# Theoretical study of a new saturation technique for magnetization transfer experiments

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## Introduction

Magnetization transfer (MT) between bulk water and metabolite protons enable a new contrast in MR imaging [1-2]. MT imaging contrast is given by the magnetization transfer ratio MTR = $S_{sat}/S_0$. $S_{sat}$ is the remaining water signal after off-resonant saturation and $S_0$ the image signal without saturation. If MTR is recorded for various frequency offsets the z-spectrum is obtained. Challenges of z-spectrum acquisition are the reduction of spillover effects which is partial water saturation during off-resonant irradiation, $B_0$ correction, and asymmetry analysis. If these problems can be solved specific MT variants like chemical exchange saturation transfer (CEST) or amide proton transfer (APT) can be exploited. We studied a new saturation scheme with variable saturation power to overcome these challenges.

## Theory

We introduce the condition $\omega_{1,vari}=c\cdot\Delta + d$ (1), with variable ***c*** and ***d***, into the Bloch-McConnell equations of two transferring pools. The result is a linear dependence of the RF amplitude $B_1 = \omega_1/\gamma$ on the offset of the saturation frequency from the water resonance and the analytical solution of MT derived by Henkelman *et al*. [3] will change:

$$M_{zA} = \frac{\frac{R_B\, kM_{0B}}{R_A} + R_{RFB} + R_B + k}{\frac{kM_0}{R_A}(R_A + R_{RFB}) + (1 + \frac{(c\cdot\Delta+d)^2}{(\Delta^2 R_A T_{2A})})(R_{RFB} + R_B + k)}$$

$$R_{RFB} = (c\Delta + d)^2 \cdot \frac{\frac{1}{T_{2B}}}{\frac{1}{T_{2B}}^2 + (\Delta - \omega_B)^2}$$

**Table 1: simulation parameters**

| Pool | A (water) | B (CEST) |
|---|---|---|
| $M_0$ | 1 | 0.01 |
| $R_1=1/T_1$ | 0.4 Hz | 2 Hz |
| $R_2=1/T_2$ | 10 Hz | 20 Hz |
| position | 0 ppm | 2 ppm |
| $k$ | | 500 Hz |

Here $M_{zA}$ is the water magnetization in z-direction, $R_{A,B}$ are the $T_1$ relaxation rates, $k$ is the transfer rate, $R_{RFB}$ is the RF absorption line shape of pool B, $\omega_B$ is the frequency offset of pool B from the water resonance, and $\Delta$ is the saturation frequency offset. For $d = 0$ these equations show for small $\omega_1$ only a dependence on a newly derived variable $\Delta_b = \Delta - \omega_B$ and no longer on $\Delta$.

## Material and Methods

The Henkelman model was calculated with and without implementation of condition (1) with parameters shown in Tab. 1 for a magnetic field of $B_0 = 3$ T (1 ppm corresponds to a $B_1$ of 6 $\mu T$). For simulation of i*n vivo* conditions (pulsed saturation, not reaching steady state) a fully numerical solution of the 6 coupled Bloch-McConnell equations was modified with a mean $B_1$ (cw power equivalent [4] ) that fulfils (1). Both models were calculated for different values of $c$ and $d$ to find the optimal value for $c$ and to show the dependence on residual constant fields $d$. We interpret pool A as water pool and pool B as CEST pool.

## Results and Discussion

Figure 1 shows the modified Henkelman model with different values of c. The CEST peak is isolated from direct water saturation at *0 ppm*. The strength of the transfer effect is similar to the unmodified solution with constant saturation power. Both models can be compared when the varying saturation power at *2 ppm* equals the constant saturation power ( $\omega_{1,const} = \omega_{1,vari}(2\,ppm)$ ) which is shown in Fig. 2. $MTR_{asym}=S_{sat}/S_0(-2ppm) - S_{sat}/S_0(+2ppm)$ values are equal for both methods, but the new method offers a higher stability as the asymmetry analysis simplifies.

The fully numerical solution showed similar results in both approaches even if the resonances are broader and the amplitude is smaller. $MTR_{asym}$ of both methods also returned similar values and the isolation of the CEST pool worked equally well. This shows that condition (1) can be used for mean $B_1$-fields of RF pulse employed in clinical MR scanners. When ***d*** increases, the new z-spectra transit into common z-spectra. At a size of ***d*** corresponding to $B_0/B_1$ inhomogenities $\sim 0.1$ ppm = 25.5 Hz there is a broadening of the water line as demonstrated in Fig. 1. For small *d,* this stays a small perturbation around the water resonance, and the isolation of the CEST pool is not severely affected.

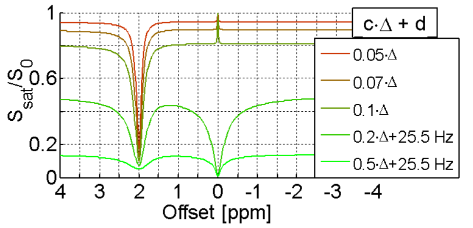


**Figure 1:** modified Henkelman model at different values of c and d.

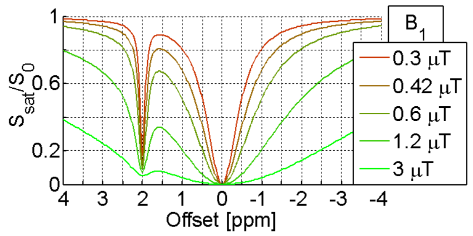


**Figure 2:** Henkelman model with different constant $B_1$

## Conclusion

In this theoretical study we could show that two pools in MT can be isolated by modifying the saturation scheme with condition (1).This has the benefit of not perturbing the asymmetry analysis by direct saturation effects hence correction which are generally required to maximize the measurable effect can be neglected. Phantom and *in vivo* examinations are in progress to evaluate the theoretical background experimentally.

## References

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