RARE/Turbo Spin Echo Imaging with Simultaneous MultiSlice Wave-CAIPI

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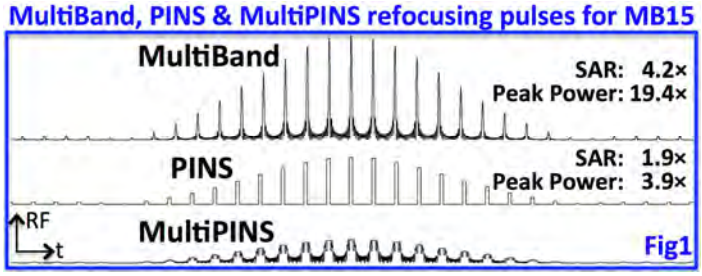
Target Audience: Scientists interested in Simultaneous MultiSlice (SMS) and Rapid Acquisition with Refocusing Echoes (RARE) imaging as well as clinicians interested in fast high quality imaging.

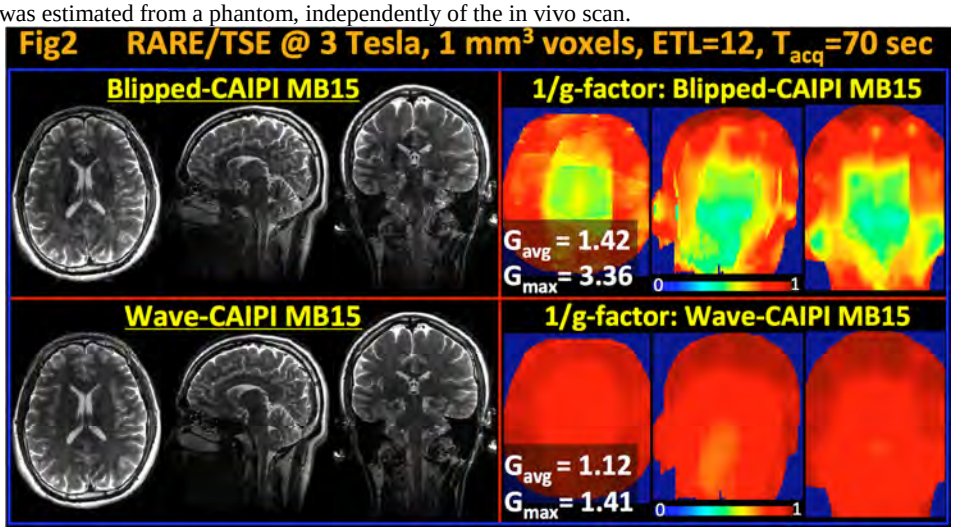
Purpose: RARE/Turbo Spin Echo (TSE) [1] is the most commonly used sequence in clinical imaging, which allows faster acquisition than conventional spin echo imaging by refocusing the magnetization using multiple 180° refocusing RF pulses per each 90° excitation. While this permits efficient sampling of k-space, the application of multiple refocusing pulses increases the Specific Absorption Rate (SAR). RARE can be sped up through in-plane acceleration, which causes g-factor noise amplification as well as the intrinsic √R SNR penalty. RARE can also be accelerated using SMS imaging, which enables acceleration without reducing the number of k-space lines, and hence without √R penalty. However, SMS further aggravates the SAR limitation of RARE since the power deposition of conventional MultiBand (MB) pulses is proportional to the MB factor. The recently proposed Power Independent of Number of Slices (PINS) [2] pulses have been deployed in SMS-RARE to enable low SAR acquisition at 3T and 7T [3]. This previous study employed blipped-CAIPI acquisition that creates interslice shifts for improved parallel imaging (PI) [4,5], and allowed MB factor 8 at 2 mm slice thickness. In this work, we incorporate novel Wave-CAIPI acquisition [6] and MultiPINS RF refocusing [7] into SMS-RARE imaging to enable MB=15 acceleration at high isotropic resolution. The Wave-CAIPI acquisition fully harnesses the spatial variation in coil sensitivities to enable minimal g-factor noise at this high acceleration level, while the MultiPINS RF design further reduces SAR of the SMS refocusing pulse by ~2× to allow high slice resolution refocusing pulses at short duration (5-6ms). With the use of these novel technologies, high quality whole-brain T_2-weighted RARE imaging at **1 mm isotropic resolution was achieved in 70 sec with minimal g-factor penalty.**



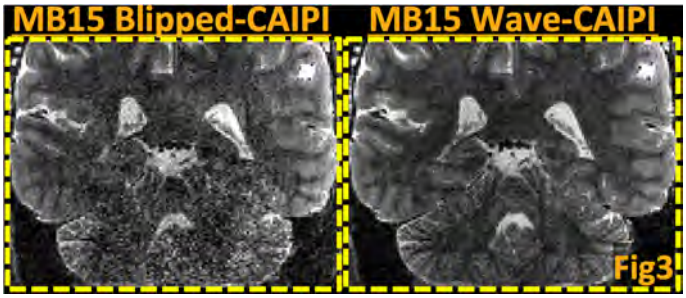
Methods: **MultiPINS:** synergistically combines MB and PINS refocusing to reduce SAR and peak power. Since PINS sub-pulses are played only *between* the gradients blips, MultiPINS utilizes the time interval *during* the blips to play MB pulses.

SMS Wave-CAIPI: incurs interslice shifts across aliasing slices while traversing a helical trajectory in 3D SMS k-space [8] to spread the aliasing in all 3 spatial axes, including the fully-sampled readout dimension. **Acquisition & Reconstruction:** A healthy subject was scanned at 3T to acquire MB15 RARE data using blipped- and Wave-CAIPI with Echo Train Length (ETL) = 12, BW = 130 Hz/px, 256×192 in-plane matrix size and 255 coronal slices, TR/TE = 4000/90 ms in T_{acq} = 70 sec. Coil sensitivity profiles were estimated from low resolution 2×2×3 mm TSE data with JSENSE algorithm [9]. K-space trajectory for Wave-CAIPI was estimated from a phantom, independently of the in vivo scan.

Results: **Fig1** shows MB, PINS and MultiPINS refocusing pulses for MB15 with 6 ms duration and time-bandwidth product of 2.4. SAR of the MB and PINS are 4.2× and 1.9× higher than MultiPINS, while the peak powers are 19.4× and 3.9× higher. MultiPINS was the only pulse that could be played for in vivo SMS-RARE imaging without exceeding the SAR limit. **Fig2** presents the reconstructions and g-factor analysis for blipped- and Wave-CAIPI. Compared to blipped-CAIPI that attains g_{max}=3.36 and g_{avg}=1.42, Wave-CAIPI demonstrates a **2.4-fold improvement in g_{max}**. In **Fig3,** Wave-CAIPI is seen to retain SNR and image quality more successfully especially in the middle of the imaging volume where receive coils have decreased sensitivity and orthogonality.



Discussion: For SMS Wave-CAIPI, combination of *i)* acceleration by acquiring more slices rather than undersampling (thus avoiding √R penalty) and *ii)* spreading the aliasing in 3D to minimize g-factor is very powerful. For comparison, √R penalty from R=2-fold in-plane acceleration alone (√R=1.41) would have resulted in the same noise amplification as the maximum g-factor penalty incurred by MB15 Wave-CAIPI. Further, the 1 mm isotropic resolution we attain permits reformatting into multiple viewing planes, thus obviating the need for lengthy acquisitions with thick slices at different orientations. Clinical RARE imaging contains significant Magnetization Transfer Contrast (MTC), which is not present in PINS acquisitions. As MultiPINS refocusing combines MB and PINS components, it also presents the flexibility of using different mixing ratios to adjust MTC for a specific clinical application. Finally, employing a 3D-FLASH [10] reference scan will allow more efficient coil sensitivity estimation.



Conclusion: Combination of Wave-CAIPI acquisition and MultiPINS refocusing enables MB15 SMS-RARE with low SNR penalty at reduced SAR. High speed with high resolution and low SNR penalty make this approach attractive for clinical imaging where high throughput is desired and motion in longer sequences degrades image quality.

First two authors contributed equally to this work.

References: [1] Hennig J, MRM'86; [2] Norris DG, MRM'11; [3] Norris DG, MRM'14; [4] Breuer FA, MRM'05; [5] Setsompop K, MRM'12; [6] Bilgic B, MRM'14; [7] Eichner C, MRM'14; [8] Zahneisen B, MRM'14; [9] Ying L, MRM'07; [10] Frahm J, J Comput Assist Tomogr'86