T_1 Mapping: Methods and Challenges

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Purpose: In this educational abstract, we provide an overview of the main T_1 mapping methods and we outline the challenges in performing quantitative T_1 measurement. We describe the gold standard (Inversion Recovery), as well as two widely used alternative methods (Look-Locker and Variable Flip Angle) that speed up the scanning and fitting procedures at the expense of accuracy and precision. The e-poster will include sample T_1 maps of phantoms and in-vivo human brains acquired with each of the above methods, and it will provide a list of useful T_1 mapping references.

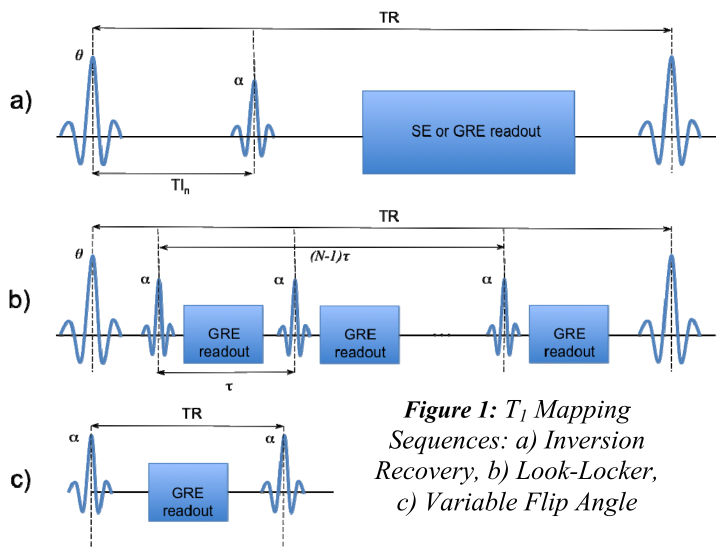

***Figure 1:** T_1 Mapping Sequences: a) Inversion Recovery, b) Look-Locker, c) Variable Flip Angle*

Outline of Content:

***Inversion Recovery (IR) T_1 Mapping*:** This gold-standard method for T_1 mapping [1,2] consists of inverting the longitudinal magnetization and sampling the MR signal at several points (TI_n) along its exponential recovery with a time constant T_1. The IR pulse sequence is repeated N times, each time applying the same (typically adiabatic) inversion pulse, followed by different waiting times (TI_n), and an imaging module that can be either spin echo (SE) or gradient echo (GRE). TR must be on the order of the longest measured T_1 to achieve sufficient magnetization recovery. The general equation used for the fitting procedure is given by: $S_n = a + be^{-TI_n/T_1}$, where a and b are complex-valued parameters and TI_n is the inversion recovery time of the nth IR scan [3]. For precise and accurate measurement, it is recommended to perform at least four scans with TIs that span the range of expected T1 values [3]. The gold-standard method does not assume a perfect inversion pulse, but it requires temperature monitoring as T_1 values change with temperature [4]. Additional simplifications can be made if TR>>T_1, or by assuming specific values for θ and α (e.g., 180° and 90°, respectively).

***Look-Locker (LL) T_1 Mapping*:** The Look-Locker sequence is similar to the gold standard scan in that it prepares the magnetization with an inversion pulse, but instead of a single sample of the recovery curve per TR it applies a train of N low flip angle pulses spread across the TR with spacing τ [5]. The signal after the nth sampling pulse is given by: $S_n = \beta\,(1 - DR\, e^{-n\tau/T_1^*})$ where

$$\beta = \frac{M_0(1-e^{-\tau/T_1})}{(1-\cos\alpha\, e^{-\tau/T_1})\sin\alpha}, \quad DR = -\left(\frac{\cos\alpha\,(1-[\cos\alpha\, e^{-\tau/T_1}]^{N-1})}{1+\cos\alpha\,[\cos\alpha\, e^{-\tau/T_1}]^{N-1}} + 1\right) \text{ and } T_1^* = \frac{\tau}{\tau/T_1 - \ln(\cos\alpha)}.$$

This model is sensitive to field inhomogeneity because it assumes perfect RF pulses of negligible duration and no lag between the RF pulse and the readout. The sensitivity to α reduces as τ/T_1 increases, so spreading the sample points across TR improves accuracy.

Variable Flip Angle (VFA) T_1 Mapping: This method can be used to acquire 3D T_1 maps in clinically feasible times [6, 7]. It utilizes two or more spoiled gradient-echo scans with varying flip angles. The equation describing the signal behavior in a spoiled gradient echo sequence is:

$$S_n = \frac{PD\,(1-e^{-TR/T_1})\sin\alpha_n}{1-\cos\alpha_n\, e^{-TR/T_1}}.$$

This equation assumes TR>T_2* and perfect RF spoiling. Additional noise assumptions can reduce the fitting routine to a weighted least-squares procedure [8]. As is the case for the two previous methods, the VFA method should not assume perfect knowledge of the flip angle α. To account for B_1 inhomogeneities, a field map can be acquired along with the T_1 mapping scans.

Summary: We have outlined the basic pulse sequences and models for accurately mapping the T_1 relaxation time. Attention should be paid to the assumptions underlying any model simplifications, and it is always recommended to check a new method against the gold standard using simulations [9].

References:

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