Single-slice mapping of submillisecond T_2 using spin echo prepared ultra-short echo time imaging

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Introduction

Measurement of the transversal relaxation time T_2 is one of the most established techniques to characterize material samples or biological tissue by means of NMR. This fact is related to the direct connection of T_2 and the mobility of the spin bearing molecules. If the molecular mobility is restricted, direct spin-spin interactions become relevant and extremely short T_2 values are expected. This situation is partially given for protons in biological tissues like cortical bone, cartilage or tendon where T_2 values of a few ms or less are observed [1, 2]. Extremely short T_2 values are also reported for quadrupolar nuclei like ^{23}Na, ^{35}Cl and ^{17}O [3-5]. In this study we present a slice-selective MRI method for mapping of submillisecond T_2. The method utilizes fast T_2 preparation of the magnetization by a spin echo followed by slice-selective ultra-short echo time (UTE) imaging [6].

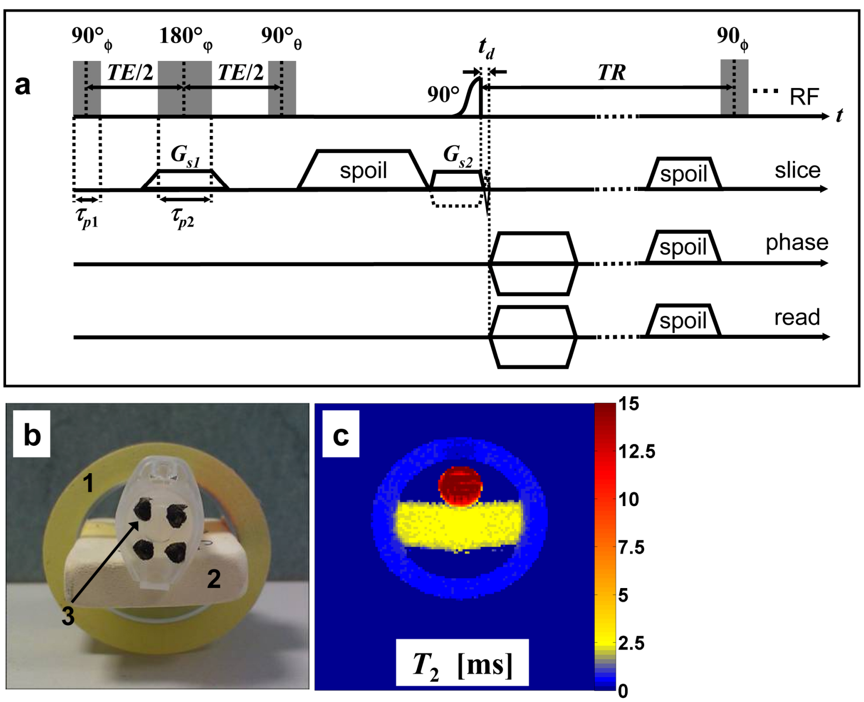
Material and Methods

All the experiments were performed on a 9.4 T Bruker Biospec 94/20 USR small animal system equipped with 740 mT/m x,y,z-gradients and a laser controlled positioning system. A ^{1}H quadrature volume resonator with a diameter of 6 cm was used in transmit/receive mode.

The RF pulse sequence used for the T_2 mapping (Figure a) can be divided into two parts: *i*) a T_2 preparation interval and *ii*) a slice-selective UTE image readout with radial k-space sampling scheme. In order to suppress out-of-slice contamination and unwanted echoes during image acquisition the RF pulses are applied using a 4-step phase cycle with ϕ = const. = x, φ = (y, y, -y, -y), θ = (-x, x, -x, x) and the 180° RF pulse is applied in combination with a slice-selection gradient G_{s1}. The gradient strength G_{s1} was chosen according to $G_{s1} = G_{s2}{\cdot}BW_{180}/(c{\cdot}BW_{90})$. Here, BW_{180} = bandwidth of the refocusing RF pulse, BW_{90} = bandwidth of the 90° half-gauss RF pulse and c is a constant which was optimized in separate experiments. In all experiments BW_{90} = 6.85 kHz and BW_{180} = 16 kHz was used. The gradient strength G_{s2} was calculated by the scanner software according to $G_{s2} = 2\pi{\cdot}BW_{90}/(\gamma{\cdot}d)$, where d = slice thickness of the half-gauss RF pulse and γ = gyromagnetic ratio. A value of d = 2 mm and c = 1.5 resulted in an acceptable total Gaussian-like slice profile with a half-height-width of 4 mm (experiments not presented here).

T_2 maps were measured on a phantom consisting of an arrangement of a roll of adhesive tape (Tesa®, Germany, Fig. b(1)), an eraser made of natural rubber (Laeufer® SW-0240, Germany, Fig. b(2)), and a 4% w/w agar gel (Fig. b(3)).

Parameters for the T_2 mapping: TE = 0.42 - 40.42 ms with 27 increments, TR = 70 ms, t_d = 44 µs, polar undersampling factor = 1.5, FOV = (64 × 64) mm^2, matrix = 128 × 128, BW = 1.9 kHz/pixel, and $\tau_{p1} = \tau_{p2}/2$ = 40 µs. The measured signal intensity S_i of the i-th pixel was fitted by $S_i(TE) = S_{0,i}{\cdot}exp(-TE/T_{2,i})+y_{0,i}$. Here, $S_{0,i}$ = scaling constant, $T_{2,i}$ = value of transversal relaxation time and $y_{0,i}$ = offset of the i-th pixel.



Results and Discussion

Within our minimal achievable TE (= 420 µs) the T_2 measurements on the phantom revealed exponential signal decays for all used materials. Fig c shows the measured T_2 map. Analysis of an exemplary 32 pixel ROI gave: T_2(adhesive tape) = (0.63 ± 0.01) ms, T_2(rubber) = (2.46 ± 0.06) ms and T_2(agar) = (14.69 ±0.6) ms.

The minimum achievable TE depends on the durations of the first three RF pulses and on the ramp time of the slice-selection gradient G_{s1}. Since these parameters are hardware dependent (filling factor of the coil, maximum transmitter power, gradient slew rate) the minimum value of TE may vary for different scanners.

In experiments where only a certain region of the sample is of interest and the total measurement time is the limiting factor a slice-selective 2D imaging method is beneficial because it is less time-consuming than a 3D imaging method. Depending on the scanner hardware the presented method allows mapping of T_2 down to a few hundreds of microseconds. However, for $T_2 \approx \tau_{p1}$ effects of in-pulse relaxation should be taken into account. The presented method could be useful in studies on material samples, short T_2 biological tissue as bone, cartilage or tendon and on short T_2 quadrupolar nuclei like ^{23}Na, ^{35}Cl, and ^{17}O.

References:
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