Improving SNR per unit time in Diffusion Imaging using a blipped-CAIPIRINHA simultaneous multi-slice EPI acquisition

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Introduction: The acquisition of simultaneous slices using EPI with either frequency shifting methods (1-3), parallel imaging methods (4-7), or echo shifting the slices such as in the SIR method (8-9) has the potential to increase the number of diffusion directions obtained per unit time, allowing more diffusion encoding in high angular resolution diffusion imaging (HARDI) and diffusion spectrum imaging (DSI) acquisitions in a clinically relevant scan time. Unlike conventional parallel imaging with EPI, which does not significantly increase the number of slices achievable per second, simultaneous multi-slice methods do not under-sample the k-space data, instead they unalias simultaneously excited slices using the SENSE or GRAPPA algorithm. This leads to time reduction given by the number of simultaneously encoded slices (R_{slice}). The SNR reduction, however, is given simply by the g-factor of the slice unaliasing, rather than $g\sqrt{R}$. Diffusion methods with 2D EPI are especially attractive for simultaneous multi-slice methods since the diffusion preparation time and number of slices needed for whole-head isotropic coverage (60-100 slices) yields a lengthy TR and M_z remains fully relaxed even when the number of slices per second of acquisition is increased by R_{slice}. This means that if the g-factor can be kept close to unity, the scan can be significantly shortened without reducing the SNR of the acquisition. In this work, we apply the simultaneous multi-slice method using a novel blipped-CAIPIRINHA technique (10) to lower the g-factor penalty of parallel imaging and demonstrate $R_{slice} = 3$ using slice-GRAPPA reconstruction (11). We thus reduce the scan time up to 3 fold without significant SNR degradation compared to the longer acquisition. We validate the method using g-factor maps and Bayesian estimation of diffusion parameters (i.e. bedpostx) (12) with HARDI acquisitions in the brain. We show that a 60 slice, 2mm isotropic, b=1000, 64 direction HARDI acquisition that would normally take 10 minutes can be acquired in just over 3 minutes with no appreciable artifact or loss in SNR.

Methods: Non-accelerated and 3x slice-accelerated twice-refocused SE-EPI diffusion acquisitions were obtained from a healthy volunteer using Siemens TIM Trio scanner with a 32-channel head array coil. Imaging parameters for the non-accelerated acquisition were: resolution=2mm isotropic; FOV = 208x208x120 mm; Partial Fourier = ¾; matrix size = 104x78x60; b = 1000 s/mm^2, 64 directions, one b=0 image, TR/TE = 9s/96 ms, total image time 9.75 mins. The imaging parameters for the 3x slice-accelerated blipped-CAIPIRINHA acquisition were the same except 3 slices separated by 4 mm were simultaneously excited, resulting in a TR of 3s and a total acquisition time of 3.25 mins. For the accelerated acquisition, RF pulses (90^o and 180^o) were designed using the SLR algorithm (13) with frequency modulation and summation to produce simultaneous multi-slice excitation. We reduced SAR using VERSE (14) while keeping each RF pulse to within 4 ms. Retained SNR (1/g factor) was calculated for the accelerated acquisition using pseudo-multiple replica method (15). For both acquisitions, bedpostx (www.fmrib.ox.ac.uk/fsl/) was used to estimate samples from the posterior probability density function (PDF) of the principal and crossing fiber orientations. These estimated samples of the PDFs were used to calculate the 95% uncertainty angle for the fiber orientations. Q-Ball diffusion Orientation Distribution Functions (dODF) were also estimated using the spherical harmonic basis (16).

Results: Fig. 1 top: shows the aliased and unfolded b=0 images of a selected group of 3x simultaneously acquired slices, where blipped-CAIPIRINHA technique was used to impose a FOV/2 shift between the slices. As shown in the bottom part of Fig. 1, high retained SNR is achieved with this acquisition. Note, in some regions the retained SNR is greater than unity indicating some noise cancellation in the reconstruction process as previously demonstrated in low R in-plane GRAPPA acquisitions (17). With a reduction of TR from 9s to 3s, assuming T_1 of white matter to be 1.1s, signal loss due to T_1 recovery effect is small (~6.5%), leading to an overall SNR of the accelerated acquisition that should be very similar to the non-accelerated one (despite the 3x shorter acq. time). **Fig. 2** shows comparisons of the diffusion reconstruction of the two acquisitions; **left:** directionally encoded colormaps**, right:** maps of the 95% uncertainty angle for estimate of the principal (fiber 1) and crossing (fiber2) fiber orientations. Near identical results for the non-accelerated and accelerated acquisitions can be observed (despite the 3x shorter acquisition time of the simultaneous-multi-slice method). As expected the uncertainty of the principal fiber orientation is low in white matter. Furthermore, the uncertainty of the estimates of the secondary crossing fiber (where determined to exist) are low in putatively crossing fiber regions such as the anterior region of the corona radiata (indicated by white arrows). Again, little difference is seen in the two acquisitions. **Fig. 3** shows the Q-ball dODF of the two acquisitions in the highlighted area (orange box). Again high level of similarity is observed.

Conclusion: In this work demonstrate a blipped-CAIPIRIHINA technique for HARDI acquisitions and demonstrated its ability to reduce scan time 3 fold without any appreciable loss in SNR or diffusion information. Given the benefit achieved, this method could help enable fast acquisition of HARDI and DSI data, making them more applicable to clinical applications.

Support: NCRR P41RR14075 and NIBIB R01EB006847. **References: 1.** Weaver JB. et al, MRM 1988:8:275. **2.** Paley MN. et al, MRI 2006:24:557. **3.** Wu EL. et al, ISMRM 2009p.2678. **4.** Larkman DJ. et al, JMRI 2001:13:313 **5.** Breuer FA. et al, MRM 2005:53:684 **6.** Nunes RG. et al ISMRM 2006p.293 **7.** Moeller S. et al, ISMRM 2009p.1544 **8.** Feinberg DA. et al, MRM 2002:48:1 **9.** Reese T. et al, JMRI 2009:29:517 **10.** Setsompop K. et al ISMRM 2010 submitted **11.** Blaimer M. et al, JMRI 2006:24:444 **12.** Behrens T. et al, MRM 2003:50:1077 **13.** Pauly J. et al IEEE TMI 1991:10:53 **14.** Conolly SM. et al, JMR1988:78:440 **15.** Robson PM. et al, MRM 2008:60:895 **16.** Descoteaux et al. MRM 2007:58:497 **17.** Polimeni JR. et al, ISMRM 2008p.1286

FIGURE 1

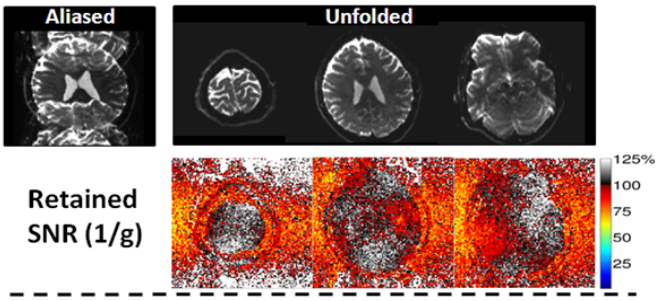

FIGURE 2

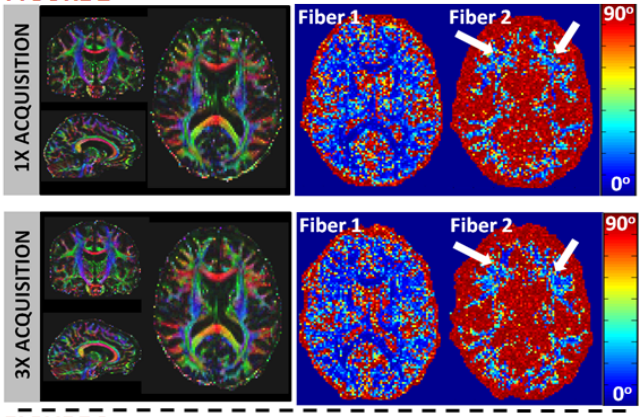

FIGURE 3