

# Signal-to-noise ratio optimization for radial acquisition in 23-sodium magnetic resonance imaging

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## Introduction

Sodium MRI is characterized by lower signal-to-noise ratio (SNR) compared to conventional 1H MRI due to the relatively low abundance of sodium nuclei. Therefore, optimizing sequence parameters is vital. Repetition time (TR) and flip angle (FA) strongly influence the acquired signal amplitude, leading to a trade-off between SNR, specific absorption rate (SAR), and total acquisition time (TA). Conventionally, such optimum is achieved for a particular value of T1 and TR via choosing the Ernst angle as the excitation FA. Such approach disregards SAR considerations and practical considerations of TA. The objective of this study is to determine the optimal set of parameters that maximizes SNR while keeping SAR and TA within acceptable limits.

## Methods

The signal intensity (S) for a spoiled gradient echo acquisition, expressed in Eq.1 in Fig.1, describes the dependence of the signal on TR, FA, and T1 relaxation time [1]. If radial acquisition is employed, the image SNR is proportional to S and to the square root of the number of projections in k-space (Np) (Eq.2 in Fig.1). This signal model involves multiple interdependent parameters, making direct optimization difficult. To address this, constraints can be introduced via TA and SAR. TA can be expressed as the product of Np and TR (Eq.3 in Fig.1), The relationship between SAR, FA, and TR is given by Eq.4 in Fig.1. FA and Np can thus be expressed as functions of TR. This reduces the SNR model to a function of TR only (Eq.5 in Fig.1). The SNR can then be optimized with respect to TR using numerical optimization.

To experimentally verify the possibility of this optimization, scans with density-adapted 3D radial sequence [2] were performed on a homogeneous phantom with T1 of 50 ms in a 7T Siemens Terra scanner using Rapid Biomedical 1H-23Na head-only birdcage coil. To verify the relationship between SAR, FA, and TR experimentally, phantom images were acquired with varying TR (Fig.2a) and FA (Fig.2b). Finally, acquisitions were made with different Np, keeping the other sequence parameters constant (Fig.2c). Then the optimal TR was determined by maximizing the SNR. For the TA value of 6:13 min and SAR value fixed at the IEC limit of 3.2 W/kg head SAR [3], the corresponding optimal FA and Np were derived from the imposed constraints. These optimized parameters were then used in the acquisition, alongside four non-optimal acquisitions acquired with the same TA and SAR.

## Results

Phantom scans confirmed the relationships between SAR, Np, FA, TR, and SNR. SAR was confirmed to vary quadratically with flip angle (Fig.2b) and inversely with TR (Fig.2a). SNR followed the expected dependence on the square root of Np (Fig.2c).

Numerical optimization found the TR maximizing SNR under the two constraints, from which the optimal FA and Np were derived. TR, FA and Np were 25ms, 38° and 14698 projections, respectively. The resulting theoretical and experimental SNR values are illustrated in Fig.2d with optimal theoretical constrained SNR reaching 93.8% of the SNR expected at the same TR and TA with Ernst angle (53°) acquisition.

## Discussion

Conventional SNR optimization methods in MRI are commonly based on the spoiled steady-state signal equation [4] where the optimum is provided by the Ernst angle. However, these approaches are not always practically applicable. In this work, introducing constraints on SAR and TA enabled a practical optimization of the sequence parameters while maintaining realistic acquisition conditions.

The proposed work showed that SNR optimization can be reduced to the optimization of a single parameter, TR, from which the corresponding optimal FA and Np can be derived. The experimental results demonstrated a good fit between the theoretical model and phantom measurements. The optimal parameters provided significant SNR improvement compared with suboptimal acquisitions. The results also showed that the optimization is particularly effective for short TR values (5–100ms). For longer TR values, the reduction in the Np required to maintain a fixed TA leads to a rapid decrease in SNR, making these acquisitions less efficient. Additionally, for longer TR, SAR restrictions are alleviated and Ernst angle acquisitions become more favorable.

Although the present study was performed on phantoms, the proposed method could be applied *in vivo* and may help improve the quality of sodium imaging acquisitions in clinical and research applications.

## Conclusion

The practical framework presents a sequence parameter optimization in  $^{23}\text{Na}$  MRI under SAR and acquisition time constraints. By modeling the relationships between SAR, TR, FA, Np, and SNR, the optimization problem was reduced to a single-variable numerical optimization. These results demonstrate the potential of the proposed method to improve sodium MRI acquisition efficiency and image quality.

# Data and Code Availability Statement

Code on SNR optimization is available on

[https://github.com/CyclotronResearchCentre/SNRoptim\\_23NaMRI/tree/main](https://github.com/CyclotronResearchCentre/SNRoptim_23NaMRI/tree/main)

## References

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$$S \propto \frac{1 - e^{-TR/T_1}}{1 - \cos(FA)e^{-TR/T_1}} \sin(FA) e^{-TE/T_2^*} \quad (1)$$

$$SNR \propto S \sqrt{N_p} \quad (2)$$

$$TA = N_p \cdot TR \quad (3)$$

$$SAR \propto \frac{FA^2}{TR} \quad (4)$$

$$SNR(TR) \propto \frac{\sin\left(\sqrt{SAR \cdot TR}\right) (1 - e^{-TR/T_1})}{1 - \cos\left(\sqrt{SAR \cdot TR}\right) e^{-TR/T_1}} \sqrt{\frac{TA}{TR}} \quad (5)$$

Figure 1: Theoretical derivation of constrained SNR optimization.

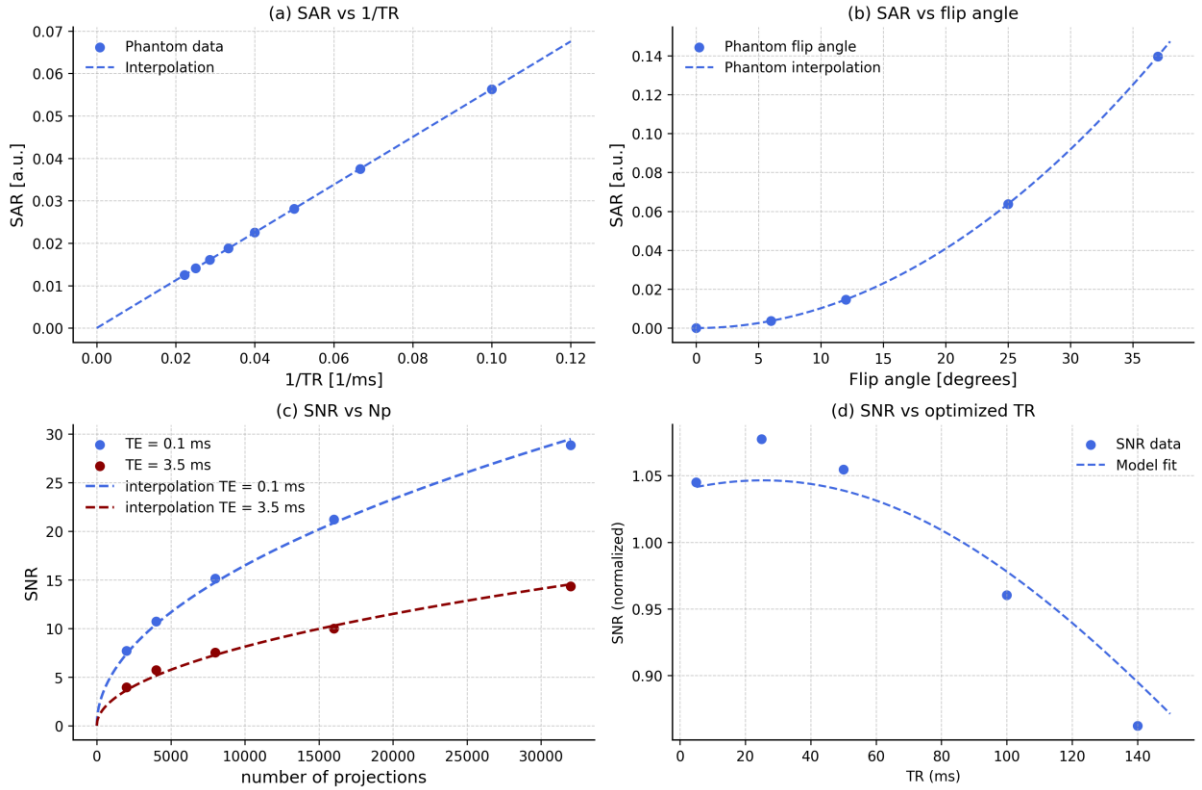


Figure 2: Phantom measurement fitting results. a) SAR values as a function of the 1/TR used. b) SAR value as a function of the applied FAs. c) SNR value as a function of the number of projections used. d) Observed and theoretical SNR as a function of TR, normalized to the mean of observed SNR values.

