**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.

**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 ($T_{1n}$) 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 ($T_{1n}$), 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: $S_n = a + be^{-\frac{\tau}{T_1}}$, where $a$ and $b$ are complex-valued parameters and $T_{1n}$ is the inversion recovery time of the $n^{th}$ IR scan [3]. For precise and accurate measurement, it is recommended to perform at least four scans with $T_{1n}$ that span the range of expected $T_1$ 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 $\theta$ and $\alpha$ (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 $\tau$ [5]. The signal after the $n^{th}$ sampling pulse is given by: $S_n = \beta (1-DR e^{-\frac{\tau}{T_1}})$ where

$$\beta = \frac{M_0(1-e^{-\frac{\tau}{T_1}})}{(1-\cos \alpha e^{-\frac{\tau}{T_1}}) \sin \alpha}, \quad DR = \frac{\cos \alpha (1-\frac{\cos \alpha e^{-\frac{\tau}{T_1}}}{\cos \alpha e^{-\frac{\tau}{T_1}} + 1})}{1 + \cos \alpha [\cos \alpha e^{-\frac{\tau}{T_1}}]^N + 1}$$

and $T_1^\star = \frac{\tau/T_1 - \ln(\cos \alpha)}{\tau/T_1 - \ln(\cos \alpha)}$. 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 $\alpha$ reduces as $\tau/T_1$ 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:

$$S_n = \frac{PD (1-e^{-\frac{\tau}{T_1}}) \sin \alpha}{1-\cos \alpha e^{-\frac{\tau}{T_1}}}$$

This equation assumes TR>>$T_1^\star$ 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 $\alpha$. 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:**