TOSSI (T-One insensitive Steady State Imaging): Sequence optimization and first results in tumor patients

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Introduction TOSSI provides a conceptual framework for fast acquisition of images with pure T_2 contrast [1]. Here, this is accomplished in practice by inserting non-equally spaced inversion pulses into a TrueFISP imaging sequence, so that magnetization alternatively resides in states parallel and antiparallel to B_0 for durations TP and TA, respectively. With the periods TP and TA adequately chosen, T_1 contrast can efficiently be removed from resultant TrueFISP images. The purpose of this paper is to give both an analytical description of ideal signal behavior and to create pathways for TOSSI sequence optimization, i.e. for the calculation of adequate TP and TA values. Furthermore, the performance of the technique is demonstrated in a study on patients with brain tumors.

Theory: After initial $\alpha/2$-preparation [2], the TrueFISP signal in good approximation evolves towards the steady state signal with an apparent relaxation time T_1^* (derived for $TR \ll T_1, T_2$ from an expression given in [3]):

$$T_1^* = \left(\frac{1}{T1}\cos^2\frac{\alpha}{2} + \frac{1}{T2}\sin^2\frac{\alpha}{2}\right)^{-1}, \qquad \text{(eq.1)}$$

where α denotes the flip angle. Assuming eliminated T_1 relaxation (i.e. $T_1 \to \infty$), a simple expression is obtained for the ideal signal time course:

$$M_{xy}(t) = M_0 \sin\frac{\alpha}{2}\exp\left(-\frac{t}{T2}\sin^2\frac{\alpha}{2}\right), \qquad \text{(eq.2)}$$

where M_0 is spin density. Thus, the initial signal as well as the apparent decay rate depend on the flip angle. The according longitudinal magnetization component is:

$$M_z(t) = M_0 \sin\frac{\alpha}{2}\exp\left(-\frac{t}{T2}\sin^2\frac{\alpha}{2}\right). \qquad \text{(eq.3)}$$

It can be easily shown that, for a certain longitudinal magnetization M_z, the optimum theoretical TP/TA ratio R_{opt} for cancellation of T_1 relaxation influence is

$$R_{opt}(t) = \frac{1+M_z(t)}{1-M_z(t)}. \qquad \text{(eq.4)}$$

By inserting eq.3 into eq.4, optimized temporal schemes for subsequent times TP and TA can be found for T_2 ranges of interest at a certain flip angle. In Fig1a, the ideal signal courses at α=50° are depicted for different T_2 values, especially for short T_2 times between 75ms and 125ms which are often encountered in the brain. The corresponding ideal R_{opt} values are described by functions decreasing with time. These appear to be very similar for the short T_2 times, and thus an intermediate R_{opt} works sufficiently well for a wider range of T_2 times. The ideal signal curve is well reproduced by simulated curves with optimized varying TP/TA. T_2 values are seperated effecitvely independent of their T_1 and essentially pure T_2 contrast is generated (Fig 1b). On the other hand, the normal TrueFISP signal time course at α=50° depends on both T_2 and T_1 (Fig 1c).

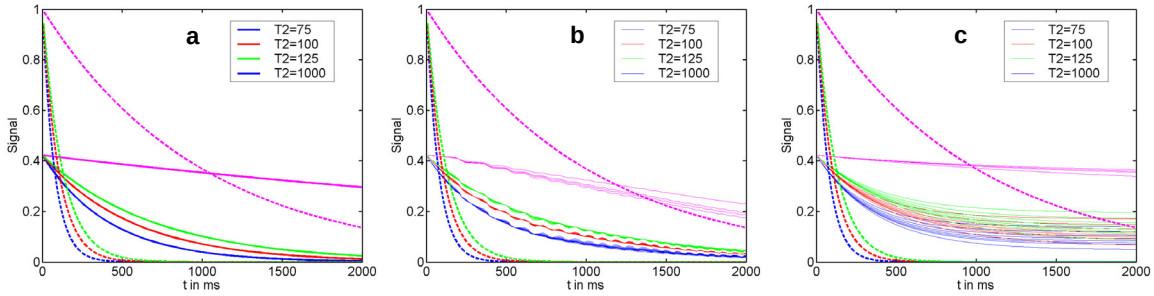

Fig1: Calculations and Simulations for T2=75, 100, 125, 1000ms and T1=800-3000ms:
Ideal signal decays (a), simulated TOSSI (b) and normal TrueFISP (c) signal time courses. Dotted lines represent free T2 relaxation.

Methods: Implementations of the TOSSI concept with different timing schemes were tested on a 1.5T whole body scanner (Vision, Siemens Medical Solutions). The basis for all experiments was a standard TrueFISP sequence with TR=6.46ms. Each imaging block was prepared with an $\alpha/2$- and concluded with an $-\alpha/2$-pulse [2]. Due to software constraints, 'single shot' versions of the TOSSI sequence could only be implemented with constant TP/TA ratios. For example, a scheme with TP=241ms and TA=104ms was shown to provide artifact free T_2-weighted images of the human brain with a matrix size of 248x256 within less than 2s. This sequence was employed in a study with brain tumor patients, and the results were compared to images obtained with standard T_2-weighted TSE and TrueFISP sequences.

Results: In Fig2, sample images from a patient with brain metastasis are shown. Gray and white matter appear with similar intensity in the TrueFISP image (a), whereas the TOSSI image exhibits pure T_2 contrast (b), very similar to the corresponding T_2-weighted TSE image (c). A large metastatic tumor in the occipital white matter is visible in all images. However, the surrounding edema and a much smaller lesion in the frontoparietal white matter are hardly visible in the TrueFISP image, while both are clearly delineated in the TOSSI image, corresponding to their appearance in the T_2-weighted TSE image (arrows).

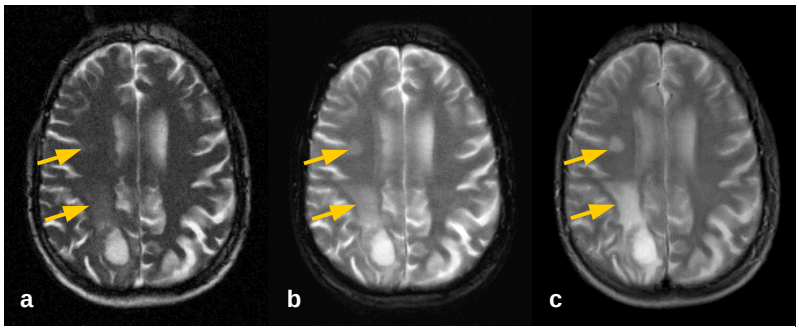

Fig2: Brain tumor patient images: a) TrueFISP (α=50°, TR=6.46ms) b) TOSSI (α=50°, TR=6.46ms) c) TSE (TE=98ms, TR=3s)

Conclusion With the TOSSI concept, fast acquisition of purely T_2-weighted TrueFISP images is possible. Both the initial signal and the apparent decay rate can be influenced by the choice of flip angle. In the data presented, a comparatively low flip angle of 50° was used, giving a slow decay and thus sufficient time for the acquisition of a whole image. In patients, T2-weighted images without artifacts were obtained even without the use of optimized varying TP/TA values. However, on modern scanners, further optimization of TOSSI sequences for specific applications should be feasible with the aid of the presented analytical description.

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References [1] Schmitt P, Jakob PM, Haase A, Griswold M. Proceedings ISMRM 2003, Toronto, #551. [2] Deimling M, Heid O. Proceedings of the 2nd Annual Meeting of SMR, San Francisco, 1994. p 495. [3] Scheffler K. Mag Reson Med 2003;49:781-783.