# 2D Radial Sodium MRI using VERSE

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## Introduction:

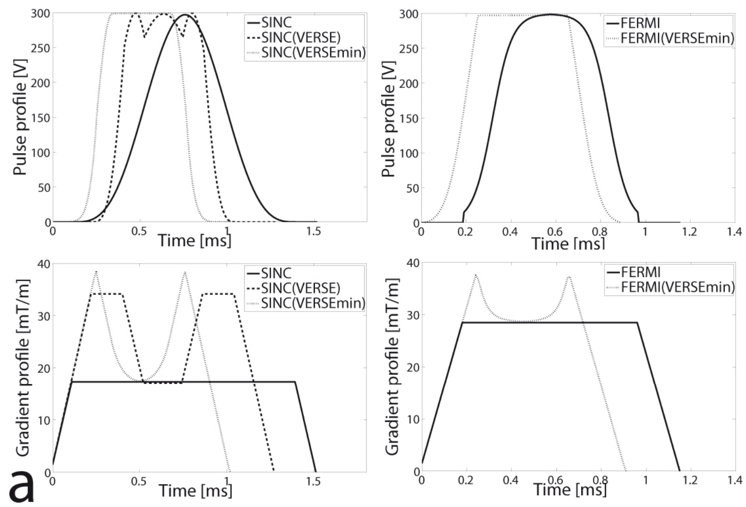
Minimal echo times are required for sodium MRI with a fast biexponential transversal decay ($T_{2f}^* \approx (0.5–4)$ ms and $T_{2s}^* \approx (15–30)$ ms, [1]). Density-adapted 2D radial imaging [2] is preferred for heart and cartilage measurements enabling anisotropic voxel sizes. The RF pulse duration is limited by gradient slew rate, amplitude, and RF peak power. The latter is the limiting factor for high flip angles and/or high reference voltages (e.g. of abdominal coils). The minimal necessary RF pulse duration was investigated, depending on flip angle and reference voltage of the coil. Therefore, sinc waveforms with two different VERSE approaches (cf. Fig. 1a left) were used. A Fermi pulse (cf. Fig. 1a right) with simple gradient and RF pulse design is proposed to further decrease the pulse duration. Sodium heart measurements are shown to demonstrate SNR changes in myocardium due to different minimal echo times.

## Methods:

Measurements were performed on a 3 T whole-body MR scanner (Magnetom Tim Trio, Siemens Healthcare, Erlangen, Germany) with a double-tuned ($^1H/^{23}Na$) birdcage head coil for slice profile measurements and a surface transmit/receive array (both: Rapid Biomedical GmbH, Würzburg, Germany) for heart measurements. Maximum allowed slew rate and gradient amplitude of the scanner were 170 T/(m s) and 40 mT/m. A conventional sinc-shaped RF pulse was used with a slice thickness of 8 mm, a time-bandwidth product of two, and an apodization using a Hanning filter. A two-speed VERSE RF pulse [3] and a time-optimal VERSE algorithm [4] were used. A Fermi pulse with following shape $B_1(t) = (1+\exp((|t|-a)/b))^{-1}$ was implemented, which possesses nearly the same energy transfer efficiency as a rectangular RF pulse but without strong sidelobes (in the slice profile) due to a smoother drop to zero. The parameters were chosen to be $a \approx 0.34$ and $b \approx 0.056$ (cf. Fig. 1b). The RF transmitter voltage is proportional to the product of reference voltage and flip angle. Simulations of pulse durations were performed depending on that product for two transmitter voltages. SAR values were calculated as the time integral over $B_1^2(t)$. Radial imaging was performed with following parameters: TR = 40 ms, FA = 65°, readout time = 10 ms, projections = 640, 16 averages resulting in a total scan time of about 10 min considering ECG-triggering.

## Results:

The minimal pulse lengths are shown in Fig. 2a for a slice thickness of 8 mm. For higher allowed transmitter voltages, the pulse duration is shorter if it is limited by RF peak power constraints, while its duration is equal for small flip angles and/or reference voltages where it is limited by hardware gradient constraints. Normalized SAR values of these different RF pulses are shown in Fig. 2b. Simulated SNR gains are shown in Fig. 2c for three fast relaxation times $T_{2f}^*$ (60 % fast component, 40 % slow component with 25 ms). The highest SNR benefit (16.9 %) is reached if the pulse duration (plus slice rephaser) is in the order of $T_{2f}^*$. SNR measurements of blood result in nearly the same values of 20.2, 20.5, and 20.8 for 2D with SINC and SINC(VERSEmin) and 3D imaging (cf. Fig. 3). Therefore, the real voxel size should be about the same considering the intrinsic broadening of 2D and 3D radial sequences [5]. The SNR advantage of SINC(VERSEmin) over SINC is 7.5 % in myocardium due to different echo times (1.54 ms/2.08 ms). The shortest echo time (0.55 ms) is obtained by 3D imaging.



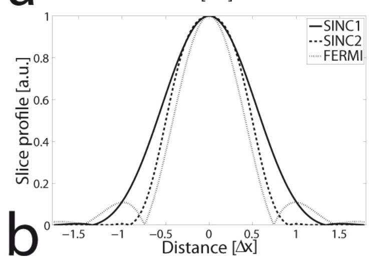
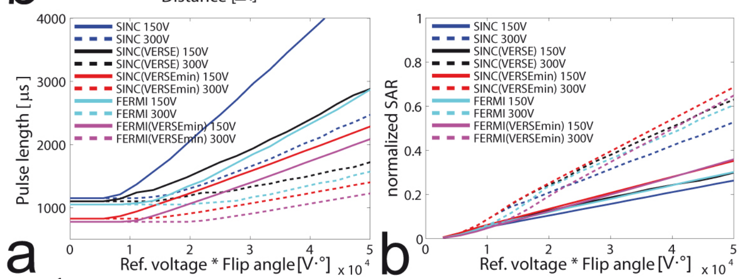




FIG. 1. ***a:*** *RF pulse and gradient profiles for sinc excitation and two different VERSE methods (left) and for Fermi-shaped pulse profiles (right).* ***b:*** *Simulated slice profiles for sinc excitation with time-bandwidth product of two (SINC1) and four (SINC2) and Fermi excitation (FERMI).*



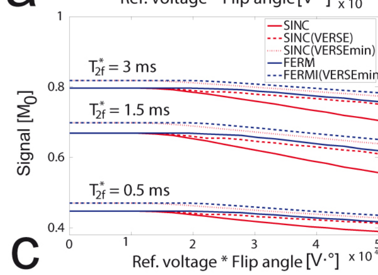
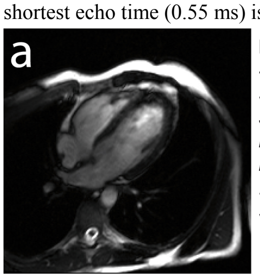




FIG. 2. ***a:*** *Minimal pulse durations dependent on the reference voltage, applied flip angle, and maximum allowed transmitter voltage.* ***b:*** *Normalized SAR values for these different RF pulse schemes.* ***c:*** *Simulated SNR gain for three different fast relaxation components of sodium (60% fast and 40% slow component with 25ms). A slice rephaser duration of 600µs is assumed.*



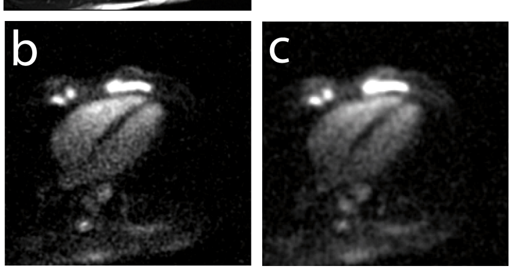




FIG. 3. ***a:*** *Proton localizer in 4-chamber view. 2D (b) and 3D (c) sodium images with similar SNR values of blood but different echo times and nominal resolutions.*
*2D: 2.92 x 2.92 x 8 mm$^3$*
*3D: 3.6 x 3.6 x 3.6 mm$^3$*

## Discussion and Conclusion:

If the RF pulse duration of slice-selective excitation is limited by RF peak power constraints, the pulse duration can be strongly decreased (cf. Fig. 2a) using time-optimal VERSE algorithms or other RF pulse shapes such as Fermi pulses (cf. Fig. 1). If abdominal coils with high reference voltages of 600 V–1200 V are used for sodium heart measurements, slice-selective RF pulse durations can be decreased to the order of 3D rectangular pulses. Fig. 2 provides information about the efficiency of different RF pulse types, dependant on the coil geometry, subject, applied flip angle, and maximum allowed transmitter voltage. Since repetition times are not limited by SAR constraints, RF pulse durations can be minimized. Otherwise the duration would still be shorter due to the higher energy transfer efficiency of VERSE. The SNR gain in myocardium with 3D imaging is not only caused by TE shortening but also by blurred blood signal due to lower in-plane resolution compared to 2D imaging. Therefore, anisotropic resolutions are preferred for some studies (e.g. heart, cartilage) avoiding partial volume effects.

It was shown that shortening the RF pulse duration leads to a significant SNR increase, especially for short $T_2^*$ components such as myocardium (cf. Fig. 3).

**References:**

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