Signal Behavior of FLASE and TSE for measuring trabecular bone - Theory and Experiments

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Introduction

Recent studies have shown that spin echo based sequences are more reliable than gradient echo based sequences in quantification of trabecular bone volume [1]. Since high resolution requires long imaging time, fast sequences like turbo spin echo (TSE) and FLASE (fast large angle spin echo) are widely used [2-4]. TSE gains its speed by acquiring multiple echoes per excitation, while the number is limited by the short T_2 (=60ms) of fatty marrow. Since a 90° excitation pulse is usually used in this sequence, long repetition times are needed to allow full relaxation of the bone marrow, which results in long scan times. Our idea to shorten the scan time was to decreasing the excitation angle according to the Ernst angle formulation while matching the total scan time to a FLASE protocol.

Theory

Starting from the Bloch equations, a formula for the signal of a Spin Echo can be derived as [5]

$$S = \sin\alpha \cdot \frac{1-\exp\left(-{}^{(T_R-T_E\cdot\left(TF-\frac{1}{2}\right))}/_{T_1}\right)-e^{-T_R/T_1}}{1-\cos(\alpha)\cdot e^{-\frac{T_R}{T_1}}} \cdot e^{-\frac{T_E}{T_2}} \quad (1)$$

where α denotes the flip angle and TF the turbo factor for TSE. The term $\exp(-(T_R-(TF-0.5))\cdot T_E/T_1)$ includes the fact that effective T_1-relaxation starts after the last refocusing pulse. Further important parameters determining the SNR are the total number of acquired data points N and the readout bandwidth BW, which can be written as

$$SNR \propto \sqrt{N/BW} \qquad (2)$$

Materials and Methods

Using Eq. (1) and (2) the expected signal was calculated for the parameters shown in Tab. 1. Since FLASE uses a highly asymmetric echo, the total number of acquired data points was set to $N_{FLASE} = 0.625 \cdot N_{TSE}$. The parameters are chosen that way, that measurement time is the same for all experiments, which means, the same number of echoes per unit time is acquired. The flip angles are derived via the Ernst equation $\cos(\alpha) = \exp(-TR/T1)$ assuming T_1 = 300ms.

To prove the calculations, measurements with the same parameters were performed with a peanut oil phantom, which has similar relaxation times as bone marrow. A noise prescan was implemented in both sequences and SNR quantification was done using SNR units reconstruction [6].

	FLASE	TSE
T_E [ms]	11	18
T_R [ms]	80	[160, 320, 480, 640]
TF	1	[2, 4, 6, 8]
α	140°	[55°, 70°, 77°, 83°]
BW [Hz/px]	30	110

Tab. 1: Parameters for FLASE and TSE. The relaxation rates used are T_1 = 300ms and T_2 =60ms)

Results

The calculated signal is shown in Fig. 1 in comparison with the measured SNR from the phantom. Values are normalized with the signal from FLASE for a better comparison. The calculations and experiments show a very good agreement. Due to the $\sin\alpha$ dependency of the signal, FLASE would have the lowest signal. But thanks to its low receiver bandwidth, the SNR is as high as for a TSE with T_R=320ms, α=70° and TF=4. Using a turbo factor of six with TR=480ms can increase the SNR about 20% without lengthening total scan time. However, choosing even longer echo trains results only in small further improvements. As a drawback the point spread function shows a 35% larger full width at half maximum (FWHM) with TF=8 and 23% at TF=6 than FLASE as a result of the T_2-filtering of the outer k-space lines.

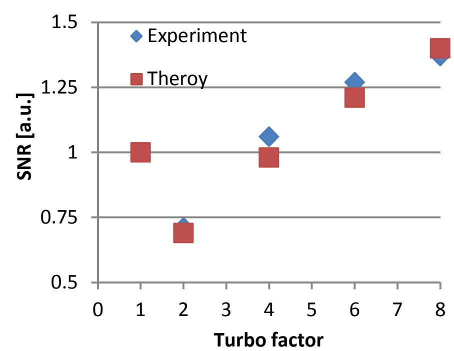

Fig. 1: A graph showing normalized SNR values for different turbo factors. A turbo factor of 1 corresponds to FLASE.

Discussion

The calculations show that the use of lower excitation flip angles can be used to increase the SNR efficiency of TSE. SNR can be increased compared to FLASE by using a TSE with T_R=480ms, α=77° and TF=6 without longer scan time, but at the cost of broadening the PSF. Longer echo trains are not recommended, since T_2-decay noticeably decreases image quality.

Acknowledgments

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