A simple correction for B_1 inhomogeneities in MTR measurements

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Introduction

RF B_1 transmit field nonuniformity of ± 10%, caused primarily by skin depth and dielectric resonance effects, is a large source of error in quantitative MR measurements, such as MTR, where MTR histogram dispersion is a significant associated problem. B_1 mapping could facilitate systematic correction for such errors, but is problematic due to the complex relationship between MTR and B_1 (1), and its potential dependence on tissue type.

Methods

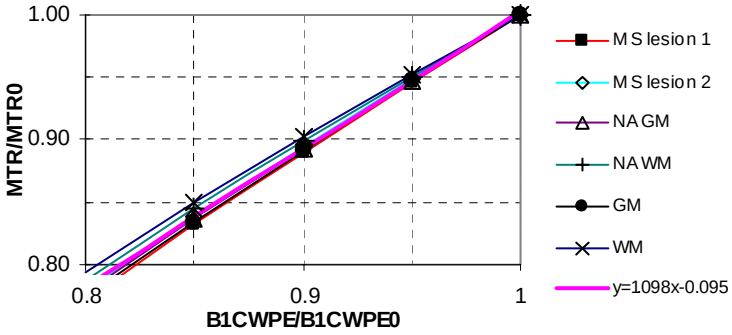
Mathematical Modelling: The binary spin bath model for qMT (2) was used to model the dependence of pulsed MTR on B_1 for individual tissue types (normal white and grey matter in controls, and MS lesions and normal-appearing white and grey matter in MS patients) for a modified Euro-MT sequence (3). Ramani's 'Continuous Wave Power-Equivalent' B_{1CWPE} (4) is the root mean square (rms) value of the saturating field, with amplitude:

$$\omega_{CWPE} = \gamma B_{1CWPE} = \gamma \sqrt{\frac{1}{T R'} \int_0^{\tau_{sat}} B_1^2(t)\, dt} \qquad \text{(eq1)}$$

where $B_1(t)$ is the time-domain shape of the MT pulse, τ_{sat} is the MT pulse duration and TR′ is the time between successive MT pulses.

Parameters required by the model were obtained from previous experimental work (4). B_{1CWPE0} is the optimised B_{1CWPE} for the Euro-MT sequence, and MTR_0 is the MTR at $B_{1CWPE}=B_{1CWPE0}$. A set of theoretical normalized graphs were then plotted (fig 1), the motivation being that for a given sequence a simple relationship between MTR/MTR_0 and B_{1CWPE}/B_{1CWPE0} may exist. The average linear equation for MTR/MTR_0 over all brain tissue types, in the range B_{1CWPE}/B_{1CWPE0}=0.8-1.0, was found to be $MTR/MTR_0 = 1.098 (B_{1CWPE}/B_{1CWPE0}) – 0.095$ (eq2). The maximum variation in MTR/MTR_0 between tissue types (Centrum Semiovale MS lesion and Frontal WM) is approximately 2% at a B_1 reduction of 20%.

Figure 1: Normalised MTR: selected tissues



Experimental Verification: Data were acquired using a modified Euro-MT sequence (3) in a birdcage head coil in a 1.5T GE Signa scanner. The parameters of the spoiled 2D gradient echo sequence are: TR/TE=960/12 ms (TR'=34ms), FA=20˚, acquisition matrix 256x128, reconstructed matrix 256x256, FOV=25x25cm with ¾ FOV in the phase direction. This was implemented on 28 5mm slices for whole brain coverage. A Gaussian MT pulse, τ_{sat}=7.68ms was applied prior to the acquisition of each slice.

B_1 transmit coil nonuniformity was simulated by decreasing the Euro-MT pulse from its nominal FA value of 500˚. Preliminary investigations were carried out on the European MAGNIMS project phantom, before studying 5 control subjects. 1 control subject was scanned on 4 separate occasions in order to investigate reproducibility. B_1 field mapping was carried out on 3 subjects using the Double Angle Method (5).

Results

Averaging normalized data over all controls and tissue types gives $MTR/MTR_0 = 0.744 (B_{1CWPE}/B_{1CWPE0}) + 0.256$ (eq3). Figures 2 and 3 show the application of the theoretical and experimental MTR B_1 correction to measured *in-vivo* MTR data with known B_1 errors.

Figure 2: Theoretical (eq2) MTR B1 correction: Frontal WM (mean of 4 scans)

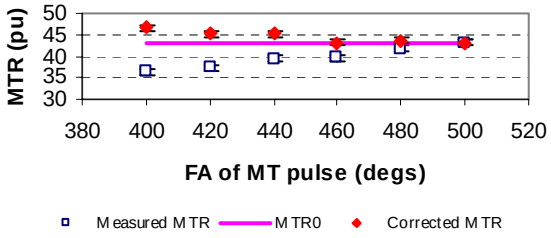
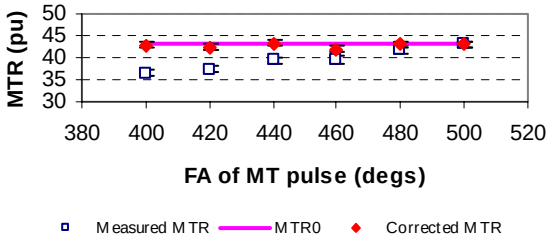


Figure 3: Experimental (eq3) MTR B1 correction: Frontal WM (mean of 4 scans)



The average FWHM of MTR histograms ≈5pu, and did not significantly narrow after correcting for B_1 inhomogeneities. B_1 histograms plotted using data from three control subjects have FWHM's ranging from just 1.95 to 5.30 % of the nominal B_1 value, which may explain this result.

The standard deviation (SD) of an individual measurement (calculated for frontal white matter using the Bland-Altman method for repeated pairs of measurements (6)) is 0.58pu. Thus the minimum detectable MTR difference in an individual pair of measurements, with 95% confidence limits (CL), is 1.13pu. One control was scanned four times and the SD for frontal white matter in this subject was found to be 0.71pu.

Discussion and Conclusions

1. For a B_1 reduction of 8%, the error in the measured MTR is reduced from approximately -3.6pu to 0.2pu (fig 2) on application of the theoretically derived correction, which is better than the 95% CL of an individual measurement. The applied B_1 correction improves for B_1 values closer to the nominal B_1 value.
2. The experimental MTR B_1 correction required is different from that derived from modelling. These variations may be explained by limitations in the CWPE model. Theoretically predicted MTR's were consistently higher than measured values, because CW methods are more efficient than pulsed schemes; thus the CWPE MTR is the maximum achievable MTR with a pulsed sequence (7).
3. A B_1 mapping technique was used to quantify the B_1 nonuniformity errors and correct for these errors in both MTR maps and MTR histograms.

References: [1]Berry I et al. J Magn Reson Imaging 1999; 9: 441-446, [2]Henkelman RM et al. Magn Reson Med 1993; 29: 759-766, [3]Barker GJ et al. Proc ISMRM 5th meeting 1997; 1556, [4]Ramani A et al. Magn Reson Imaging 2002; 20: 721-731, [5]Stollberger R et al. 1988, Proc SMRM, works-in-progress volume, 106, [6]Bland and Altmann Lancet 1986; 1 (8476); 307, [7]Ramani A et al. Proc ISMRM 8th meeting 2000; 2078.

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