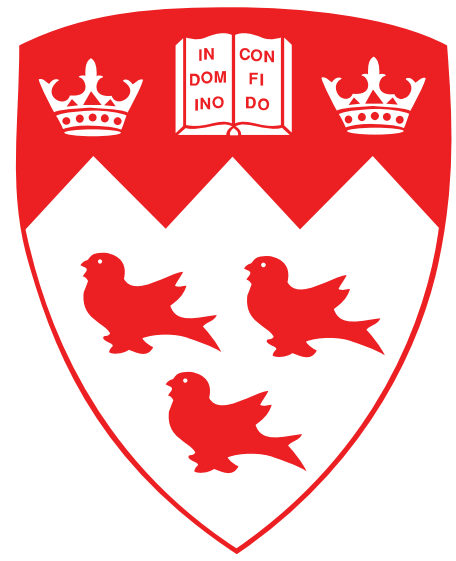




B₁-Sensitivity Analysis of qMT

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Introduction

- B₁ 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. T₁ mapping) may also require B₁ maps. For example, variable flip angle (VFA) T₁ mapping requires B₁ maps, while inversion recovery (IR) typically does not¹.
- Local (e.g. artifacts) or global (e.g. systemic biases) inaccuracies in B₁ mapping² will propagate to the fitted qMT parameters differently, depending on the T₁ method.**
- We present a simulation-based analysis of the B₁ sensitivity of pulsed qMT, investigating the propagation of the B₁ error to the qMT parameters using different T₁ mapping methods (VFA vs. IR).
- We demonstrate the pool-size ratio F is robust against B₁ inaccuracies when VFA T₁ 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 approximations⁴.

Healthy WM qMT Tissue Parameters

- F = 0.122
- kf = 3.97 s⁻¹
- R_{1f}, R_{1r} = 1.11, 1.0 s⁻¹
- T_{2f}, T_{2r} = 27.2 ms, 10.96 μs

qMT Protocol (SPGR)

- TR = 25 ms
- α_{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 fitted⁵ for 10,000 B₁ and T₁ value combinations.
 - T₁ varied independently of B₁ for this step (without any assumptions on the measurement method.).
 - 100 B₁ values between 0.5 to 2 (B_{1,true} = 1).
 - 100 T₁ value between 0.1 s to 4 s (T_{1,true} = 0.9 s).
- qMT was also fitted using T₁ from simulated VFA signals¹:
 - TR = 25 ms, α = 3° and 20°, T₁ = T_{1,true}
 - T₁ values were fitted from the VFA data using each B₁ error value.

Results – B₁ vs. T₁

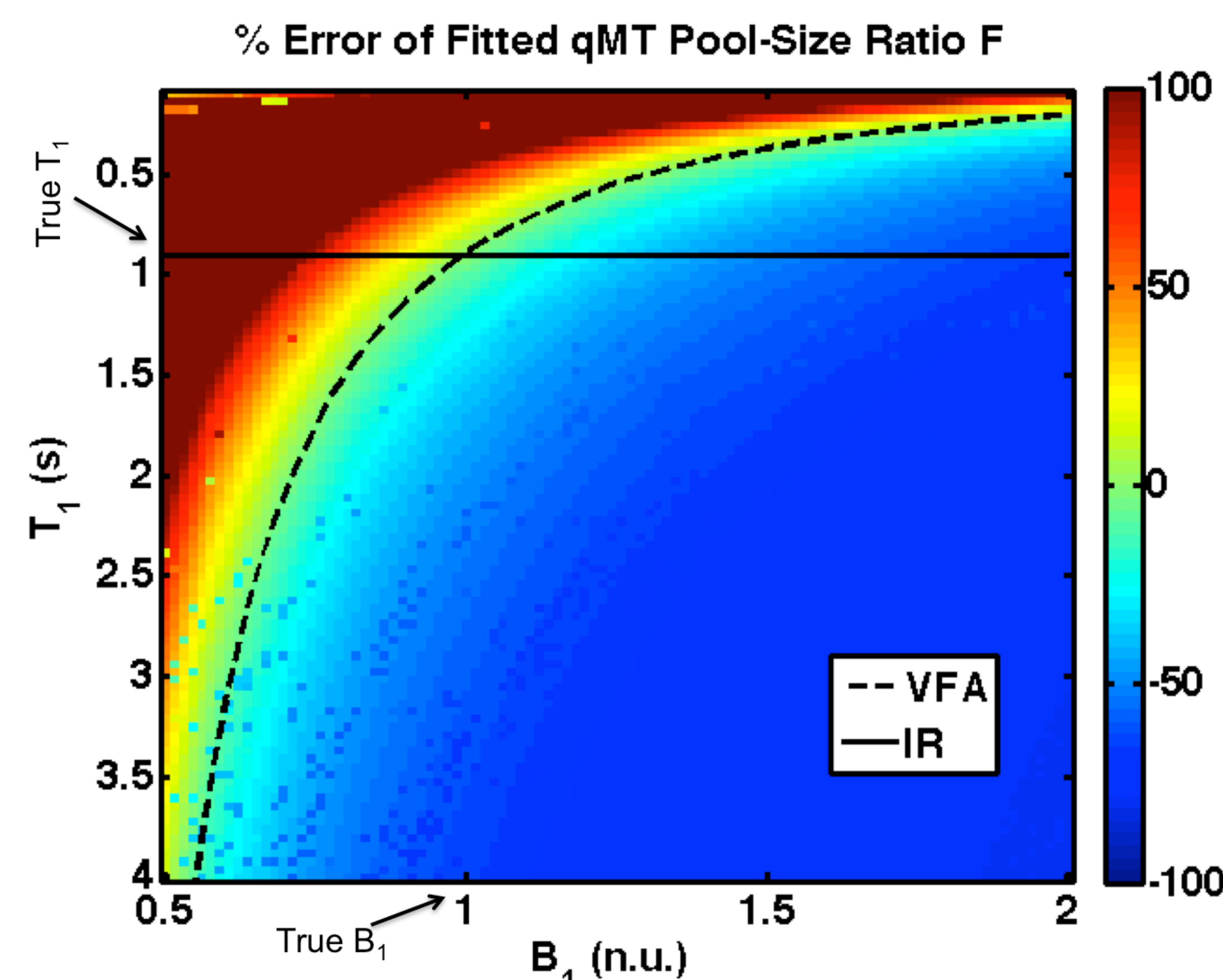


Figure 1. Percent error in fitted qMT F values in the presence of a wide range of B₁ and T₁ errors (B_{1,true} = 1 n.u., T_{1,true} = 0.9 s).

Results – VFA vs. IR

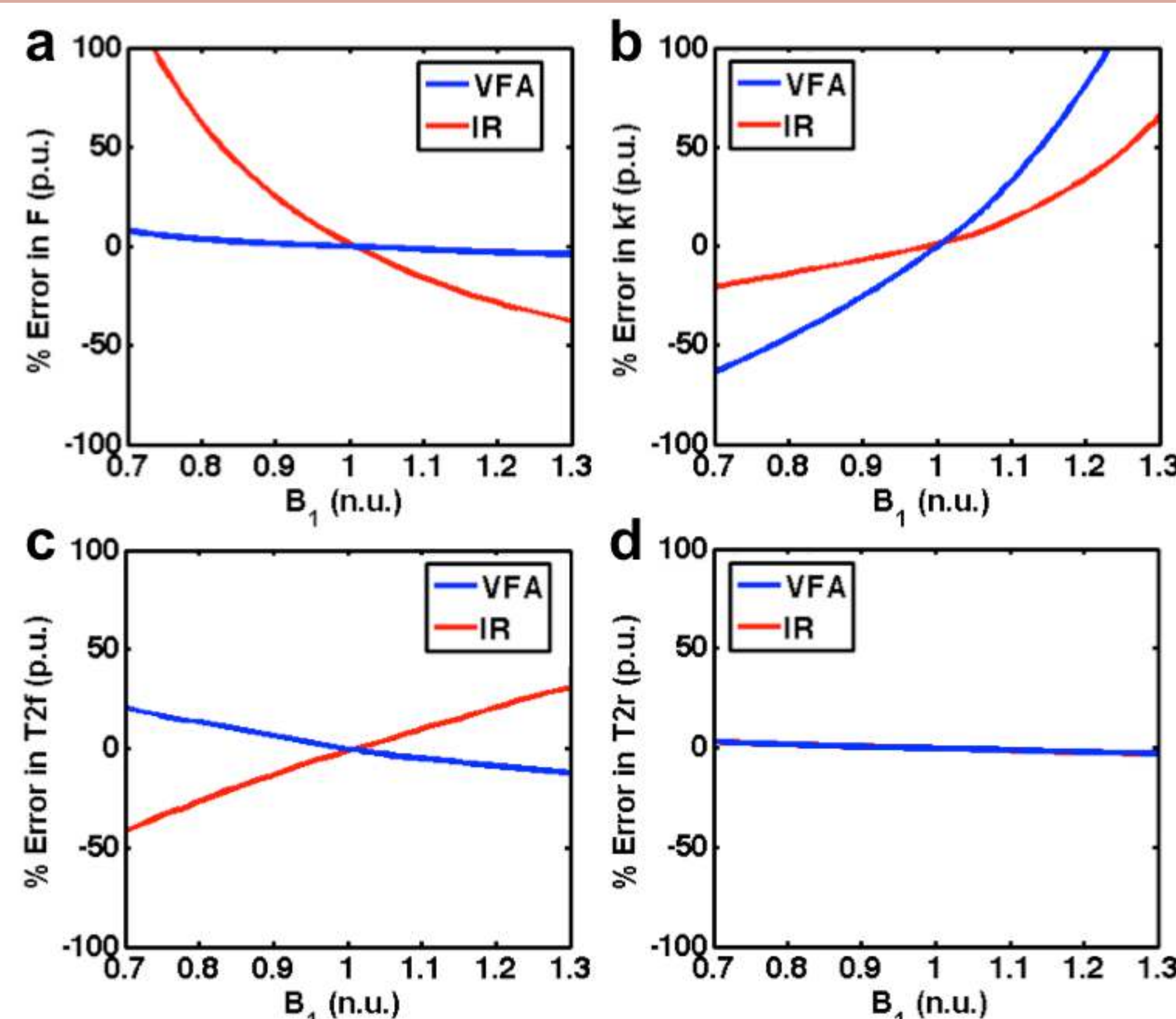


Figure 2. Percent error in fitted qMT parameters for a range of B₁ errors (a – pool size ratio (F), b – magnetization exchange rate (kf), c – free pool T2 (T_{2f}), d – restricted pool T2 (T_{2r})). See solid and dashed lines in Fig. 1 for the B₁-dependence of VFA (solid) and IR (dashed) T₁.

Results

- The superimposed lines in Fig. 1 show the range of errors in the fitted pool-size ratio F using a B₁-independent T₁ method (e.g. IR) (solid line), and from VFA T₁ mapping (dashed line).
- Figure 2 shows the errors in fitted qMT parameters (F, kf, T_{2f}, T_{2r}) using B₁-independent (IR) and VFA-measured T₁ for a range of B₁ inaccuracies that may be observed in vivo.
- Errors in F induced by B₁ errors were greatly reduced by using VFA T₁ mapping (Fig. 2a - blue).
- A substantial increase in errors of kf occurs for VFA relative to IR (Fig. 2b - blue), while T_{2r} remains insensitive to B₁ inaccuracies for both cases.

Discussion

- The qMT pool-size ratio F was shown to be nearly B₁-error insensitive when using VFA T₁ mapping (Fig. 2a - blue).
- Using a B₁-independent T₁ measure, such as IR, produces large qMT F errors (>100% to -45% for B₁ errors between ±30%, Fig. 2a - red). VFA T₁ 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 T₁ mapping should be used in the pulsed qMT protocol to reduce the effects of B₁ inaccuracies.
- For applications of qMT where kf is the biomarker of interest (e.g. cartilage imaging⁶, systemic inflammation⁷), our results suggest that a B₁-independent measure of T₁ 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 T₁ are nearly insensitive to B₁ inaccuracies.
- Under certain circumstances, B₁ mapping could be omitted altogether without substantial bias to F values.
- Pulsed qMT using B₁-independent measures of T₁ (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 B₁-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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