TARGET AUDIENCE. MRI clinicians and scientists interested in efficient, complete $T_1$, $T_2$, proton density (PD) characterization.

PURPOSE. The $T_1$ and $T_2$ relaxation times, and proton density (PD) contain almost all of the $^1$H MRI information routinely used in clinical diagnosis and research, but are seldom imaged directly. In addition, their accuracy depends critically on $B_1$-field homogeneity, making field mapping essential, especially at higher field strengths. Here we propose a novel ‘Tri-FA’ method to measure and image $T_1$, $T_2$, PD and $B_1$ with only 4 acquisitions—the minimum possible. This ‘Tri-FA’ method encodes $T_1$ with 3 varied flip-angles (FA), and $T_2$ via long $0^\circ$ BIR-4 pre-pulses instead of spin-echoes. 2D and 3D ‘Tri-FA’ MRI is demonstrated in vitro and in vivo at 3 Tesla.

METHODS. It was recently noted (1) that self-refocusing $B_1$-independent rotation (BIR-4) adiabatic pulses are prone to intra-pulse $T_2$ decay that depends on the BIR-4 pulse duration ($\tau$), $B_1$ amplitude, sweep frequency, but is independent of BIR-4 FA. Using four spoiled gradient-echo sequence (SPGR) acquisitions, the ‘Tri-FA’ measures signals $S_{1-3}$ acquired with the same TR (eg, 600ms) but varied excitation FAs ($\theta_{1-3}=30^\circ$, $80^\circ$, $140^\circ$), and a $4^{th}$ signal, $S_4$ acquired with a $\tau=20$ms $0^\circ$ BIR-4 prepulse (excitation FA=$\theta_{1}$, TR’=1036ms). It can be shown that: $S_{1-3}=M_0(1-E_1)\sin(q.\theta_{1-3})/(1-E_1\cos(q.\theta_{1-3}))$, and $S_4=M_0(1-E_1')\sin(q.\theta_{1})E_p/(1-E_1'\cos(q.\theta_{1}).E_p)$, where $q$ reflects the $B_1$ field inhomogeneity. $T_1$, $T_2$, $M_0$, and $q$ are solved from $S_{1-4}$.

Tri-FA was validated in 2D and 3D MRI studies on a clinical Philips 3T scanner. In vitro validation was performed on 11 CuSO$_4$ doped agarose phantoms with $186 \leq T_1 \leq 1332 ms$, $13.2 \leq T_2 \leq 227$ms. In vivo brain studies were performed on healthy consenting adult volunteers (3D matrix =224x224x5, FOV= 200x200x25mm$^3$; 2D matrix=224x224, FOV=200x200x5mm$^3$). Tri-FA measurements were compared with the central slices of standard 3D spin-echo (SE) $T_2$, partial saturation (PS) $T_1$, PD maps and $B_1$ maps acquired by actual flip-angle imaging (AFI)(2). 2D Tri-FA measurements were corrected for slice profile distortions.

RESULTS. The measured $T_1$, $T_2$, PD and $B_1$ of the phantoms are plotted vs. the standard values in Fig.1(a-d). The $T_1$, $T_2$, $B_1$, and PD errors(%) vs the standard values is 2.5%±14%, 3.6%±9%, 0.9%±8%, and 3.6%±4%, respectively. In vivo 3D results from a volunteer are shown in Fig.1(e-h). Mean ($\pm$SD) errors are -4.8($\pm$10.4)% for $T_1$, and 1.1($\pm$12.5)% for $T_2$, measured in the boxes annotated in Fig.1(e). For 2D Tri-FA brain MRI, errors are -3.6($\pm$6)% for $T_1$, and -8.5($\pm$3.6)% for $T_2$ after slice profile correction. Analysis shows Tri-FA provides considerably higher accuracy/unit time vs other parameter mapping methods (DESPOT1/2, etc; not shown).

Conclusion. The novel Tri-FA method offers a minimum-acquisition option for imaging single-component $T_1$, $T_2$, and PD, with $B_1$-inhomogeneity self-correction. Tri-FA was validated in 3D applications at 3T, as well as 2D MRI where standard methods can fail.


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Fig 1. (a-d) In vitro Tri-FA results vs. standard values in 11 phantoms. (e-h) Color coded in vivo 3D Tri-FA maps for a volunteer.