On Magnetization Transfer and balanced SSFP

O. Bieri[1] and K. Scheffler[1]

[1]MR-Physics, Department of Medical Radiology, University of Basel / University Hospital, Basel, Switzerland

Introduction. Balanced steady state free precession (bSSFP) suffers from a substantial signal loss in tissues due to magnetization transfer (MT) (1). In this work, MT effects in bSSFP are modulated by a modification of the sequence scheme: Strong signal attenuations are achieved with short radiofrequency (RF) pulses, whereas near full bSSFP signal is obtained by an elongation of the slice excitation profile. Optimized bSSFP protocol settings are derived that yield maximal sensitivity to MT while minimizing contribution from other impurities, such as off-resonances. Evaluation in human brain shows high correlation with commonly used gradient echo sequences. In summary, a novel method to generate and quantify MT from bSSFP image acquisitions is presented and factors that optimize and influence this contrast are discussed.

Methods. Measurements were performed on a Siemens Avanto 1.5 T system. Prior findings (1) suggest up to 2-fold signal reductions due to MT (Fig. 1a). The average rate of saturation (*W*) in the longitudinal magnetization of protons associated with macromolecules is given by (see (2))

$$\langle W(\Delta)\rangle \propto \tau_{RF}^{-1}\int dt\cdot\omega_1^2(t) \propto BW_{RF}\int dt\cdot\omega_1^2(t) \qquad [1]$$

where $\omega_1(t) = \gamma\,|\mathbf{B}_1(t)|$ describes the RF excitation field strength. Elongation of the pulse duration by a factor of β, i.e. $\tau_{RF} \rightarrow \beta\cdot\tau_{RF}$, as shown in Fig. 1b, reduces the amplitude (and bandwidth, BW) by the same amount, i.e. $\omega_1 \rightarrow \omega_1/\beta$, for identical flip angles. As a result, $\langle W(\Delta)\rangle \rightarrow \langle W(\Delta)\rangle/\beta^2$ in Eq. [1] and thus saturation should be efficiently reduced.

It is customary to quantify MT effects by the magnetization transfer ratio, $MTR \propto (M_0 - M_{SAT})$, expressed in percentage units (pu). M_0 and M_{SAT} denote the signal amplitude measured without and with RF saturation pulses, respectively (3). In the case of incomplete T_1 recovery, as produced by the short TRs of bSSFP, the unperturbed magnetization (i.e. proton density M_0) is substituted with the transient equilibrium magnetization M_{bSSFP} to yield

$$MTR = 100\cdot(M_{bSSFP} - M_{SAT})\cdot M_{bSSFP}^{-1}\cdot pu \qquad [2]$$

Here, M_{bSSFP} refers to the MT-free signal (Fig. 1b), whereas M_{SAT} denotes the weighted one (Fig. 1a). It may be of interest to note that direct effects constitute the steady state and are thus accounted for, i.e. absorbed, in M_{bSSFP}. Hence, any observed signal attenuation in M_{SAT} relates to MT effects only.

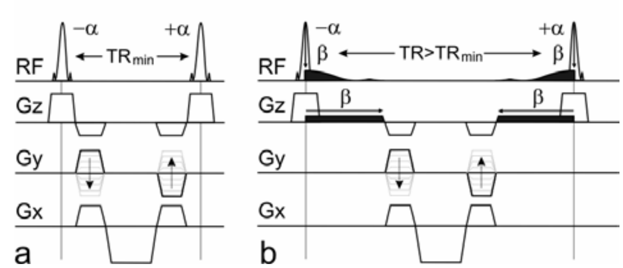

Fig.1:(a) Common bSSFP protocol with minimal TR. (b) Modified bSSFP protocol with RF pulse elongation (β) to modulate MT-related signal attenuations

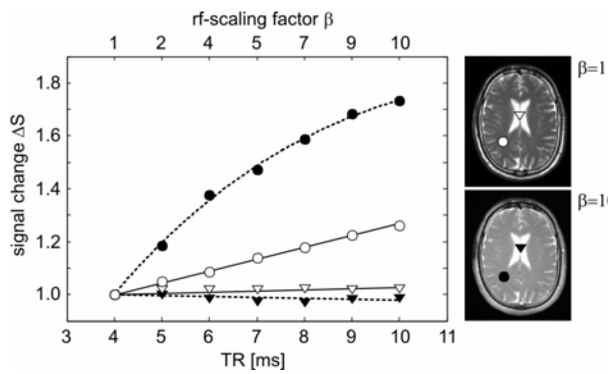

Fig.2: CSF (∇) and WM (O) bSSFP signal change ΔS with TR (open symbols, Fig. 1a) and in combination with pulse elongation (filled symbols, Fig. 1b) using α=40°. The images on the right are windowed identically and represent the initial and final stage (top: TR = 4 ms, τ_{RF} = 640 μs; bottom: TR = 10 ms, τ_{RF} = 6400 μs).

Results & Discussion. Experiments on water phantoms (data and analysis not shown) certify that the slice excitation profile is not altered by RF pulse elongation and non-MT related signal variations minimize for near optimal flip angles ($\alpha_{opt} \approx \cos^{-1}[(\varepsilon-1)/(\varepsilon+1)]$, $\varepsilon = T_1/T_2$). Figure 2 displays the WM signal change for a series of bSSFP images either with increasing TR only or in combination with RF pulse elongations. Reduction in saturation or increase in bSSFP signal is predominantly larger with longer RF pulses compared to an increase in TR only. This yields an estimate of MT-related WM signal attenuation of about 2 which is in good agreement with the theoretical predictions of 1.7–2 found in (1). A strong increase in MTR values with increasing flip angles is also observed (not shown, see also (1)) and it is found that MT effects maximize close to the maximal bSSFP amplitude ($\alpha_{MT} \approx \alpha_{opt}$, if near maximal saturation can be achieved with α_{opt}, see Eq. [1]). From this, using preferred minimal TR acquisitions (3.2ms) with short RF durations (τ_{RF}=270μs) for M_{SAT} and long RF (τ_{RF}=4000μs) and TR (6.9ms) for M_{bSSFP}, high correlation in bSSFP MTR values as compared to the ones using GRE-MT methods (α=20°, TR=19 ms, TE=4.1 ms with Gaussian-shaped off-resonance pulses of 7.68 ms duration at 1500 Hz, α=270°) were found.

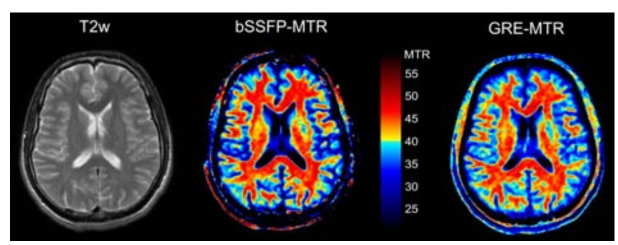

Fig.3: T2-weighted image (left). BSSFP-MTR (middle) and GRE-MTR (right) maps show high correlations. MTR values for WM (GM) of about 45-50% (35-40%) were found.

Conclusion. A new and fast method based on RF pulse duration modification for the generation of MT image contrast using bSSFP is presented. MTR values from bSSFP are similar to standard methods, but are weighted by the steady state. This might deliver a somewhat modified MT contrast that can be of potential use in clinical diagnosis where pathologies affect relaxation times. In addition, determination of MTR values benefits from the high SNR in combination with very short acquisition times as achieved with bSSFP.

References. 1. Bieri & Scheffler, *MRM* **56** (2006) 2. Graham & Henkelman, *JMRI* **7** (1997) 3. Dousset et al. *Radiology* **182** (1992).