Effect of RF Pulse Duration on T2 Quantification Using Multi-Echo Spin Echo Sequences

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Introduction. Besides spin density, relaxation times ($T_{1,2}$) are the most basic intrinsic tissue parameters in MR imaging. Typically, a Carr-Purcell-Meiboom-Gill (CPMG) pulse train is used as a gold standard for T_2 quantification of tissues or pathologies of interest [1]. It is thus not surprising that considerable effort has been undertaken to account and correct for all the practical issues related to T_2 quantification using multi-echo spin echo (SE) type of sequences, such as nonideal slice profiles, partial volume effects, Gibb's ringing and many others [2]. In this work, we will show that finite RF effects may lead to a general overestimation of the true T_2 value of tissues by 5-10% using multi-echo SE sequences.

Theory & Methods. In principle, T2 mapping is very simple and bases on the acquisition of SE from a long train of 180° pulses after a 90° excitation. For simplicity, we consider the most basic CPGM type of experiment to assess finite RF effects on T2 quantification: Simple projections along readout (RO) are used (no phase encoding) and hard pulse excitation is used to circumvent issues related to nonideal slice profiles (including spoiler gradients around the 180-refocussing pulses). The prototype of such a sequence is shown in Fig. 1a. During RF refocusing, any orthogonal transverse magnetization flips from its initial position through a longitudinal state into its final opposite transverse state (see Fig. 1b). The mean fraction of time (ζT_{RF}) during which the magnetization is pointing along the z-axis is indicated as gray shaded region in Fig. 1b. It is quite evident that during this longitudinal alignment, no transverse relaxation takes place which in turn should affect derived T2 values (see Fig. 1c). Since the transverse magnetization is dephased prior to any 180° pulse (to avoid contributions from longitudinal states), only 64% of the transverse states undergo such a longitudinal alignment (see Fig. 1a, RO). This leads to the following modification to TE to yield an effective TE_{eff} which takes into account reduced transverse relaxation effects during RF refocusing:

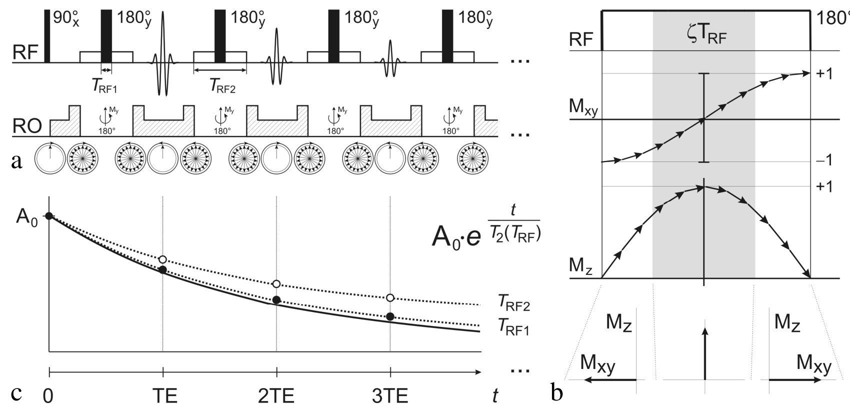

Fig. 1: Prototype of a CPMG multi-echo SE T2 mapping sequence using hard pulses (RF) of variable durations ($T_{RF1,2}$) and simple projections along readout (RO) including spoiler gradients around the 180° refocusing pulses (a). During RF refocusing, the transverse state flips up and the mean fraction of time, the magnetization is pointing upwards (ζT_{RF}) is indicated as gray shaded area (b). As a result, T_2 values should prolong with increasing refocusing duration (c).

$$TE_{eff} = TE_{SEQ} - 0.64 \cdot \zeta \cdot T_{RF} \quad \Rightarrow \quad T2_{SEQ} = T2_{eff} \cdot \left(1 - 0.64 \cdot \zeta \cdot T_{RF} / TE_{SEQ}\right)^{-1} \qquad [1]$$

Measurements were performed on a 1.5T clinical scanner (Siemens Espree) and on two aqueous (as to circumvent magnetization transfer effects) spherical phantoms with different T2/T1 were used. For modulation of T2 effects from RF pulses, the duration of the hard pulse (T_{RF}) can be adjusted between 1ms – 8ms to fill TE (see Fig. 1a) for a fixed echo-spacing of $n \cdot TE = n \cdot 10$ms. Typically, 64 echoes were acquired with a resolution of 1mm (256 pixels for the projection). Measurements were completed by numerical simulation of the pulse sequence displayed in Fig. 1a using a one-step standard solver for non-stiff ordinary differential equations for numerical integration of the Bloch equations.

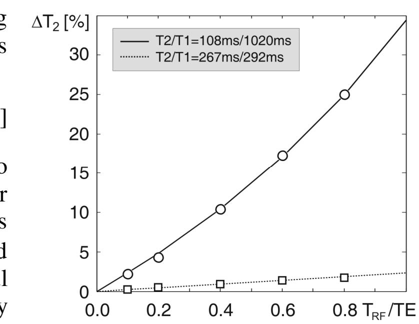

Fig. 2: Finite RF effects on absolute T2 quantification using the multi-echo SE sequence as shown in Fig. 1a for two species of T1~T2 and of T2<<T1 (solid, dotted line: simulation of sequence using numerical integration of Bloch equations & open circles, squares: measurement using aqueous probes). Deviation T2 refers to $\Delta T2 = (T2_{seq} - T2)/T2$.

Results & Discussion. Simulations (see Fig. 2) revealed the expected deviations (i.e. overestimations) of multi-echo SE T2 measurements from the true T2 with increasing RF pulse echo-time portions (T_{RF}/TE). Interestingly, T2 deviations strongly depend on T1/T2: For similar T2 ~T1 (dotted line), T_{RF} has a negligible effect on the assessed T2, whereas for T2 << T1, a strong dependence on T_{RF}/TE is found (solid line). For hard pulses, $\zeta \approx 0.4$ is found, indicating that during 40% of the refocusing time, no transverse relaxation takes place. As a result, Eq. [1] is modified to yield

$$T2_{SEQ} \approx T2_{eff} \cdot \left(1 - 0.25 \cdot \left(1 - T_2 / T_1\right) \cdot T_{RF} / TE_{SEQ}\right)^{-1} \qquad [2]$$

The mean longitudinal alignment of the magnetization during RF refocusing (ζT_{RF}) thus leads to a reduction in the effective echo-spacing and thus to an overestimation of the true T2 for species with T2<<T1. Typically, echo-spacing is short (TE < 10 ms), since T2 times in tissues are low (T2 ~ 60 ms), whereas 180° pulses are long (T_{RF} ~ 3 – 5 ms) from SAR limitations. As a result, T_{RF}/TE portions can be quite substantial (~ 0.5). Results and analysis will be extended to slice selective refocusing.

Conclusion. Care has to be taken in the analysis of multi-echo SE images for absolute T2 quantification. Finite RF pulse effects may results in similar inaccuracies as other well-known issues, such as nonideal slice profiles.

References. [1] Tofts P, Quantitative MRI of the brain, Wiley (2003). [2] Haacke et al., Magnetic Resonance Imaging, Wiley (1999).