

Correction for residual effects of B1+ inhomogeneity on MT saturation in FLASH-based multi-parameter mapping of the brain

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Target audience

MR physicists

Purpose

In magnetization transfer (MT) imaging, the evolution of the binary spin bath after the off-resonant saturation pulse can be described by simultaneous apparent T1 relaxation of both pools as in fast exchange and simultaneous equilibration of the partial saturation (1). From MT-weighted FLASH, the MT-related partial saturation of the free water can be calculated using a PD-w and a T1-w reference signal (2). Such MT-saturation maps are independent of the underlying T1 and largely compensated for flip angle inhomogeneities. For an established multi-parameter mapping (MPM) protocol at 3T (3), we discuss the source and correction of residual effects of flip angle inhomogeneity.

Theory

With increasing flip angle α_{sat} of the MT-pulse, the z-magnetization of bound macromolecular pool is destroyed, but the effected saturation becomes increasingly lower than α_{sat}^2 (as expected for small changes in Mz). Thus, the inherent B1+ correction of the MT-sat maps (by α_{sat}^2), results in a residual overestimation in regions of low B1+ and underestimation at high B1+ (Fig. 1A). For any given tissue and MPM protocol, an additional linear dependence of the MT-sat value δ on α_{sat} was assumed: $\delta(\alpha_{sat}) = A [1 - B \alpha_{sat}] \alpha_{sat}^2$ (1) where A and B are heuristic constants that can be calibrated by varying α_{sat} . When α_{sat} is spatially modulated by the flip angle bias field f, the square contribution cancels by calculation and the residual bias term is corrected by: $\delta(\alpha_{sat}) = \delta(f \alpha_{sat}) [1 - B \alpha_{sat}] / [1 - f B \alpha_{sat}]$ (2)

Methods

In an established multi-parameter mapping (MPM) protocol (3) on a 3T MR system (Siemens TIM-Trio), the nominal flip angle of the MT-pulse (220°, 4ms Gaussian, 2kHz off-resonance) was varied between 280° and 120° in five healthy adults. The estimated MT-sat values from ROIs in splenium, caudate head and lateral ventricle were divided by α_{sat}^2 to show the linear relationship of eq. (1). Maps of A and B were derived by linear regression with pertinent bias fields (4) using FSL. Estimated MT-sat maps were corrected by eq. (2) with $B \alpha_{sat} = 0.4$ and displayed as a color-overlay (Fig. 1).

Results

The linear relationship in (Fig 2) confirmed the residual bias model. Deviations were observed at $\alpha_{sat} < 120^\circ$. In the caudate head B was slightly smaller than in splenium (0.043 ± 0.004 vs. 0.046 ± 0.005), but the maximum of the gray matter (GM) mode of $\delta(\alpha_{sat})$ was consistent to splenium. Accordingly, maps of B did a single mode in brain tissue without differences between GM and WM (not shown). Thus, the averaged B across tissue and subjects can be used for a post hoc correction of MT-sat maps; with $B \alpha_{sat} = 0.4$ in eq. (2). Of note, the model is not valid for cerebro-spinal fluids with MT-sat being close to zero.

Bias-corrected MT-sat maps were more symmetric (Fig 1) and show more consistent values in subcortical WM and brainstem and a better separation of modes in the histograms.

Discussion

We presented a heuristic model for B1-heterogeneity of MT-sat maps rooted in the saturation dynamics of the MT-pulse. The model parameter B needs to be calibrated for the specific MT-pulse and protocol. The model can also be used to scale MT-sat maps to a different value of α_{sat} . WM and GM yielded very similar values, which is in line with reports of similar absorption lineshapes in qMT (5). This permits a simple post-hoc correction of MT-sat using B1+ mapping yielding a small, but considerable improvement of MT-sat maps.

References

(1) Helms and Piringer *NMR Biomed* (2005)18:44-50. (2) Helms et al. *MRM* (2008)60:1396-1407. (3) Draganski et al. *NeuroImage* (2011)55:1423-34 (4) Lutti A et al. *MRM* (2010)64:229-238. (5) Sled and Pike. *MRM* (2001)46:923-31.

Figure 1: MT-sat map prior (left) and after (right) bias correction

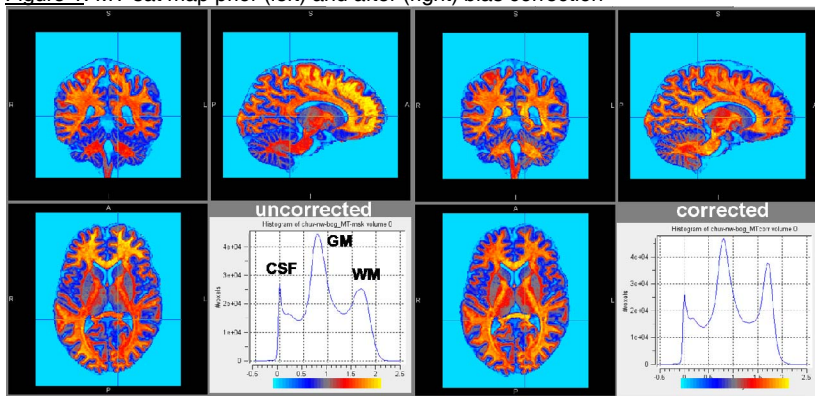


Figure 2: Plot of δ / α_{sat}^2 over α_{sat} (in rads)

