Fast 3D T_2 measurement with a magnetization prepared TrueFISP sequence

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Introduction

3D spin-echo (SE) and turbo-spin-echo (TSE) T_2 weighted imaging suffers from high acquisition duration because of the necessary long repetition times (TR). Also, the very long echo trains of 3D TSE do not allow for T_2 weightings with short echo times which would be necessary for accurate T_2 mapping. For 2D cardiac T_2 measurement a sequence was proposed which applies two 90° rectangular pulses and a Malcolm-Levitt composite pulse train of four 180° refocusing pulses (MLEV-4 [1]) for T_2 weightening prior to imaging [2]. In this work, the same T_2 preparation method is combined with a fast 3D TrueFISP imaging sequence (3D T_2p-TrueFISP). A spiral phase encoding scheme is used in order to acquire the central k-space lines directly after the T_2 preparation [3]. Depending on resolution and field of view (FOV) a T_2 weighted 3D dataset with an arbitrary T_2 weighting could be acquired in less than 30 seconds.

Methods

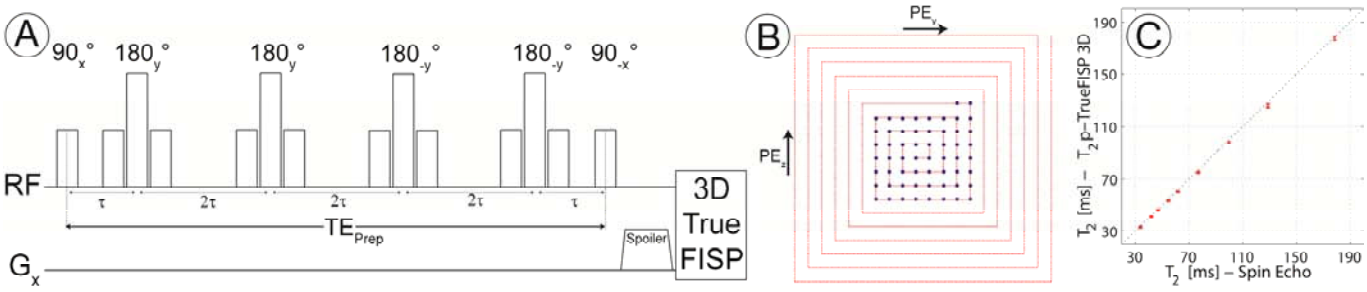

***Figure 1**: (A) T_2 preparation module consisting of a 90_x° excitation pulse, an MLEV-4 pulse train of four 180° composite pulses and a 90_{-x}° tip-up pulse. (B) Spiral phase encoding scheme: The central k-space lines are read out directly after magnetization preparation to generate an image whose contrast is only dependent on the magnetization directly after preparation.(C) Phantom T_2 measurement with a 2D SE sequence and the 3D T_2p-TrueFISP sequence.*

T_2 Preparation: A scheme of the preparation module is shown in Figure 1A. The T_2 preparation consists of a 90_x° rectangular excitation pulse which flips the magnetization on the transversal plane where it is subject to T_2 relaxation. The magnetization is refocused by an MLEV-4 composite pulse train. After the refocusing pulses a 90_{-x}° tip-up pulse flips the magnetization back on the longitudinal axis. The strength of the T_2 weighting can be varied by changing the preparation time TE_{Prep} (Figure 1A). After the 90_{-x}° tip-up pulse a spoiler dephases remaining transverse magnetization.
3D TrueFISP imaging: Before acquisition a Kaiser-Bessel preparation [4] with 10 pulses was applied to stabilize the initial signal oscillations of the TrueFISP sequence. The image contrast must be dependent on the magnetization directly after the preparation module. Therefore a spiral phase encoding (PE) scheme was implemented to acquire the central k-space lines at first [3]. This PE scheme is shown in Figure 2B.
Measurements: All experiments were performed on a Magnetom Skyra 3T MRI Scanner (Siemens Healthcare, Erlangen, Germany). The body coil was used for transmission and a 16-channel head coil for reception.
The accuracy of the method was validated by scanning a phantom containing 9 tubes with a 2D spin-echo sequence and the 3D T_2p-TrueFISP sequence. To achieve same T_1 relaxation times but varying T_2 times the tubes have been filled with the same concentration of Gd-DTPA but differing concentrations of agarose. The T_1 time is ~1000 ms in every tube whereas the T_2 time varies between ~30 ms and ~190 ms.

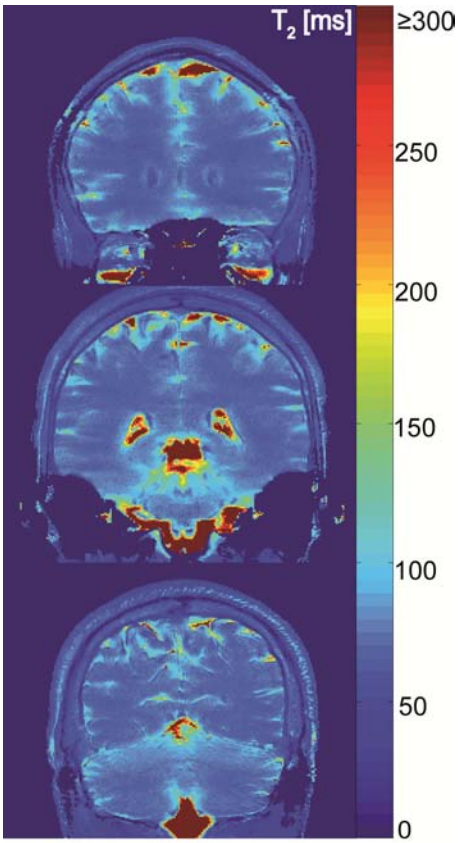

***Figure 2:** Three coronal slices of the 3D T_2 Map of the healthy volunteer.*

Phantom imaging parameters of the 2D spin-echo: FOV: (5x60x120)mm³; TE/TR: (40ms…504ms)/7000ms; bandwidth: 400 Hz; in plane resolution (1.8x1.8)mm²; flip angle: 90°.
Phantom imaging parameters of the 3D T_2p-TrueFISP protocol: FOV: (130x60x120)mm³; TE/TR: 1.96ms/3.92ms; bandwidth: 870Hz; resolution: (5.0x0.9x0.9) mm³; flip angle: 45°. The same echo times were used in both experiments: TE_{SE}/TE_{Prep}: (40, 64, 88, 120, 184, 248, 304, 400, 504)ms.
A healthy male volunteer was scanned with the 3D T_2p-TrueFISP protocol with following imaging parameters: FOV: (216x150x180)mm³; TE/TR: 2.3ms/4.6ms; bandwidth: 725Hz; resolution: (3.0x0.8x0.8)mm³; flip angle: 45°. Additionally a GRAPPA acceleration factor of 2 was used in both PE directions leading to an acquisition time of 21s per 3D volume. For T_2 mapping eight TE_{Prep} times (40, 64, 80, 160, 304, 504, 1000, 3000)ms were acquired. Including five seconds of free relaxation after each measurement this leads to a total measurement time of 203s for the 3D T_2 map.
Post processing: All post processing steps were performed in MATLAB. Before fitting, the datasets have been masked by thresholding. Fitting of the monoexponential T_2 decay equation was performed using a Levenberg-Marquardt optimization algorithm.

Results and Discussion

Figure 1C shows the phantom T_2 values obtained from the spin echo and the T_2p-TrueFISP measurement. A very good agreement between the two methods can be observed. In Figure 2 three coronal slices of the T_2 map of the volunteer are shown. Two regions of interest have been drawn into white matter and gray matter with the help of a T_1 weighted 3D dataset. The mean value and standard deviation were calculated: T_2^{Gray} = (106 ± 11)ms; T_2^{White} = (68 ± 4)ms. These values are in good agreement with the values mentioned in the literature [5]. This work shows that precise, high resolution T_2 mapping is possible in reasonable scan times. Acquisition speed could be further increased by using partial-Fourier techniques or higher GRAPPA acceleration factors. The sequence has the potential to be used in abdominal imaging because short acquisition times are necessary due to breathholding. No strong banding artifacts were observed in the brain measurements at the TR of 4.6ms. But banding artifacts could quickly become a problem in regions where the B_0 field is less homogeneous or when longer TR are necessary at higher resolution or limited specific absorption rate. In conclusion, this sequence provides T_2 weighted contrast at high resolution with high signal to noise ratio within a fraction of scan time required for a similar 3D TSE acquisition. When quantitative mapping of T_2 is not required this sequence would also provide a fast alternative for conventional T_2 weighted imaging.

References

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