Diffusion Sensitivity of 3D-GRASE in ASL Perfusion

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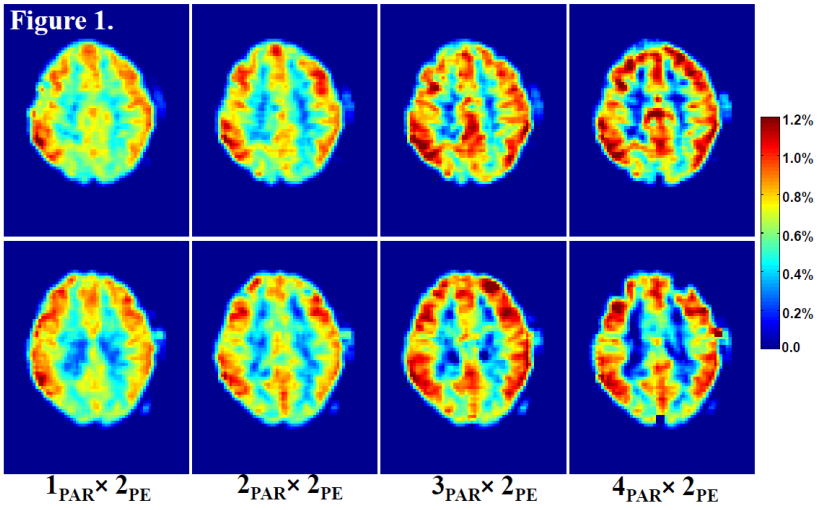
Purpose: Pseudo continuous ASL (pCASL) with segmented 3D-GRASE or RARE readout is recommended for mapping of whole brain perfusion (1). Both in-plane and through-plane segmentation was used to improve point spread function (PSF) and SNR (2). To maximize SNR, k-space centric-reordering scheme is often combined with low refocusing flip angle, which also helps to mitigate specific absorption rate (SAR). Similar to other CPMG-based sequences such as TSE (3,4), a considerable fraction of dephased transverse magnetization in 3D-GRASE and RARE can be stored as longitudinal magnetization components that may sustain along the echo train. Thus, the imaging, crusher and spoiler gradient may introduce appreciable diffusion sensitivity which intensifies along the echo train. As described in (3), the effective b-factor can reach up to 30-50 s/mm^2 in TSE. Although both the reference and perfusion-weighted signals are subject to the same diffusion gradient, the perfusion signal, especially the labeled blood within capillaries and venules, has effective ADC several orders higher than that of the brain parenchyma (5,6). In this study, the diffusion sensitivity of 3D-GRASE and its effect on perfusion quantification will be investigated.

Methods: Seven healthy volunteers were recruited for this IRB approved study. All experiments were performed on a 3T Siemens Trio scanner using a 12 channel head RF coil. PCASL labelling and background suppression (BS) were implemented (7). Echo-shifting was applied for segmentation in the PE direction. Total labeling time was 1600ms with a post-labeling delay of 1400 ms. The sequence parameters for 3D-GRASE were: FOV of 240×192×120 mm^3; matrix of 80×64×40 with 20% oversampling in partition and 6/8 partial Fourier in phase encoding; TR of 4 sec with total acquisition time of 6 min; echo spacing of 700 μs and echo train duration of 21 ms; refocusing RF flip angle of 120°. Up to four different segmentation schemes were evaluated: $4_{PAR}\times 2_{PE}$, $3_{PAR}\times 2_{PE}$, $2_{PAR}\times 2_{PE}$ and $1_{PAR}\times 2_{PE}$. To acquire reference images, a TR of 8 sec and post-labeling delay of 6.4 sec was adopted. A pair of crusher gradient on slice direction (28 mT/m, 0.54 ms) was placed around each refocusing RF pulse, so the effective b-value for primary and stimulated echo formed across a single echo train is ~0.1 s/mm^2 and ~0.4 s/mm^2, respectively.

Results & Discussions: Fig 1 shows the maps of averaged rCBF (the ratio between perfusion signal and reference signal) at two slices for one subject under different segmentation schemes. The similar patterns on rCBF behavior have been observed for all seven subjects in this research. As demonstrated in Fig 1, the GM rCBF increases progressively with the increases of partition segmentation factor. On average, about 15% rCBF increase is estimated between $1_{PAR}\times 2_{PE}$ and $4_{PAR}\times 2_{PE}$ for this subject, while the differences between $3_{PAR}\times 2_{PE}$ and $4_{PAR}\times 2_{PE}$ is relatively small.



The effect of segmentation scheme on WM rCBF is more heterogeneous. In subcortical WM, only a slight rCBF change can be noticed. However, in deep WM regions, rCBF decreases sharply with the increases of partition segmentation factor.

The observed GM rCBF diffusion sensitivity can be attributed to the similar diffusion effect as simulated for RARE and TSE sequence (3). The only difference is that microvascular blood signal is subject to pseudo-diffusion effect (IVIM) with effective D* up to 4 mm^2/sec (5). Therefore, along the 3D-GRASE echo train, the intravascular ASL signal decays much faster than the parenchymal signal. This leads to an additional dispersed PSF along partition direction for intravascular ASL signal, and reduces its rCBF contribution. Note that in a typical pCASL experiment, ~17-25% of signal originated from intravascular water (5,8). This explains the underestimation on GM rCBF at low segmentation factors.

It is known that for a myelinated axon, the water residence time in myelin, τ_{myelin}, can be as high as 2 sec (9). Hence, the extravascular ASL water may preferably reside at the extra-axonal space, especially perivascular space, which may have a much higher T2 than that of tissue water (10). This may lead to an over-estimation of rCBF at low segmentation factor. Meanwhile, intravascular perfusion signal at cortical GM area may leak to the sub-cortical WM due to the additional dispersed PSF along partition direction, further exuberates rCBF overestimation in subcortical WM.

Conclusion: While pCASL with 3D-GRASE is often recommended for SNR, SAR, spatial resolution and geometric distortion, significant error on regional brain perfusion quantification could occur in single shot or multi-shot segmented acquisitions. As demonstrated in this study, diffusion sensitivity is responsible for a noticeable perfusion under-estimation in GM, and a significant perfusion over-estimation in sub-cortical WM. Therefore, a 6 or 8 shot 3D-GRASE acquisition scheme ($3_{PR}\times 2_{PE}$ or $4_{PAR}\times 2_{PE}$) is recommended for accurate perfusion quantification. The improved PSF from highly segmented acquisition is especially important to mitigate possible overestimation in sub-cortical WM.

References: [1] Alsop, et al, MRM 2014; ePub. [2] Vidorreta, et al, NMR in Biomed 2014; 27(11). [3] Weigel & Hennig, MRM 2012; 67(6). [4] Weigel, JMRI 2014, ePub. [5] Wang, et al, JCBFM 2007; 27(4). [6] Le Bihan, Radiology 1988; 168(2). [7] Wu, et al, MRM 2007; 58(5). [8] Silva, et al, MRM 1997; 38(2). [9] Dortch, et al, MRM 2010; 64(3). [10] He, et al, MRM 2012; 67(2).