implementation of closely spaced high flip angle pulse trains can be difficult to achieve and leads to high SAR, which can be limiting at ultra-high field (7T). Here, we assess the combination of 3D-EPI, using a train of low flip angle EPI readouts, with ASL and SENSE acceleration in the two phase encoding directions to significantly reduce the echo train readout time relative to 2D EPI.

Theory: In 3D-EPI, a thick slab of tissue is repeatedly excited with a low flip angle RF pulse every TR and the slice selection replaced by a secondary phase encoding direction. The 3D volume is collected in a time $TR \cdot N_{slices}$, which can be further reduced if SENSE acceleration is applied in the slice selection. In the standard implementation of 3D-EPI, readouts are applied every TR, resulting in a lower steady state signal being reached for 3D-EPI than 2D-EPI, but the sensitivity of 3D-EPI is increased by a factor of $\sqrt{N_{slices}}$ due to volume k-space acquisition. In 3D-EPI ASL, each 3D volume is acquired after a post-label time TI, altering the steady state 3D-EPI signal. This can lead to some signal weighting in k_z, which can be overcome by progressively adjusting the flip angle across the 3D-EPI readout train. Figure 1 shows the relative theoretical sensitivity of 3D-EPI ASL compared to 2D-EPI ASL as function of number of slices.

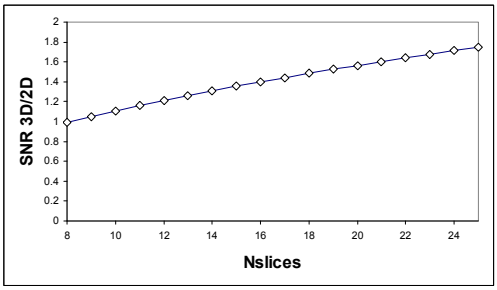

Figure 1: *Relative theoretical sensitivity of 2D- to 3D-EPI ASL as function of number of slices. Simulation assuming TR = 30 ms, flip angle = 14^0.*

Methods: 4 subjects were scanned on a 7.0 T Philips Achieva system with a volume transmit and 16-ch SENSE receive coil. A QUIPSSII FAIR ASL sequence was used with post-label delay 1.55 s, taking 6s to acquire one tag/control pair, and acquiring 50 tag/control pairs. Optimised WET and sinc pre- and post-sat pulses were used to limit static signal contamination and two background suppression pulses applied at 402/639ms. 3D-EPI image volume acquisition was initially optimised for acceleration factor in phase (P) and slice (S) direction. Table 1 summarises the 3D imaging parameters for 3 mm isotropic and 2 mm in-plane voxels, using a flip angle of 14^o to maintain a steady state in k_z. Equivalent 2D-EPI ASL shot lengths are listed, however the number of slices which could be collected using 2D-EPI was found to be limited by SAR, as shown in Table 1.

Mode	Resolution (mm^3)	No. Slices	SENSE	TE (ms)	TR (ms)	Shot Length (ms)
3D	3x3x3	20	P-2 S-1.5	9.7	20	359ms
2D	3x3x3	20 *(12)*	P-2	9.5	-	25ms/slice = 500 ms
3D	2x2x3	20	P-2 S-1.5	17	35	634ms
2D	2x2x3	*20 (12)*	P-2	17	-	44ms/slice = 880 ms

Table 1: *3D- EPI and equivalent 2D-EPI ASL imaging parameters. Number of slices shown in brackets indicates practical restriction in number of slices due to SAR limit at 7T.*

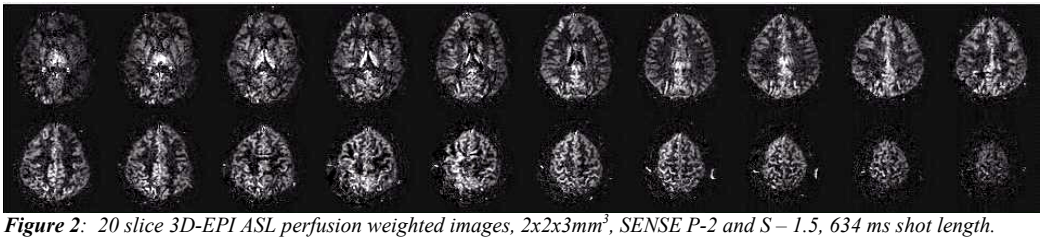

Figure 2*: 20 slice 3D-EPI ASL perfusion weighted images, 2x2x3mm^3, SENSE P-2 and S – 1.5, 634 ms shot length.*

To illustrate the potential use of 3D-EPI ASL for functional studies with whole head coverage, a combined visual/motor fMRI experiment was performed. A flashing checkerboard was presented and the subject was asked to tap their fingers during visual stimulation. The paradigm comprised 31s ON, 31s OFF, TR=6.2s, 15 cycles. FMRI analysis performed using FEAT (FSL, FMRIB, Oxford), with Z-score images threshold at $P < 0.05$.

Results: Figure 2 shows the perfusion weighted images for the 2x2x3mm^3 3D-EPI ASL collected in ~ 600 ms. Slices displayed equal background suppression across all slices, and the PW signal is found to be homogeneous across slices. Figure 3 shows results of the functional task overlaid on the selected visual/motor slices and the corresponding base images acquired using 3D-EPI.

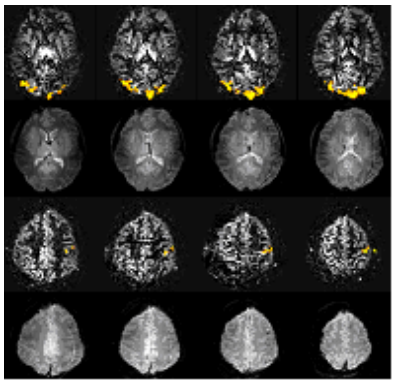

Figure 3: Functional activation overlaid onto difference ASL image, and corresponding 3D EPI base image shown

Discussion: 3D-EPI using parallel acceleration in two phase encoding directions provides a method of whole head ASL acquisition: (1) with improved SNR compared to 2D-EPI, (2) reduced label decay (3) without compromising spatial resolution or scan time and (4) overcoming the SAR restrictions that can affect 2D-EPI due to the large readout flip angle coupled with high SAR due to pre-saturation/label. A 20 slice acquisition of 2x2x3mm^3 2D-EPI would take ~900 ms (Table 1), which is a significant increase on 3D acquisition time, and would practically exceed SAR limits. 3D-EPI provides a sensitive method to acquire whole head perfusion images which is essential to study global, rather than focal perfusion changes, for example in patient studies, or to study widespread functional changes such as the response to hypercapnia/hyperoxia.

References: [1] Garcia et al., MRM, 54,336-372, 2005. [2] Gunther et al MRM 54:491-498 2005 [3] Duhamel and Alsop. ISMRM 2004 518 [4] Wong et al. ISMRM 2006 3427 **Acknowledgements:** This work was supported by the MRC.