B_1-Sensitivity Analysis of qMT

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Introduction

- B_1 mapping is an important measurement used to correct the excitation flip angle and MT saturation powers in pulsed quantitative magnetization transfer (qMT) imaging.
- Additional measurements necessary for qMT (e.g. T_1 mapping) may also require B_1 maps. For example, variable flip angle (VFA) T_1 mapping requires B_1 maps, while inversion recovery (IR) typically does not[1].
- **Local (e.g. artifacts) or global (e.g. systemic biases) inaccuracies in B_1 mapping[2] will propagate to the fitted qMT parameters differently, depending on the T_1 method.**
- We present a simulation-based analysis of the B_1 sensitivity of pulsed qMT, investigating the propagation of the B_1 error to the qMT parameters using different T_1 mapping methods (VFA vs. IR).
- We demonstrates the pool-size ratio F is robust against B_1 inaccuracies when VFA T_1 mapping is used, but this comes at the cost of an increase in error in the exchange rate kf.

Methods

- Pulsed MT SPGR signals were simulated in MATLAB (MATLAB2011a, The Mathworks Inc.) using the Sled and Pike approximations[4].

Healthy WM qMT Tissue Parameters

- F = 0.122
- kf = 3.97 s^{-1}
- R1f, R1r = 1.11, 1.0 s^{-1}
- T2f, T2r = 27.2 ms, 10.96 μs

qMT Protocol (SPGR)

- TR = 25 ms
- $\alpha_{excitation}$ = 7°
- Gaussian-Hanning MT pulses
  - Pulse duration =10.2 ms
  - α_{MT} = 142° and 426°
  - Off-resonance frequencies (for each α_{MT}) = 423.9 Hz, 1,087.5 Hz, 2,731.6 Hz, 6,861.6 Hz, and 17,235.4 Hz.

Data Fitting

- The qMT signal was subsequently fitted[5] for 10,000 B_1 and T_1 value combinations.
  - T_1 varied independently of B_1 for this step (without any assumptions on the measurement method.).
  - 100 B_1 values between 0.5 to 2 ($B_{1,true}$ = 1).
  - 100 T_1 value between 0.1 s to 4 s ($T_{1,true}$ = 0.9 s).
- qMT was also fitted using T_1 from simulated VFA signals[1]:
  - TR =25 ms, α = 3° and 20°, T_1 = $T_{1,true}$.
  - T_1 values were fitted from the VFA data using each B_1 error value.

Results – B_1 vs. T_1

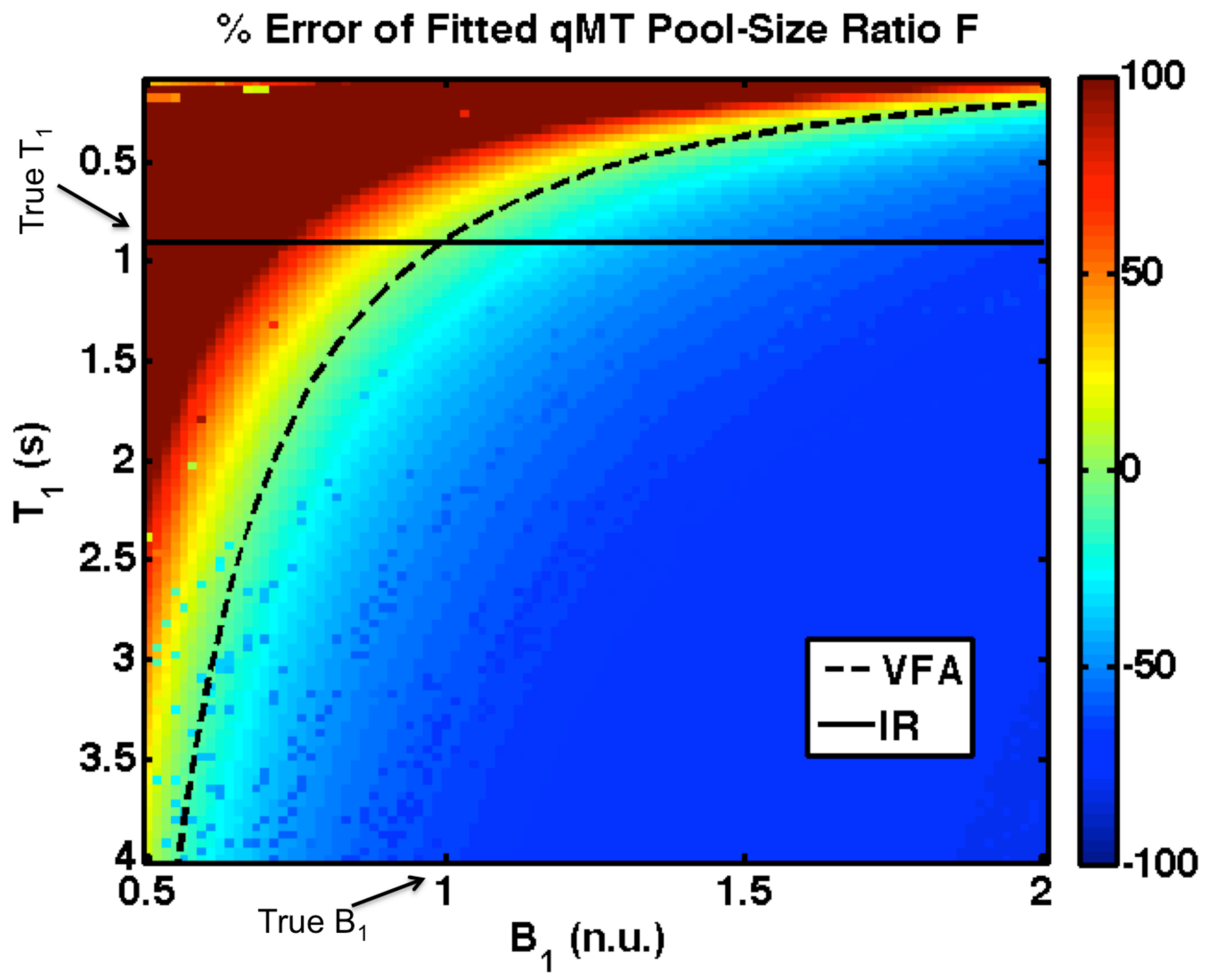

Figure 1. Percent error in fitted qMT F values in the presence of a wide range of B_1 and T_1 errors ($B_{1,true}$ = 1 n.u., $T_{1,true}$ = 0.9 s).

Results – VFA vs. IR

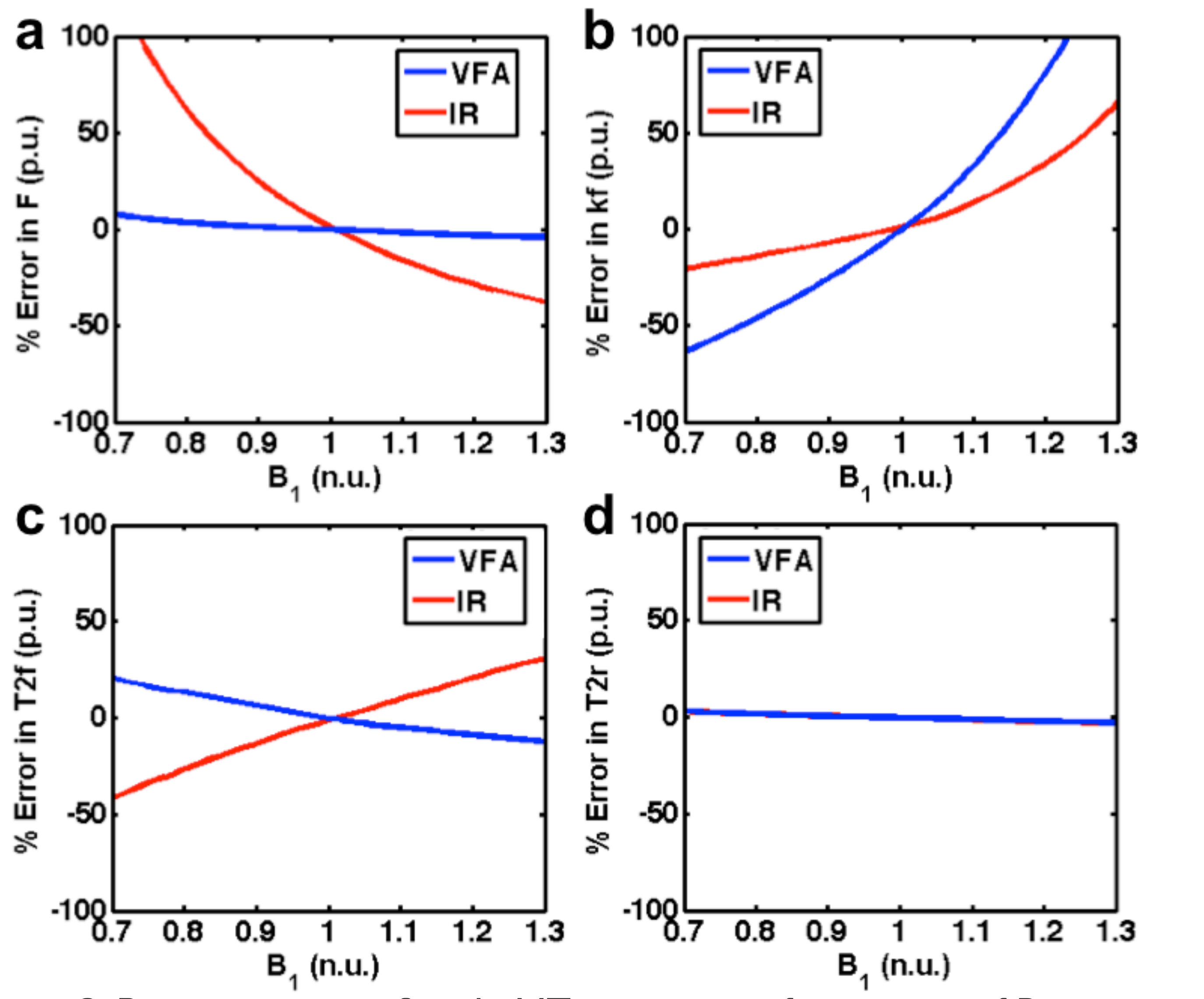

Figure 2. Percent error in fitted qMT parameters for a range of B_1 errors (a – pool size ratio (F), b – magnetization exchange rate (kf), c – free pool T2 (T2f), d – restricted pool T2 (T2r)). See solid and dashed lines in Fig. 1 for the B_1-dependence of VFA (solid) and IR (dashed) T_1.

Results

- The superimposed lines in Fig. 1 show the range of errors in the fitted pool-size ratio F using a B_1-independent T_1 method (e.g. IR) (solid line), and from VFA T_1 mapping (dashed line).
- Figure 2 shows the errors in fitted qMT parameters (F, kf, T2f, T2r) using B_1-independent (IR) and VFA-measured T_1 for a range of B_1 inaccuracies that may be observed in vivo.
- Errors in F induced by B_1 errors were greatly reduced by using VFA T_1 mapping (Fig. 2a - blue).
- A substantial increase in errors of kf occurs for VFA relative to IR (Fig. 2b - blue), while T2r remains insensitive to B_1 inaccuracies for both cases.

Discussion

- The qMT pool-size ratio F was shown to be nearly B_1-error insensitive when using VFA T_1 mapping (Fig. 2a - blue).
- Using a B_1-independent T_1 measure, such as IR, produces large qMT F errors (>100% to -45% for B_1 errors between ±30%, Fig. 2a – red). VFA T_1 mapping kept qMT F errors within a moderate range (7% to -3%, Fig. 2a - blue).
- These results suggest that, when investigating the pool-size ratio (a biomarker for white matter myelin density), VFA T_1 mapping should be used in the pulsed qMT protocol to reduce the effects of B_1 inaccuracies.
- For applications of qMT where kf is the biomarker of interest (e.g. cartilage imaging[6], systemic inflammation[7]), our results suggest that a B_1-independent measure of T_1 may be preferable instead of the VFA method (Fig. 2b – red).

Summary

- This work demonstrated that pulsed qMT pool-size ratio F maps fitted using VFA T_1 are nearly insensitive to B_1 inaccuracies.
- Under certain circumstances, B_1 mapping could be omitted altogether without substantial bias to F values.
- Pulsed qMT using B_1-independent measures of T_1 (e.g. IR) may be better suited for MT exchange rate (kf) mapping.
- Further sensitivity analysis of the qMT equations for different measurement protocols could be used to determine optimal qMT protocols for reduced B_1-sensitivity.

References: [1] Stikov, n. et al, MRM, doi: 10.1002/mrm.25135 (2014) [2] Boudreau, M. et al, Proc. of ISMRM, #3207 (2014) [3] Boudreau, M. et al, Proc. of ISMRM, #3167 (2014) [4] Sled J. and Pike G. B., JMR, 145:24-36 (2000) [5] Sled J. and Pike G. B., MRM, 46:923-931 (2001) [6] Stikov, N. et al, MRM, 66:725-734 (2011) [7] Harrison, N. et al, Biological Psychiatry, DOI: 10.1016/j.biopsych.2014.09.023 (2014)

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