Precise Measurement of T_2 Using the Turbo FLASH Method

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Abstract. *The authors discuss the problem of using the Turbo FLASH sequence for the measurement of T_2 in samples with short relaxation T_1. In the case of the Turbo FLASH sequence, the relaxation T_1 plays an essential role during the measurement of the T_2 relaxation. The verification of the correct value of the T_2 relaxation was performed using the spin echo (SE) approach with precise adjustment (RF flip angles). In order to clarify the errors occurring in the course of the T_2 measurement, the authors used the ROMAG software (by Zenon Starcuk jr.) to carry out the simulations for the preparatory part of Turbo FLASH.*

Keywords: Turbo FLASH, Relaxation T_1 and T_2, Measurement, Relaxometry

1. Introduction

The article presents a method for precise measurement of the T_2 relaxation based on the Turbo FLASH sequence. High accuracy results are indispensable for precise relaxometry. The Turbo FLASH sequence is suitable for dynamic MRI [1] and real-time [2, 3] measurements. In this sequence, the magnetization for the T_2 measurement in a defined volume is provided during the preparatory part before the FLASH module. The prepared magnetization is subsequently captured by using FLASH (single shot or segmented). The main disadvantage of this measurement method consists in its sensitivity to the inhomogeneity of the magnetic field B_0 (geometric distortion, artifacts).

2. Subject and Methods

Two samples with known relaxation T_1 and T_2 were measured. The first sample was a phantom (deionized water) with pre-defined relaxations ($T_1 \sim T_2$), and the second one was a plant (euphorbia). To measure the samples, we applied the spin-echo (SE) [5] and the Turbo FLASH (ultra-short sequence) techniques as indicated in Fig. 1. The residual magnetization $M_{Z(err)}$ is caused by the T_1 relaxation of the samples during the τ interval (between the end of the preparatory part and the beginning of FLASH); importantly, the magnetization causes errors in the T_2 measurement with Turbo FLASH. The progress of the Turbo FLASH measurement sequence is shown in Fig.1 and can be described by the following formula: **Preparatory part** $\{\pi/2_x - T_E/2 - \pi_{x(y)} - T_E/2 - \pi/2_{x(-x)}\} + \tau +$ **FLASH** $\{(\beta - T_R - \beta)n\}$, where β is the flip angle and n expresses the number of repetitions.

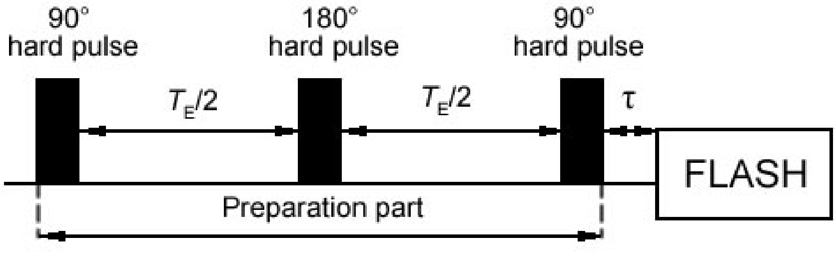

Fig. 1. Pulse diagram of the Turbo FLASH sequence for the T_2 measurement.

The simulations performed using the ROMAG software (by Z. Starcuk jr.) exhibit the relaxation T_1 of the samples during the τ interval. This effect is caused by the residual magnetization $M_{Z(\mathrm{err})}$ in all echo times within the MR images. The magnetization is significant for the samples characterized by short T_1. The time interval $\tau = 3.5$ ms (instrumentation pause) is the time between the end of the preparatory and the beginning of the FLASH parts.

All the experiments were performed using the 4.7T (Magnex) MRI system operated by the ISI Brno, AVCR. The simulations were conducted in the ROMAG software, and the processing of the measured data was carried out in the MAREVISI (8.2) and MATLAB (7.11.0) programs.

3. Results

The results of the simulations presented in Fig. 2 indicate significant impact of the T_1 relaxation and the time interval τ on the magnetization M_Z.

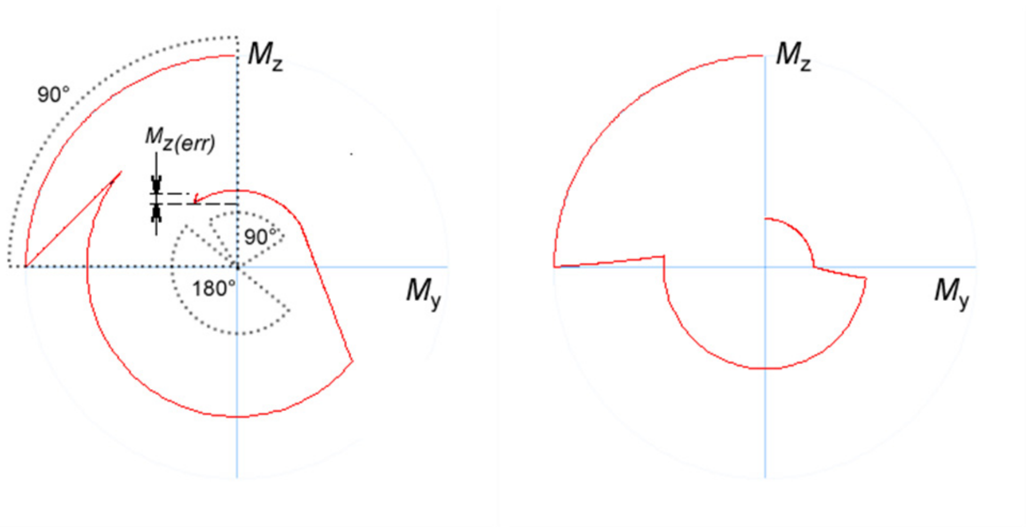

Fig. 2. Simulation of the Turbo FLASH sequence in the ROMAG software. Visualization of the magnetization behaviour during the preparatory part until the end of the interval τ. Left (simulation of the phantom): T_1= 42 ms, T_2 = 42.9 ms. Right (simulation of the euphorbia): T_1 = 470 ms, T_2 = 34 ms.

The measured phantom of deionized water exhibits short relaxations $T_1 \sim T_2$; moreover, the Turbo FLASH-based measurement of T_2 in this phantom, where T_1 (42 ms) $\gg$ T_2 (42.9 ms), has clearly shown the effect of the T_1 relaxation upon residual magnetization in the measured data (Figs. 3 and 5). In the euphorbia (Figs. 4 and 6), the residual magnetization during the T_2 measurement is negligible.

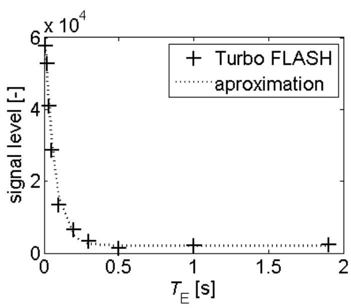

Fig. 3. Measurement of the T_2 relaxation (phantom: T_1 = 42 ms, T_2 = 42.9 ms) using Turbo FLASH.

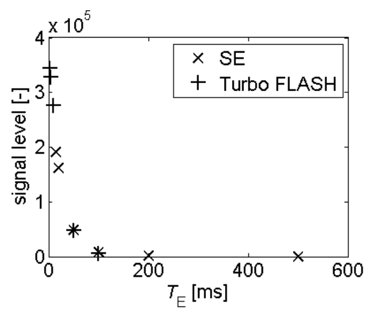

Fig. 4. Measurement of the T_2 relaxation (euphorbia: T_1 = 470 ms, T_2 = 34 ms) using the SE and Turbo FLASH.

A comparison of the spin echo approach and the Turbo FLASH sequence for the euphorbia, where T_1 (470 ms) >> T_2 (34 ms), can be seen in Figs. 4 and 6.

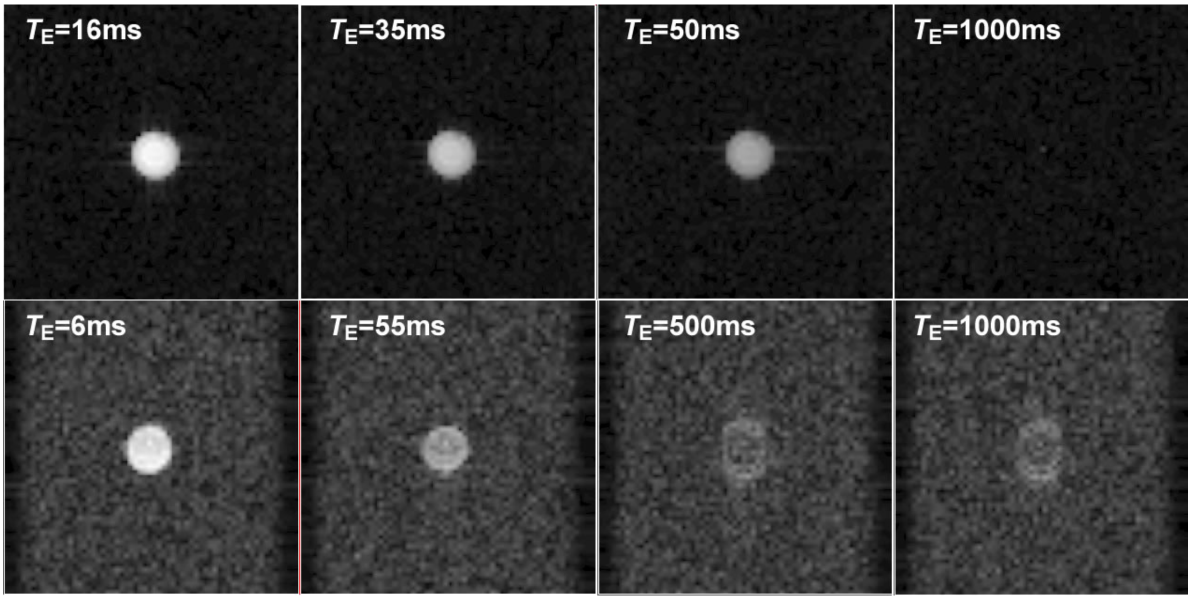

Fig. 5. MR images for the different echo times T_E of the phantom (T_1 = 42 ms, T_2 = 42.9 ms). While the upper row exhibits the SE-based measurements, the bottom row contains measurement images acquired via the Turbo FLASH sequence.

In Fig. 5, the effects of residual magnetization in MR images are shown; the magnetization occurs during the time interval τ in the samples having short T_1.

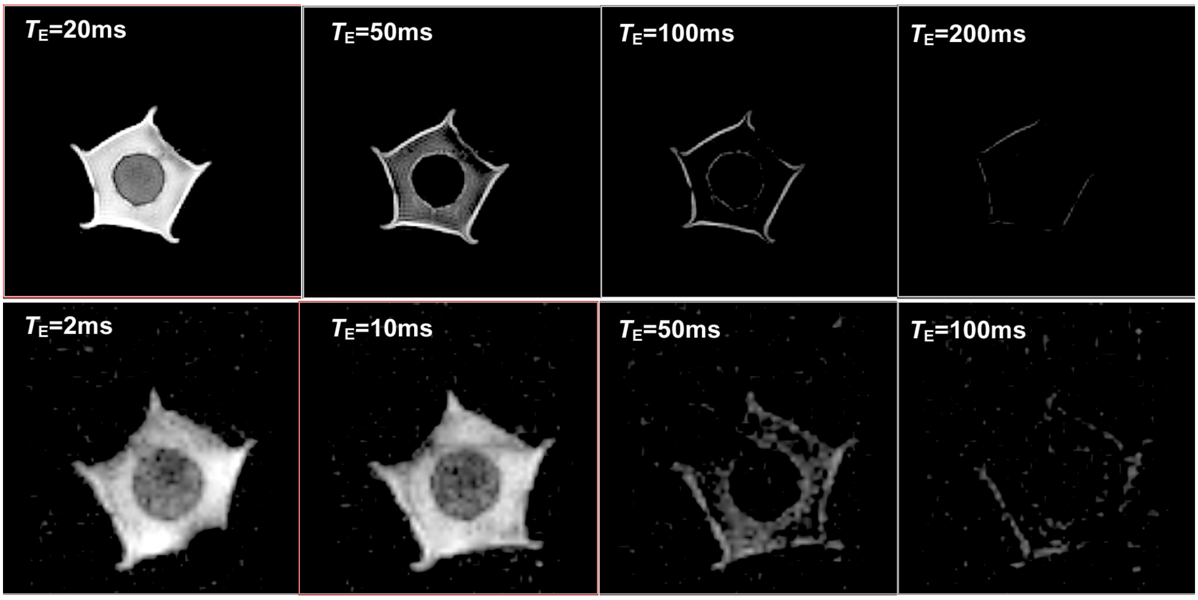

Fig. 6. MRI images of the euphorbia measured via the spin echo approach (upper row) and the Turbo FLASH sequence; T_1 (470 ms) >> T_2 (32 ms).

The reason for the actual measurement of the euphorbia (Fig.6) consists in the fact that, in this plant, the T_1 relaxation is significantly greater than the T_2 relaxation. Thus, we can easily launch an experiment to demonstrate how the Turbo FLASH sequence behaves at $T_1 >> T_2$.

A comparison of the values of T_1 and T_2 measured in the phantom via the spin echo and Turbo FLASH techniques is presented in Tab. 1 below.

Table 1. A comparison of the values of T_1 and T_2 measured in the phantom via the spin echo and Turbo FLASH techniques.

Relaxation	SE	Turbo FLASH	Turbo FLASH (without residual magnetization)
		Phantom	
T_1 [ms]	42	56.6	41.4
T_2 [ms]	42.9	42.8	42.8

4. Discussion and Conclusions

By simulating the preparatory stage for the encoding of relaxation T_2, we determined the magnitude of the error magnetization M_z(err) before the FLASH acquisition. The measurements realized with the phantoms and the euphorbia have clearly demonstrated the effects of residual magnetization for various magnitudes of T_1 at the interval of $\tau = 3.5$ ms. The greatest residual magnetization is shown by the phantom No. 1, which exhibits the relaxation value of $T_1 \sim T_2 \sim 43$ ms. Conversely, the measurement of the euphorbia, whose relaxation is expressed as $T_1 = 470$ ms, indicated very low residual magnetization which does not significantly influence the measured data. This status is caused by the fact that $T_1 >> \tau$. In the measurement of samples exhibiting long T_1 relaxation, the above-described problem does not occur, and residual magnetization is negligible. However, residual magnetization (added to the wanted signal) exerts significant influence on the data acquired in the measurement of samples with short relaxation T_1. Another aspect of importance for the measurement - in addition to T_1 - is the interval τ between the end of the preparatory part and the beginning of the FLASH acquisition. Thus, it is vital to obtain the largest possible ratio between the T_1 of the sample and the time interval τ. If the relaxation T_2 in a sample with short relaxation T_1 ($T_1 = T_2$) is to be measured, we need either to minimize the time interval τ (parameters of the hardware permitting) or to perform approximation considering the T_1 relaxation.

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