Single-Shot Susceptibility Insensitive Whole Brain 3D fMRI with ASL

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Introduction: Arterial Spin Labeling (ASL) may provide superior spatial resolution (1), better intersubject reproducibility (2,3), improved temporal stability (2,3), and reduced susceptibility artifact (4) relative to BOLD for brain activation studies. Imaging approaches reported to date, however, have suffered from combinations of reduced slice coverage, image distortion or blurring at susceptibility boundaries, and variable sensitivity across slices. Here we report a background suppressed, 3D fast spin echo ASL sequence which employs interleaved variable density spirals and parallel imaging to achieve imaging of the entire brain at under 4mm cubic resolution in a single shot and its initial evaluation for fMRI of motor activation.

Materials and Methods: All experiments were performed on a 3-Tesla whole body scanner, GE VH/i (GE Medical Systems, Milwaukee, WI) with a prototype 4-channel phased array head coil (GE Applied Sciences Laboratory). The sequence is shown schematically in figure 1. Interleaved variable density spiral trajectories of 4 ms duration were used to encode the coronal plane and standard rectilinear encoding was used for the A/P direction. Optimized spiral gradient waveforms were obtained from the time derivative of an analytic variable-density spiral k-space trajectory: $k(t,n)=\lambda t^{\alpha} e^{j(\theta(t)+\phi(n))}$ with $\alpha=1$, $\theta(t)=aLn(t+t_0)$ and $\phi(n)=2\pi n/N^{inter}$. The constants a, t_0 and λ were properly determined according to our hardware constraints (maximum slew rate $(dG/dt)^{max}$=15 G/cm/ms)) as well as the desired spatial and temporal resolutions (Δx=(18cmx18cm/48x48), T^{acq}=4ms and BW^{max}=62.5kHz). Image reconstructions were performed using IDL and statistical analysis for fMRI studies, with SPM99 (Wellcome Dept. of Cognitive Neurology). The single-shot 3D-FSE imaging sequence acquired 104 echoes using an amplitude tailored refocusing rf train with an asymptotic amplitude of 45°. Four variable-density spiral interleaves (S_{GXi} and S_{GYi}) were acquired in successive echoes for each of 26 different A/P phase encodes gradients (PEi). This acquisition corresponded to a 2 fold undersampling in the A/P direction, and a 2 fold undersampling of the high spatial frequencies in the spiral acquisition for the nominal FOV. A SENSE reconstruction was performed using a low-resolution sensitivity map acquired prior to the experiments. The FOV was larger than required in the S/I direction and in the R/L direction the full sampling of the center of k-space combined with the surface coil acquisition minimized aliasing artifact. The SENSE reconstruction produced a final 48x48x52 image, with a $3.85mm^3$ resolution. Motor activation studies were performed on volunteers using this 3D-FSE spiral imaging sequence combined with a pulsed ASL and background suppression preparation (5). 16 alternating (Rest / Task) scans, containing each 10 alternating (Label / Control) repetitions (TR=6s) of the sequence presented on the figure 1, were performed every 75s, leading to a total activation study time of 20 mins.

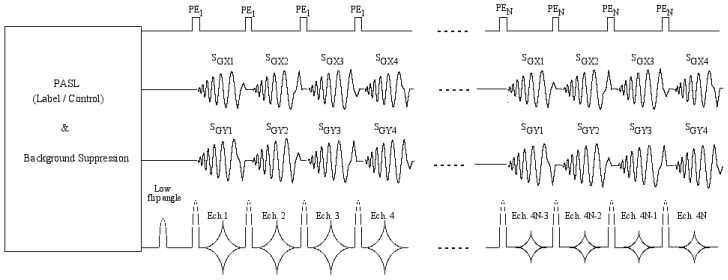

Figure 1: single-shot 3D-FSE spiral imaging sequence for fMRI studies with ASL.

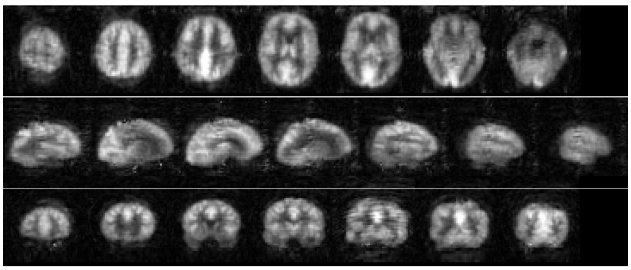

Figure 2: 3D ASL perfusion images (label-control) obtained during an activation study

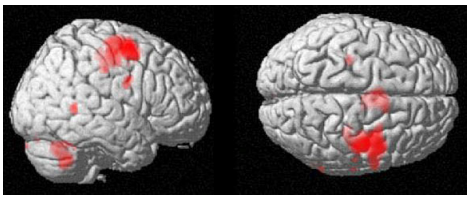

Figure 3: Motor activation image obtained by statistical analysis.

Results: Figure 2 shows representative slices of the 3D perfusion images (Label-Control) obtained during the activation study (averaging over the time the 16 activation scans (Task+Rest)) on a subject. Image quality is preserved in the inferior frontal and temporal lobes despite the large frequency variations in this area. The use of a low flip angle leads to relatively low blurring artifacts despite the long echo train length (750 ms), the lack of T_2 decay correction, and the SENSE acceleration. Only a few artifacts, due to the re-gridding procedure, are apparent (mostly in the coronal view). Motion artifacts were highly limited by the application of the background suppression. Figure 3 shows the statistical results of the motor activation measurements obtained by a classical analysis performed on the 8 first [$(Label)^{task}$ – $(Label)^{rest}$] images (4 minutes of acquisition). A p>0.001 threshold was applied and a maximum Z value of 5.75 was obtained for the activated areas.

Discussion: this paradigm for ASL fMRI can expand its utility and accessibility. While this sequence is a prototype with 4coils, rapid development of parallel imaging by manufacturers should make this capability available to the broader community shortly.

References:
1Duong TQ *et al.*, PNAS USA 98:10904-10909 (2001)
2. Aguirre GK *et al*, NeuroImage 15:488-500 (2002)
3. Wang J.J. et al. Magn Reson Med 49:796-802 (2003)
4. Liu H.L. et al., Magn Reson Med 45:431-435 (2001).
5. Ye , FQ, et al. Magn Reson Med. 44(1):92-100 (2000)