Measuring T_1 and T_2 in the Presence of B_0 Inhomogeneities

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Declaration of Financial Interests or Relationships

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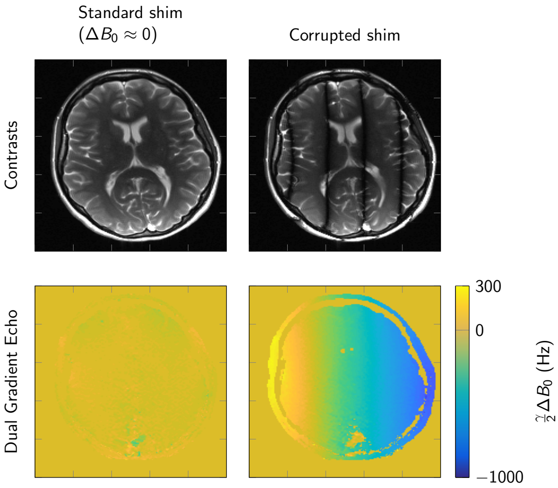
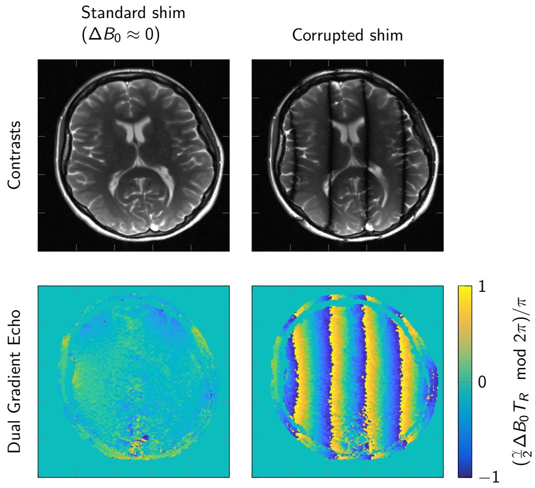
I have no financial interests or relationships to disclose with regard to the subject matter of this presentation.

Banding artifacts in bSSFP



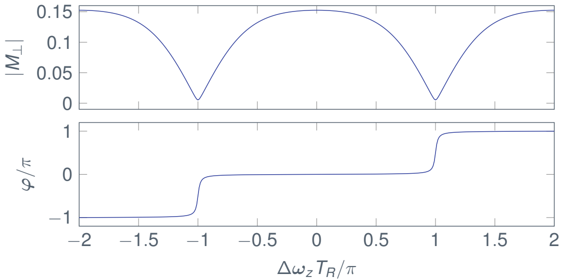
B_0 map without "wrapping"

Banding artifacts in bSSFP



B_0 map with "wrapping"

bSSFP Magnetization Trajectory



Transverse magnetization is smooth and nonzero everywhere except near the "stopping bands".

Summary

Since balanced hybrid-state free precession (bHSFP) sequences have the same issue with banding artifacts, we address it as follows:

- Incorporate B_0 inhomogeneities bias into a measure of $T_{1,2}$-encoding quality of the signal (Cramer-Rao Bound or CRB);
- Vary flip angles and phase offsets of the driving field (sweeping); and
- Optimize the CRB over the set of possible flip angles.

Cramer-Rao Bound (CRB)

A *simplified* illustrative model of the signal: $S = r(T_i, B_0) + N$ where

- r_i is magnetization during the ith read-out period;
- $r \in \mathbb{R}^{Npulse}$ where $Npulse$ is the number of pulses;
- $N \sim N(0, \sigma I)$.

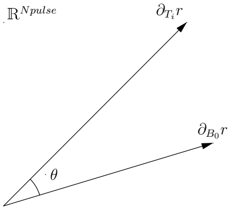
If B_0 is known,

- the CRB bounds the mean squared error (MSE) of any unbiased estimator $t(S)$ of T_i:

$$MSE(t(S)) \geq \frac{\sigma^2}{\|\partial_{T_i} r\|^2}$$

- Thus, the MSE of an efficient estimator is
  - proportional to the noise, and
  - inversely proportional to the sensitivity of the magnerization to T_i.

Cramer-Rao Bound (CRB)



If B_0 is not known,

- the CRB provides that

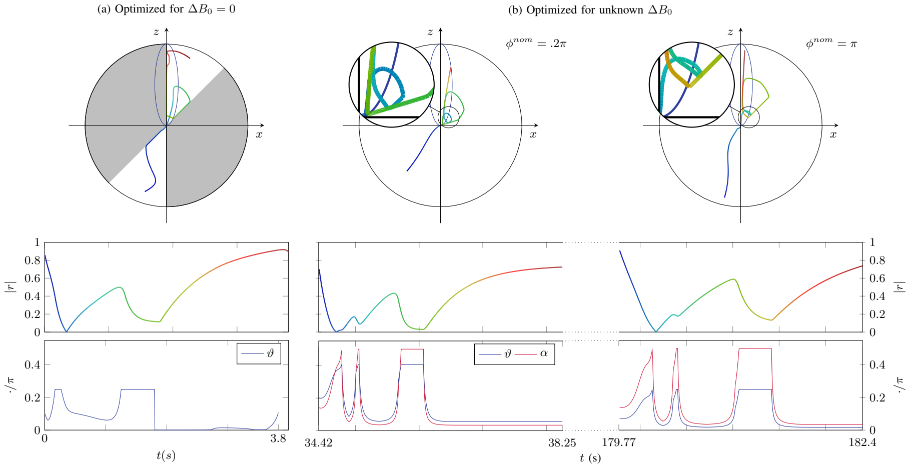
$$MSE(t(S)) \geq \frac{\sigma^2}{(1 - \cos^2\theta)\|\partial_{T_i} r\|^2}$$

  where $\cos\theta$ is the correlation between the derivatives $\partial_{T_i} r$ and $\partial_{B_0} r$.

- Thus, if the magnetization trajectory r can be designed to reduce the correlation, this CRB will be close to the CRB where B_0 is known.

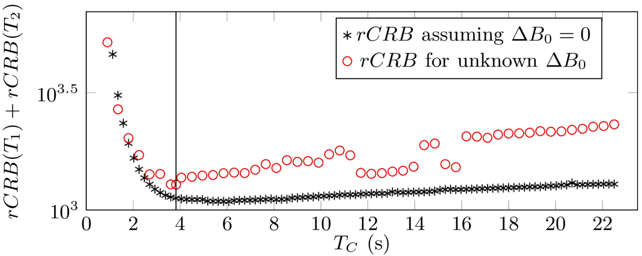
Optimal bHSFP sequence

- Assländer et al. (2018): $r(\alpha, \phi^{nom}, B_0, T_i)$ controlled by α, ϕ^{nom}.
- Thus, we can control $\partial_{T_i} r$ and $\partial_{B_0} r$, and therefore the CRB.



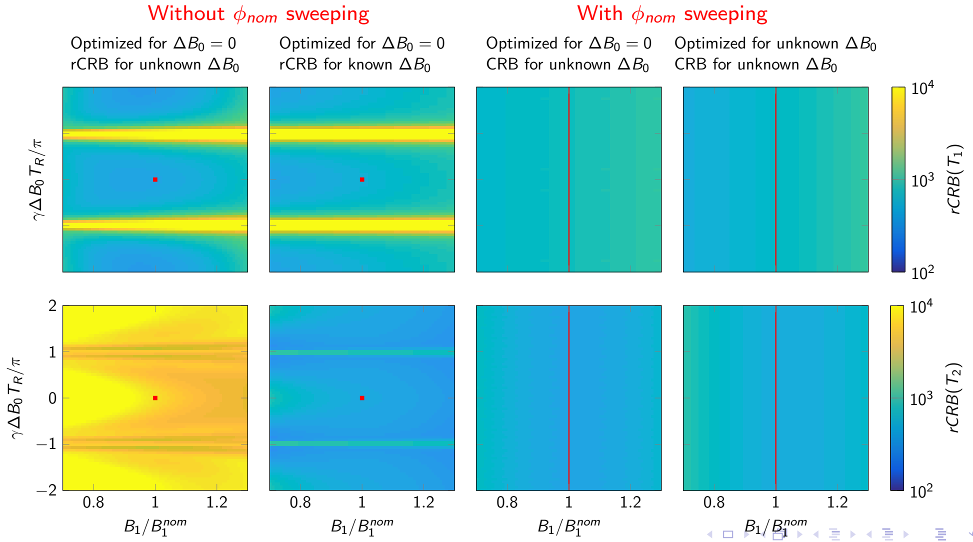
Optimal bHSFP sequence duration

- The optimal duration $T_C = 3.8$s of a pulse sequence is comparable to that for the case where B_0 variations are known.
- In each period of length T_C, a different phase offset ϕ^{nom} is introduced, with ϕ^{nom} uniformly distributed between $-\pi$ and π.
- See, generally, Benkert (2015) and Scherbakova (2018) (phase-cycling in bSSFP).



rCRB as a function of B_0 and B_1

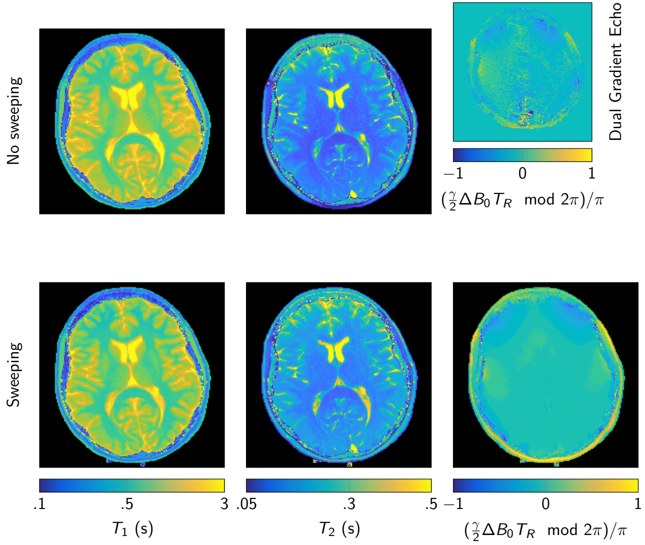
ΔB_0 need not be determined separately (B_1 is assumed to be determined separately)



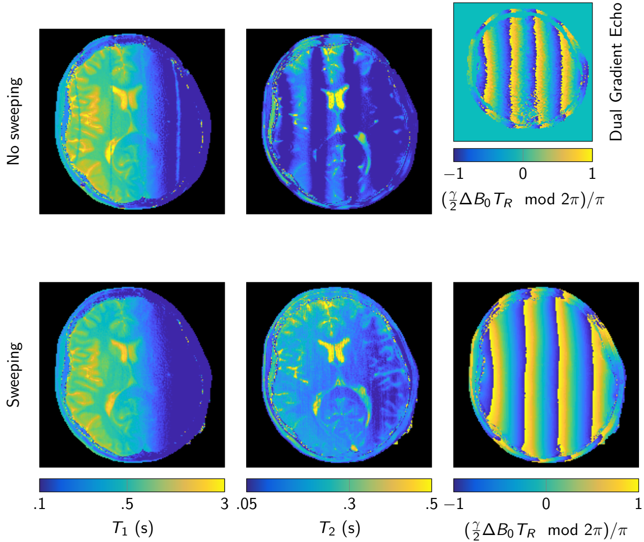
In vivo experiments

- Flip angles α_{nom} are determined by numerical optimization discussed above;
- Acquire the data in 20 cycles, each 3.8 s long;
- Phase offset of the driving field ϕ_{nom} varied over ("sweeps") $[-\pi, \pi]$ from cycle to cycle; and
- Other parameters are the same as in Assländer et al. (2018), *id.*

MRF with standard shim

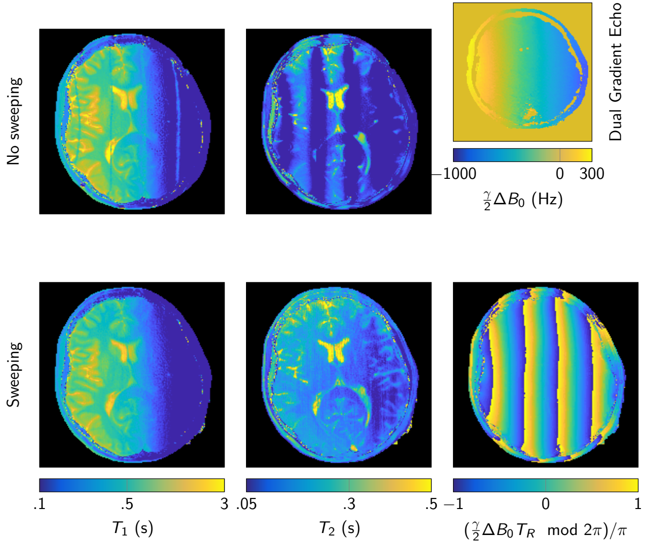


MRF with corrupted shim (sweeping)



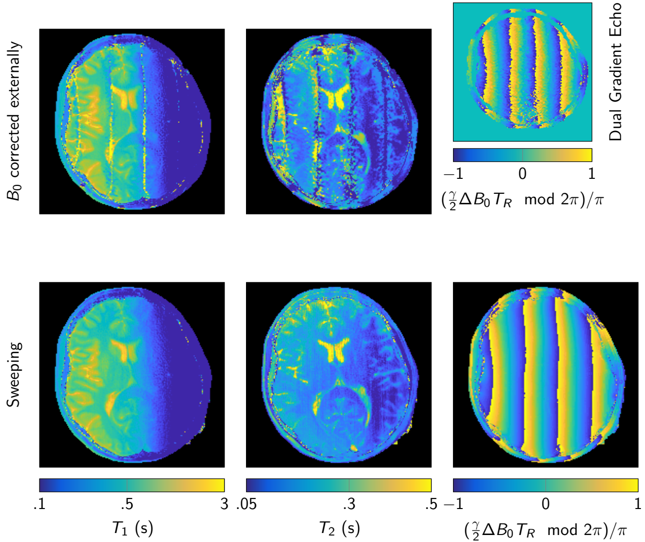
T_1 artifacts arise due to the inversion pulse fading at extreme off-resonance frequencies

MRF with corrupted shim (sweeping)



T_1 artifacts arise due to the inversion pulse fading at extreme off-resonance frequencies

MRF with corrupted shim (B_0 corrected externally)



T_1 artifacts arise due to the inversion pulse fading at extreme off-resonance frequencies

Future work

- More robust inversion or omit inversion
- 3D sequence for efficient sampling

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