Fat Suppressive and Susceptibility Tolerant PINS Pulses for Multi-band Diffusion Weighted EPI

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INTRODUCTION: Diffusion-weighted imaging with full brain coverage requires a large number of slices and thus long TRs. This in turn increases the overall acquisition time and limits clinical adoption of more complex tensor or q-Ball acquisition schemes. Simultaneous multi-band methods such as Blipped-CAIPIRINHA [1] have been proposed to accelerate such full-brain acquisitions with only a moderate g-factor penalty. To acquire multiple bands simultaneously, special RF pulses must be employed. Here, we employ PINS pulses to excite multiple slices simultaneously with limited power deposition [2]. These pulses can additionally be designed to be inherently fat suppressive. Specifically, we designed and compared two multiband excitation and refocusing schemes for diffusion-weighted EPI (DW-EPI). The first method performs fat/water separation by shifting the fat slice in opposite directions during the excitation and refocusing steps in a fashion similar to that used in [3]. The second method reduces susceptibility artifacts by matching the time-averages of the slice selection gradients of the excitation and refocusing pulses.

METHODS & RESULTS: • *PINS:* A series of hard pulses spaced by $1/\Delta$ in (excitation) k-space can excite (or refocus) a series of bands separated by a distance Δ. K-space is traversed using triangular blips of duration *d,* amplitude *a* and temporal spacing *s* (with $\gamma ad/2=1/\Delta$). For on-resonance magnetization, a given set of hard pulses and (excitation) k-space trajectory will fully specify the profile and separation of the bands. The timing and amplitude of these gradient blips will further dictate the behavior of off-resonance magnetization. • *Off-resonance:* **Method A** – The preferred method in presence of inhomogeneities might be to precede the excitation with a fat saturation pulse (such as frequency selective fat saturation or inversion recovery) and to match the average gradient amplitudes ($\gamma ad/2(d+s)$) of the excitation and refocusing pulses (**Fig. 1**), thus selecting the exact same (albeit deformed) profile each time (**Fig. 2**). **Method B** – In relatively homogeneous fields, it is possible to utilize the off-resonance sensitivity of PINS pulses to shift the refocused fat band completely outside of the excited water band (**Fig.3**) by using (e.g.) positive gradient blips between the hard pulses. In turn, negative gradient blips can be employed during refocusing to push the band in which lipid-bound protons are inverted in the opposite direction. Since both bands do not intersect, *de facto* fat suppression is performed [3]. The downside of this method is its sensitivity to susceptibility-based off-resonance (**Fig. 4**). **Figures 2 and 4** illustrate how both methods behave in homogeneous and inhomogeneous B_0 areas. A whole brain DW-EPI scan of a healthy volunteer was acquired using each method with128^2 matrix, 24 cm FOV, 32 slices of 5 mm thickness, no gap. Two bands were acquired simultaneously, thus halving the minimum TR. **Figure 5** shows the results and tradeoffs of the two suggested PINS methods.

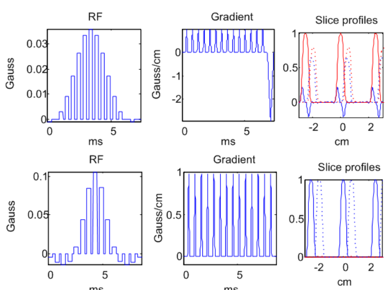

***Fig. 1** – Method A: Excitation (top) and refocusing (bottom) RF (left), gradient (middle), and resulting slice profiles (right) for the first method. Profile legend: water (full line), fat (dashed line), real (blue) and imaginary (red). Average gradients are 0.23G/cm -0.10G/cm for excitation and refocussing respectively.*

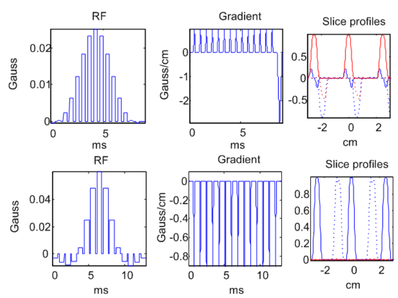

***Fig. 3** – Method B: Excitation (top) and refocusing (bottom) RF, gradient, and resulting slice profiles for the second method. Profile legend: water (full line), fat (dashed line), real (blue) and imaginary (red). Average gradients are 0.15G/cm for both excitation and refocussing.*

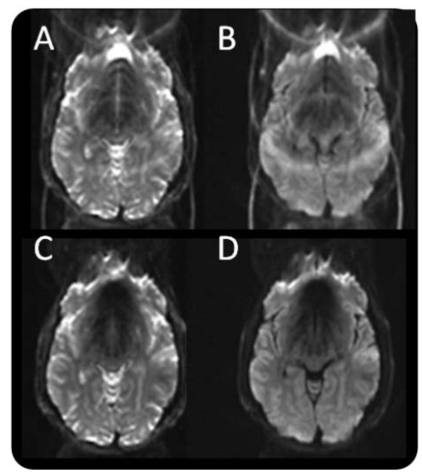

***Fig. 5** – In-vivo Multi-Band results at 3T for b=0 (left column) and isoDWI (right column) with method A (top row) and method B (bottom row). The slice was taken in a region of high field inhomogeneity. A CAIPIRINHA slice acceleration of 2 was used and full brain coverage was obtained without gaps. A conspicuous fat ring is visible with method A and regions of signal loss are visible above the sinuses with method B. No fat saturation was used in method A to illustrate the fat suppressive effect of method B.*

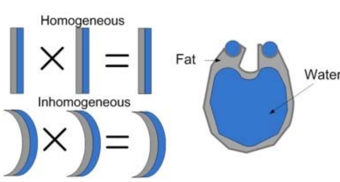

***Fig. 2** – Method A: Magnetization profile resulting from the first method. Fat (light gray), water (blue), and signal loss (dark gray) are shown. In homogeneous B_0 the fat is suppressed. In the presence of susceptibility however, deformation of the bands occurs. This can lead to signal loss and possibly improper fat separation.*

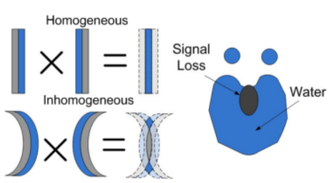

***Fig. 4** – Method B: Magnetization profile resulting from the second method. By matching the mean slice selection gradient of both RFs, identical slice bending is observed for the excitation and refocusing profiles in the presence of off-resonance.*

DISCUSSION & CONCLUSION: These results suggest that PINS pulses can be used for multi-band acquisitions. Method B clearly suffers from incomplete lipid suppression and the associated fat replicas are shifted by FOV/N. Given the low diffusivity of lipids, Method B is inadequate for DW-EPI. In contrast, Method A eliminates the fat ring and obviates the need for fat suppression preparation at the cost of a signal loss in high susceptibility regions. If such signal loss is an issue in such regions, this method should be used in conjunction with a View Angle Tilting (VAT) readout [4] to further mitigate distortions in the readout direction.

REFERENCES: [1] Setsompop et al, MRM 67, 2012; [2] Norris, MRM 66, 2011; [3] Saritas, E. et al. MRM 60, 2008; [4] Butts et al. MRM 53, 2005

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