Investigation of *BOLD* using *CARR-PURCELL* T_2 Weighting with *SPIRAL* Readout

Shalom Michaeli[1], Josef Pfeuffer[1,2], Kamil Ugurbil[1] and Michael Garwood[1]
[1]Center for Magnetic Resonance Research, University of Minnesota School of Medicine, Minneapolis, MN, USA
[2] Max-Planck-Institute for biological Cybernetics, Tuebingen, Germany

Abstract It is demonstrated that a Carr-Purcell *(CP)* technique based on the fully adiabatic pulse sequence *(CP-LASER)* with *SPIRAL* readout can be used to generate zoomed images with relatively short acquisition window *(at)* for the investigation of the mechanisms of the BOLD effect. Based on the capability of the developed technique to refocus the dynamic dephasing, it is demonstrated that the BOLD effect is suppressed as the pulse interval t_{cp} of *CP-LASER* sequence decreased.

Introduction MRI signal changes during neuronal activation are related to the changes in the content of deoxyhemoglobin, which plays a major role as an intravascular contrast agent for fMRI. During neuronal activation, the apparent and intrinsic spin-spin relaxation times ($T_2^{\dagger}$ and T_2, respectively) are expected to change. For water spins, diffusion in the vicinity of or exchange between compartments with different magnetic susceptibility lead to apparent spin-spin relaxation in spin echo sequences. Applying many refocusing pulses as in a Carr-Purcell train or applying large B_1 field for spin-locking should reduce or even eliminate this mechanism for signal loss on the transverse plane. However, the degree of suppression will depend on the magnetic field differences experienced due to diffusion during the echo intervals or to the rapidity of the exchange process relative to the echo interval. In this study, we utilize this property to investigate the mechanisms contributing to spin-echo BOLD using Carr-Purcell refocusing capability of the recently developed fast *CP-LASER-SPIRAL* technique. Changing t_{cp}, the inter-echo interval, but holding nt_{cp} constant (n=number of echo's or refocusing pulses) it is possible to compare the variations of the decay of NMR signal on the transverse plane at the same echo time; for diffusion in a linear gradient this is described by:

$$M(t) = M_0 \exp\left[-\left(\frac{2}{3}\gamma^2 G^2 D t_{cp}^2\right) n t_{cp}\right]$$

Thus, changing t_{cp}, but keeping nt_{cp}, constant varies only the contribution of the diffusion term. In addition, the diffusion influence becomes more significant as the external static magnetic field increases due to increased local susceptibility gradients, *G*.

Methods MRI studies were conducted on a 4T whole body system. A 10 cm ^{1}H surface-coil probe was used for the measurements. Each subject performed the fMRI study to determine the activation location in the visual cortex (V1) using visual stimulation. This information was used to define the voxel position for fMRI study with the *CP-LASER*[1] sequence with *SPIRAL*[2] readout (Fig 1). The pulse sequence consists of single-voxel localization (for zoomed images) using the *LASER* technique achieved by six slice selective (HS2-R15) adiabatic pulses (t_{cp} = 12.8 ms). In the *CP-LASER-SPIRAL* sequence, 16 refocusing 180° pulses in *CP* train (adiabatic HS1-R10 pulses) were employed with phase cycling according to MLEV, inter pulse time interval 2.5 ms, followed by 6 pulses as in LASER Spiral but with 6.12 ms interval in the *LASER* portion (*TE*=76.7 ms).

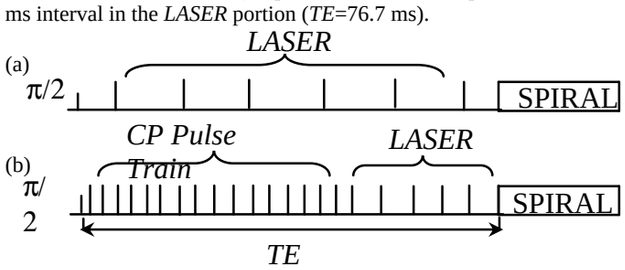

Fig. 1 Schematic representation of the *CP-LASER-SPIRAL* sequences.

TR per segment was 3s was to minimize T_1 contribution. Images were recorded using *SPIRAL* readout with: in-plane resolution of 1 mm: (i) FOV = 12.8 cm, 128-matrix and 4 segments, *at* = 29 ms.

Results and Discussion Fig. 2 demonstrates the *LASER-SPIRAL* (a) and *CP-LASER-SPIRAL* (b) images that were detected in the activated V1 area from a representative subject during the visual stimulation along with the superimposed activation maps. A pronounced difference between the activation maps was obtained in every experiment. Namely: the number of activated pixels with *CP-LASER-SPIRAL* was less than with *LASER-SPIRAL* for the same statistical threshold and their distribution was different, indicating that the *significant amount of Dynamic BOLD* was suppressed. Fig. 2c represents the time-courses detected with *CP-LASER-SPIRAL* and *LASER-SPIRAL* techniques that were obtained by inter subject averaging (n = 3) at 4T.

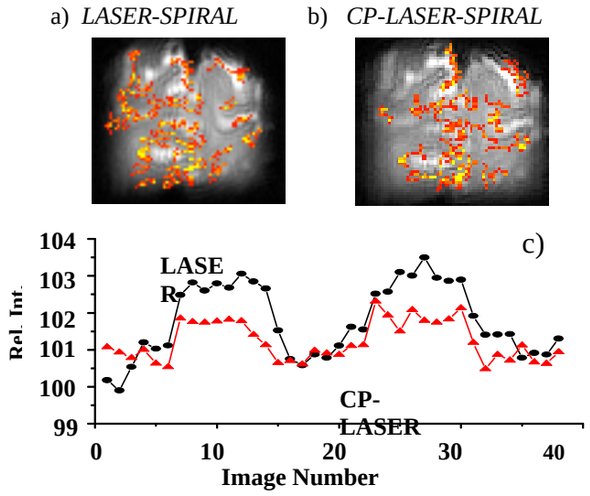

Fig. 2 Functional maps obtained with *CP-LASER-SPIRAL* (a) and *LASER-SPIRAL* (b) sequences ($p < 0.012$) at *TE*=76.7 ms. (c) corresponding timecorses.

Conclusion High resolution images were created using *CP-LASER/LASER* Spin Echo sequence with *SPIRAL* readout. The result indicate that the BOLD effect is suppressed with t_{cp},= 2.5 ms. The suppressed signals are ascribed predominantly to the dynamic BOLD effect observed in extravascular compartment due to diffusion. The residual effect is thought to originate from blood where rapid exchange of water between red blood cells interior and exterior (i.e. plasma) is the predominant cause of the relaxation; suppression of this fast exchange would require shorter t_c and/or spin-locking B_1 since it is characterized with rapid time constant (t_{ex} ~ 7 ms). This conclusion can and will be further validated by a detailed evaluation of the suppression observed as a function of t_{cp}, The technique presented here provides a framework for the functional MRI experiments that can be used to investigate BOLD mechanisms and to design experiments from which quantitative physiological parameters can be obtained.

Acknowledgment This research was supported by NIH grants P41 RR08079, NS38070 and NS39043, Keck Foundation and National Foundation for Functional Brain Imaging and the US Department of Energy.

References

1. S. Michaeli et al. Magn Reson Med (accepted for publication)
2. J. Pfeuffer (in press, 2002)
3. A. Tannus, M. Garwood, J Magn Reson A, **120**, 133 (1996)