FEASIBILITY OF APPLYING MB EPI PCASL FOR HIGH-RESOLUTION WHOLE BRAIN PERFUSION IMAGING AT 7T

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Target audience: Arterial spin labeling researchers, neuroimaging scientists and clinicians

Purpose

Ultra high fields, (≥7T), should provide significant advantages for high-resolution whole brain perfusion imaging due to greatly increased blood T_1 and signal noise ratio (SNR). However, there exist several challenges: B_1 and B_0 inhomogeneity, high specific absorption rate (SAR) and shortened T_2*. Previous 7T studies[1-3],using either FAIR[4] or pCASL[5-6], have shown promising ASL brain perfusion imaging results. However, these studies were mainly focused on the superior region of the brain due to known challenges in the inferior brain regions for ASL imaging, namely **1)** limited transmit B_1 and/or limited labeling bolus width, which results in low labeling efficiency and/or insufficient temporal bolus duration; and **2)** significant B_0 inhomogeneity, adversely affecting pCASL labeling efficiency and causing severe ghosting artifacts even with high in-plane GRAPPA acceleration factors, e.g. four for EPI[3].

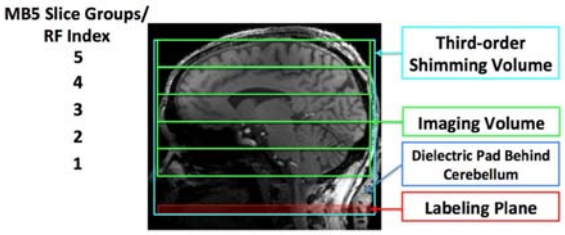

Figure 1. Positions of MB imaging slice groups/RF index, 3rd order shimming volume and labeling plane for pCASL.

Multi-Band (MB) imaging[7-11], which reduces imaging time and thus allows increased spatial and/or temporal resolution with improved coverage, has been recently demonstrated[12] and later, using FAIR, compared to single-shot 3D GRASE[13] at 3T for brain perfusion imaging. As an extension of previous work, here, we explore the feasibility and benefits of 7T for MB EPI based high-resolution *whole brain* perfusion imaging in the presence of additional challenges. For example, avoiding ghosting artifacts in the inferior brain region becomes even more critical because of the possible leakage of these ghost signals into other simultaneously acquired slices. Furthermore, at 7T where both high in-plane undersampling and high multiband factors are required, due to the short T_2* and the desire for a short acquisition window, residual aliasing among simultaneously excited slices is more challenging as compared with lower fields where the T_2* is long enough to not require in-plane undersampling. Here, we report results of whole brain high-resolution perfusion imaging studies at 7T using MB EPI pCASL, demonstrating the feasibility of achieving significantly better quality data than previous demonstrated[1-3].

Methods

Volunteers participated in this IRB approved protocol after providing informed written consent. Studies were performed on a Siemens 7T whole body MRI scanner using a Nova head coil with 32-channels for signal reception and single channel RF transmission. To address B_0 issues, 3rd order shimming was performed over a volume covering both imaging slices and the labeling plane (Figure 1). Dielectric pads were applied around the bilateral, posterior and inferior regions near the cerebellum (Figure 1) and temporal lobes to improve B_1 efficiency for both imaging and arterial spin labeling. The RF reference voltage was adjusted based on B_1+ estimation from a 3D actual flip angle imaging (AFI) measurement[14]. The relative power between the labeling pulse and EPI excitation pulses were adjusted to provide improved labeling performance while avoiding overflipping in the center of the brain during excitation. To further reduce SAR, excitation RF pulse lengths were increased, and the nominal flip angle for pCASL labeling was adjusted. MB EPI utilized blip-CAIPI[11] and RF phase optimization for reduced peak RF power[15]. Whole brain MB EPI pCASL imaging studies were performed after low-resolution pre-scan, and 200 noise images were also acquired following ASL series measurement within each scan for thermal noise and g-factor estimations. Labeling and delay times were 1.5 s and 1.6 s for gradient-balanced pCASL[5-6]. Studies were performed with different multi-band (MB) and in-plane (R) acceleration factors. The leakage levels resulting from residual MB unaliasing were quantitatively analyzed.

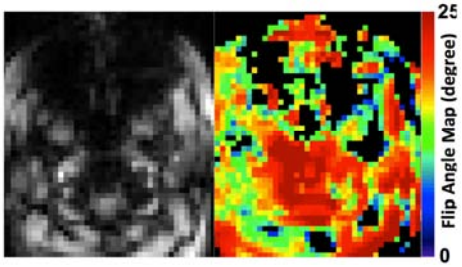

Figure 2. Actual flip angle map at the labeling plane for pCASL.

Results and Discussions

Our results indicated subject-dependent variability in terms of B_1, particularly in the inferior brain region even with applied dielectric pads, and resulted in the necessity of subject-dependent adjustment for EPI imaging excitation RF flip angles after B_1 calibration for pCASL labeling. The B_1 map at pCASL label site from one subject is showed in Figure 2.

The initial exploratory studies indicated that robust artifact-free MB EPI perfusion images could be achieved with MB and R factors 2 (M2R2), as well as MB2R3, MB3R2, MB3R3, MB4R2, and MB5R2. However, the use of R3, together with MB acceleration, greatly increased g-factor penalty; therefore, in-plane acceleration was mainly restricted to R2 for MB EPI pCASL imaging. MB EPI using MB5 and R2 images along with the corresponding perfusion-weighted images are showed in Figure 3. The mean overall relative leakage contamination fraction in EPI images after multiband unaliasing in the grey matter was less than ~6%.

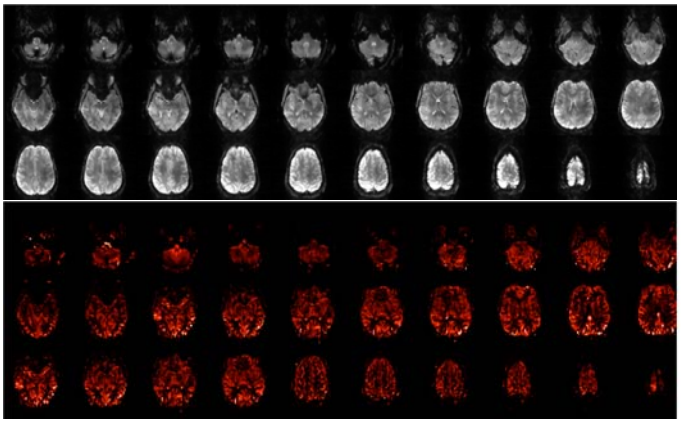

Figure 3 Control (top) and perfusion-weighted (bottom) images using MB5 EPI with R2**,** resolution 2.5 x 2.5 x 3.5 mm^3.

The use of 3rd order B_0 shims reduced ghosting artifacts in the inferior and middle brain while minimized B_0 variations at the labeling plane, which helped to avoid previously observed obvious differences of measured perfusion between the hemispheres even without off-resonance effect correction. As shown (Figure 2), the B_1 field is not uniform across the labeling arteries, which indicates that CBF quantification should take this into consideration along with B_0 effects at 7T. The use of a single-channel transmission coil, which is amiable to clinical studies, can provide sufficiently high B_1 over the labeling region but requires impractically prolonged TR without trading off RF powers between imaging and pCASL labeling; furthermore, large B_1 inhomogeneity across the overall brain can affect SNR in peripheral brain regions. These B_1 and B_0 issues can be further tackled using parallel transmit (pTX) MB pulses[17] using multi-channel transmit coils, e.g. 16, with coil elements distributed along z direction, and dynamic B_1[16] and B_0 shimming, respectively, and will be pursued in future studies.

Conclusions: With proper B_1 and B_0 optimization, high-resolution whole brain perfusion imaging using MB EPI pCASL with up to 10 times acceleration (MB5 x R2) is feasible at 7T.

Acknowledgements: P41 EB015894, U54 MH091657, P30 NS076408, P41 RR008079 and S10 RR026783.

References: 1. Luh et al. MRM 2013. **2.** Zuo et al. PlosOne 2013. **3.** Ghariq et al. Magn Reson Mater Phy. 2012. **4.** Kim et al. MRM 1995. **5.** Wu et al. MRM 2007. **6.** Dai et al. RM 2008. **7.** Larkman, et al. JMRI 2001. **8.** Breuer et al. MRM 2005. **9.** Nunes et al. ISMRM 2006: 293. **10.** Moeller et al. MRM 2010. **11.** Setsompop et al. MRM 2012. **12.** Kim et al. MRM 2013. **13.** Feinberg et al. MRM 2013. **14.** Yarnykh et al., MRM 2007. **15.** Wong ISMRM 2012:2209. **16.** Li et al. ISMRM 2011: 593. **17.** Wu et al. ISMRM 2013:70.