CEST readout comparison – who wins in a fair game?

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Introduction

An often-discussed question in CEST MRI is the question about the best readout. To make a fair comparison we want to revisit this problem once again in a controlled simulation framework (and until September *in vivo*). We focus herein on the signal-to-noise ratio (SNR), acquisition time (TA) and the width of the point spread function (Γ) and compare **FLASH**, **TSE**, and **bSSFP** for the exact same digital twin of a human brain.

Methods

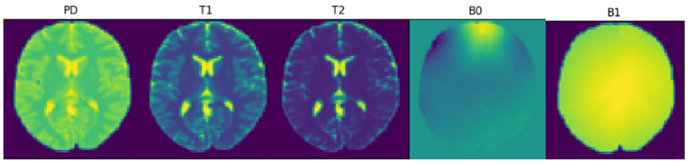

Fig 1: In silico brain phantom with realistic field inhomogeneities.

Simulation: For simulation we use the end-to-end framework MR-zero[1], which consists of a PDG[2] simulation. MR-zero can simulate arbitrary sequences like FLASH[1], TSE[3] or EPI sequences[4], characterized by the quantitative MR parameters T1, T2, T2', rB1, ΔB0, and the isotropic diffusion constant D of human brain. All parameters including B1 inhomogeneities were chosen realistically most similar to a 3T scanner, see Figure 1.

Fair comparison: All 2D sequences have identical readout bandwidth/adc duration and close to identical timing $TR_{FLASH/bSSFP} = TR_{TSE}$ with 64 centric-reordered readout lines. The TSE requires multiple shots to be comparable in PSF width, we adjust for the longer scan time by $SNR_{adj} = SNR \times 1/\sqrt{(shots)}$. We use fluid suppression with an inversion pulse and TI 2.7 s before the centric readout starts to make our analysis more focused on solid brain tissue. We don't use any other preparation, so this can be seen as an unsaturated scan, which is sufficient to compare PSF and SNR. SNR is estimated by the background-filtered mean S of the histogram of the noise-free simulation. The PSF width Γ is estimated by a Lorentzian line fit and its full-width at half-maximum. As "fair" is a strong word we compare two cases. Case a) is about the same scan time. Case b) is about reaching the same high image sharpness with PSF Γ < 0.6 pixel. To reproduce, all codes are made publicly available on https://github.com/cest-sources/Readout_comparison_in_silico.

Results

For case a) where the time is fixed, the single shot 180° TSE has a PSF width of Γ = 3.01; we used this as an upper limit for FLASH and bSSFP and adjusted the flip angle. For similar non-ideal blurring, the 180°-bSSFP and 180°-TSE are similar in Γ and SNR, 23°-FLASH is a factor 0.36 worse in SNR (Figure 2). For case b) we set a goal of PSF width of Γ = 0.6 pixel, which leads to crisp images for all readouts (Figure 3). This require 8 TSE shots (thus 8-fold scan time) and a flip angle of 120°. bSSFP and TSE outperform FLASH by a factor of 2.8 in SNR. Overview in Figure 4.

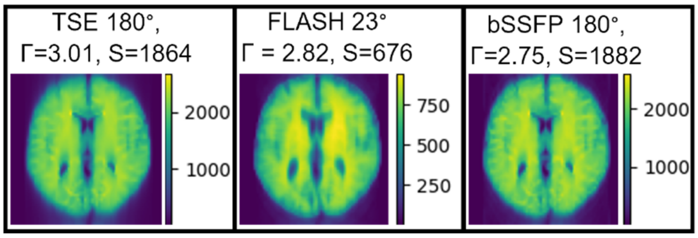

Figure 2: Case a) with same readout of 0.4s. bSSFP and TSE share the highest signal S, with bSSFP being slightly sharper. **readout time fix** ca. 0.4 s, all PSFs similar to TSE (Γ = 3.01).

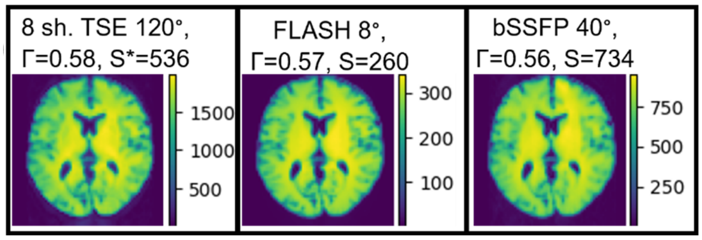

Figure 3: Case b) with same PSF width Γ ~0.6 pixel. TSE requires 8 shots for Γ = 0.58, S = 1518; the time-adjusted SNR (S*=563) is actually lower than the bSSFP with 734.

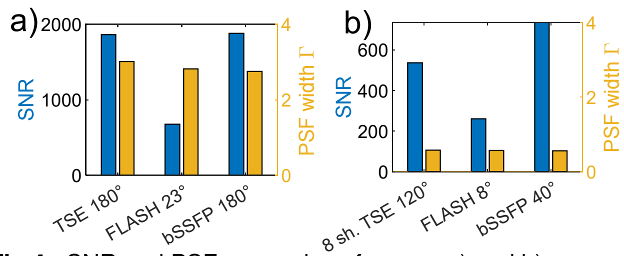

Fig 4: SNR and PSF comparison for case a) and b).

Discussion

Single-shot TSEs are blurry, but provide a lot of signal. For low resolutions this might work, for higher resolutions, the required multiple shots make the sequence ineffective. If FLASH SNR is enough, it provides a sharp readout in short time. Most interestingly, the bSSFP wins both cases outperforming TSE and FLASH in sharpness in signal, but nobody we know uses bSSFP readouts. Why not? Stability at the scanner could be an issue, which we measure until the conference. What remains unfair: Real scans may have instabilities leading to lower tSNR. All sequence could be improved by variable flip angle trains or tailored reordering patterns/ trajectories to which they might react differently. Sequences might still depend on preparation, thus CNR with CEST preparation might be a fairer comparison. We look at 2D centric-reordered versions of these sequences, but general aspects translate to 3D.

Conclusion: In silico insights reveal blurring in TSE, low signal in FLASH, and bSSFP as a promising CEST readout. We will test and compare these readouts at a real scanner in the meantime.

References

1. Loktyushin A, et al. *MRM*. 2021 doi:10.1002/mrm.28727 **2.** Endres J et al. *MRM*. 2023. doi:10.1002/mrm.30055
3. Dang et al. *MRM*. 2023; doi:10.1002/mrm.29710 **4.** West et al. Arxive 2024. doi:10.48550/arXiv.2403.17575