3D-maps of T1 and magnetization transfer (MT) related saturation from MT-FLASH images

G. Helms[1], H. Dathe[2], S. Dreha-Kulaczewski[1,3], K. Kallenberg[1,4], P. Dechent[1]

[1]MR-Research in Neurology and Psychiatry, Göttingen University, Faculty of Medicine, Göttingen, Germany, [2]Biomechanics Group, Dept. of Orthodontics, Göttingen University, Göttingen, Germany, [3]Dept of Neuropediatrics, Göttingen University, Göttingen, Germany, [4]Dept. of Neuroradiology, Göttingen University, Göttingen, Germany

Introduction:

Quantitative magnetization transfer (MT) measurements in brain are commonly performed using 3D-FLASH (1) with interleaved saturation of bound spins and continuous wave models. Employing the binary spin bath (BSB) to model the saturation transfer after MT-pulse in brain tissue, we showed that the evolution of the BSB comprises slow relaxation of both pools and rapid MT preserving magnetization (2). Here, the MT-FLASH signal was described by the free-evolution BSB model. Pertinent approximations permit to calculate T1 and MT-related saturation from an MT and two reference FLASH images.

Theory:

For TR/T1<<1 and small flip angle α<<1, the FLASH signal can be simplified by approximating the exponential and trigonometric terms:

$$S = S_0\,\alpha\,\mathrm{TR/T1} \,/\, [\mathrm{TR/T1} + \alpha^2/2]. \qquad [1]$$

Like in the trigonometric form, the Ernst angle is defined by equality of saturation created by excitation (by $1-\cos\alpha \approx \alpha^2/2$) and saturation restored by subsequent relaxation (by $1-exp(-\mathrm{TR/T1}) \approx \mathrm{TR/T1}$). MT from the bound macromolecular pool (subscript 'm'; saturated by a fraction of δ_m) to the observed bulk water (subscript 'f'; saturated by $\delta_f <<\delta_m<1$) may be expressed as time-dependent increase, δ_{MT}, in the observed saturation (3):

$$\delta_{obs}(t) = \delta_f + \delta_{MT}(t) = \delta_f + F\,(\delta_m-\delta_f)\,[1-exp(-R_T\,t)]/[1-(1-\delta_m)\,exp(-R_T\,t)]\,, \qquad [2]$$

where $F = M^0_m/(M^0_f+M^0_m)$ is the bound pool fraction and R_T is the observed transfer rate. Saturation by MT- and excitation pulse and intervals of free evolution were concatenated using the matrix formalism of (2). Discarding products of small terms (TR/T1, α^2, δ_f, F) in the general solution eliminated the dependence on intervals of TR. Thus, the additional saturation originating from the MT-pulse, $\delta_{obs}(t)$, appears in the signal equation:

$$S = S_0\,\alpha\;\mathrm{TR/T1} \,/\, [\mathrm{TR/T1} + \alpha^2/2 + \delta_{obs}(\mathrm{TR})] \qquad [3]$$

The 3 parameters in Eqs. [1] and [3], S_0, T1, δ_{obs}(TR), may be calculated by arithmetic operations from 3 images (MT + 2 references of different α).

Methods:

3D-FLASH MRI with non-selective excitation was performed at 3 Tesla (Siemens Magnetom Trio; 8-channel receive headcoil) on healthy adult volunteers and one Multiple Sclerosis (MS) patient. Sequence parameters were varied to validate Eq. [3] and optimize the SNR of the parameter maps. PD-weighting (α = 5°) ensuring sufficient CSF signal was combined with T1-w (α = 15°; TR = 11 ms). Optimal MT-effect within SAR limits was achieved on PD-w FLASH (a = 5°; TR = 25 ms) by a 12.8 ms Gaussian MT-pulse (530°; 2.2 kHz offset) (4). 1.25 mm isotropic resolution and an iPAT factor of 2 yielded a compromise between SNR and a measuring time of 13 minutes. FSL 3.2 (www.fmrib.ox.ac.uk/fsl) was used for co-registration, brain extraction, calculation and display of maps, and histogram analysis.

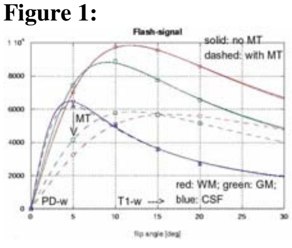
Results:

The fitted flip angle dependence with and without MT at TR = 25 ms in Fig. 1 illustrates the signal drop due to additional MT-saturation compared to PD-FLASH in the caudate nucleus (GM) and splenium of the corpus callosum (WM), but not in lateral ventricle (CSF). δ_{obs} increased with TR and pulse power. The native MT-w FLASH contrast of chronic MS black holes (right hemisphere) and an acute lesion with edema (left hemisphere) is shown in Fig. 2A. The reason for the T2-like appearance is that δ_{obs} (about 1.5% in GM, 3% in WM; Fig. 2C) exceeded the 0.4% saturation due to α. T1-values were slightly higher than reported for 3 T. Histogram analysis confirmed the high contrast visible on the δ_{obs}-map (Fig. 2B) in comparison to the T1- and S_0-maps (Fig. 2D,E). Note the distinct difference between core and surrounding edema of the ring lesion, and the radial intensity gradient of the ring lesions.

Discussion:

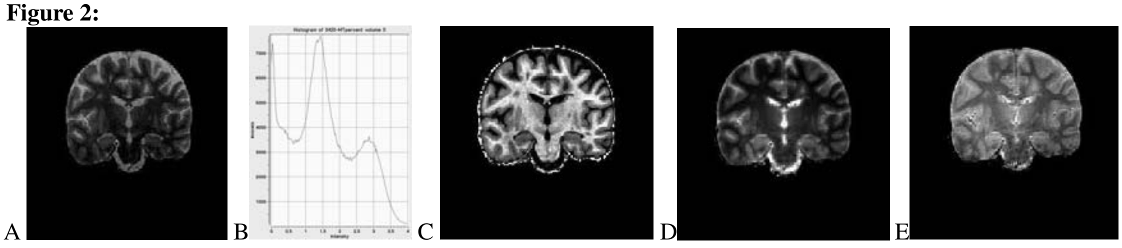
The calulated maps can provide surrogate parameters for tissue destruction (T1) and myelination (δ_{obs}) in MS. δ_{obs} has a well defined physical meaning, namely the additional percentage saturation imposed by the MT-pulse. If direct effects can be neglected ($\delta_{obs} = 0$), δ_{obs} is proportional to the bound pool fraction, although still it depends on TR and MT-pulse. Its contrast properties and the possibility of obtaining high-resolution maps within clinically feasible time suggest it as an alternative to full MT-quantification and semi-quantitative MT-ratios. Further improvements in terms of SNR/measuring time/spatial resolution appear possible in combination with a 3D-multi-echo FLASH sequence.

Figure 1:



Fitted flip-angle dependence

Figure 2:



MT-w FLASH contrast in MS patient (A), whole brain histogram of δ_{obs} (B), and parameter maps of δ_{obs}, T1, S_0 (C-E)

References:

(1) Frahm, Haase, Matthaei. *JCAT* 1986; 10:363-8. (2) Helms, Dathe, Hagberg. *Concepts Magn Reson* 2004; **21A**: 50-62. (3) Helms, Piringer. *NMR Biomed* 2005; 18:44-50. (4) Natt, Watanabe, Boretius, Frahm, Michaelis. Magn Reson Imag 2003; 21:1113-20.

Acknowledgements:

J Frahm, Göttingen, for providing the optimized 3D-MT-FLASH sequence. Grant support by the Volkswagen Foundation of Lower Saxony.