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Importance of Pulse Sequence Design in Simulation-based MRI Reconstruction

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***Abstract*— This paper investigates the effect of different sequence designs on T1, T2 and proton density (PD) estimation within a simulation-based MR reconstruction framework.**

***Clinical Relevance*— This approach offers an accurate estimation of parameter maps using fast scans.**

I. INTRODUCTION

Quantitative MRI (qMRI) can measure magnetic tissue parameters, which have potential for use in diagnosis and to study pathophysiology. Conventional multi-parameter qMRI techniques require long MR protocols. Tissue parameter estimation can be considered as an inverse problem where an MRI simulator provides the forward model within an optimization framework [1] while MRI pulse sequences may affect accuracy, precision and reconstruction time.

II. METHODS

An in-house MRI simulator was used to estimate the signal produced in the Shepp-Logan phantom [2]. A balanced steady-state free precession pulse sequence was used for simultaneous T1 and T2 sensitivity. The repetition time was 4.2ms and 30 single-shot acquisitions of 32 read-outs each were acquired, resulting in 4.5s of scanning. An adiabatic inversion pulse (10.24ms) was applied before the train of acquisitions. Given that the alteration of FA prevents the spins from reaching steady state, two approaches were tested for the excitation RF pulses' flip angles (FA) (Fig. 1A). In FA1 approach, the FA was altered randomly for each k-space, while in the second one, the FA changed across each RF pulse in a sinusoidal varying pattern (FA2). The computer model was divided into 480 voxels, with 1 isochromat each. The parameters T1, T2, PD, transmit amplitude, receiver and transmitter phase and off-resonance were estimated for each voxel. In total, 2880 parameters were optimized using the open-source package IPOPT [3]. Gradients of the objective function were computed using an adjoint formulation [4] (Fig.1B). The optimization was studied over 100 iterations. All experiments were run on a GeForce RTX 3090 graphics processing unit (NVIDIA).

III. RESULTS

Each simulation lasted 2.4 s and the adjoint gradient estimation 8 s per iteration. The optimization process lasted 40 minutes. The reconstructed parameter maps, using FA1, are shown where the estimated T1 percent error was -0.002±0.11 while for the T2 and PD the percent errors were 0.05±0.52 and 0.02±0.3 respectively (Fig.2A). FA2 was more accurate for estimating T2 values while FA1 for T1. FA1 required 50 iterations to achieve comparable T2 error (Fig.2B).

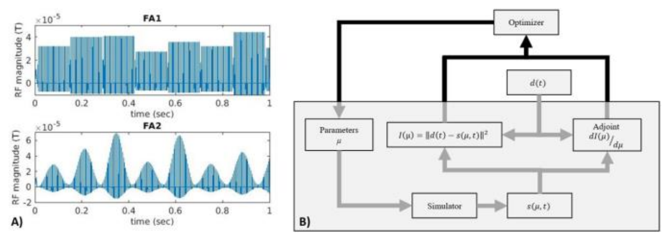

Figure 1. (a) The two approaches for the excitation RF pulses' flip angles, (b) the overview of the simulation based reconstruction approach.

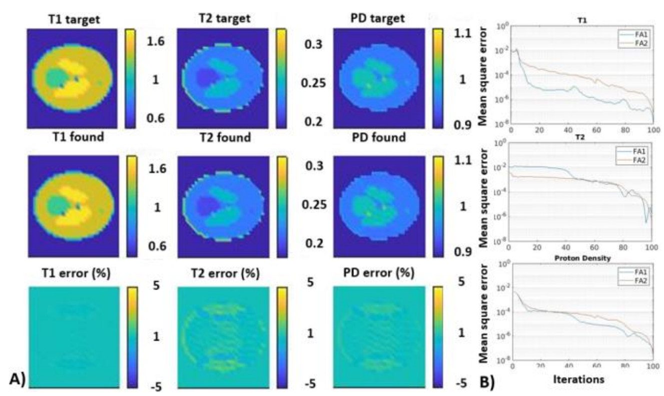

Figure 2. (a) Target, reconstracted and error maps for T1, T2 and PD, (b) mean square error per iteration for FA1 and FA2.

IV. DISCUSSION & CONCLUSION

We found adjusting the FA in optimization-based parameter estimation can influence accuracy, precision and convergence rate. Specifically, FA1 design leads to lower function value error while better T2 convergence required fewer iterations in FA2. This shows that pulse sequence design is an important aspect of simulator-based parameter estimation.

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