Towards True Arterial Intracranial TOF-MRA at 7T: Protocol Optimization Using VERSE Pulses

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Introduction

It has been shown that the visibility of the vasculature in time-of-flight (TOF) MR-angiography highly profits from increased field strengths [1-4]. To acquire truly arterial TOF data sets, the MR signal of venous blood is often saturated using spatially selective saturation pulses. Because of SAR limitations, the application of additional saturation pulses is often not possible at higher fields. To stay within the legal SAR limits TRs need to be prolonged, and high resolution MRA data sets cannot be acquired in clinically acceptable acquisition times (TA $\leq$ 10min). To overcome this problem we use the variable rate excitation (VERSE) algorithm [5]. The algorithm is applied to all RF pulses of a TOF MRA pulse sequence including the saturation pulses to measure arterial 3D TOF MRA data sets of the brain at 7 Tesla.

Materials and Methods

The VERSE algorithm takes an existing slice-selective RF pulse, and prolongs those sections of the pulse that are responsible for the majority of the energy deposition. Since SAR is proportional to $\int B_1(t)^2 dt$, these sections are the main lobes of the RF pulse. In parallel the amplitude of the slice selection gradient amplitude is modulated. To utilize the VERSE algorithm for TOF MRA, the following two optimization steps were implemented:

1. *VERSE Flow Compensation:* To minimize flow-related dephasing, the first moment of the new modulated slice selection gradient was compensated (flow compensation). Therefore, the timing and amplitudes of the existing flow-compensating gradients needed to be adapted.
2. *VERSE SAT Pulse:* Using a general implementation of the VERSE algorithm, both the excitation pulse and the saturation (SAT) pulse were subjected to optimization. In the implementation a threshold value for the RF amplitude in units of the maximum original RF amplitude is set.

The TOF MRA pulse sequence with VERSE optimization was implemented on a 7T whole body system (Magnetom, Siemens, Erlangen, Germany) equipped with a 24 channel Rx/Tx head coil (Nova Medical, Wilmington, USA). A 3D FLASH pulse sequence with flow compensation was used with a tilt-optimized non-saturated (TONE) excitation across the slab. TOF MRA of the brain vessels was performed in 3 healthy volunteers and one patient with arteriovenous malformation (AVM) using the following imaging parameters: TE = 3.5 ms, bandwidth = 165 Hz/px, TR = 28 ms, α = 17°, 2 slabs with 44 slices / slab, matrix: 704 × 568 with 0.41 mm slice thickness leading to an average voxel size of 0.31 × 0.30 × 0.41 mm^3. The venous saturation band of 20 mm thickness (α_{SAT} = 90°) was placed on the superior sagittal sinus. Using parallel imaging (GRAPPA, acceleration factor 2) an measurement time of 10 min 35 s could be achieved. In the VERSE algorithm a cut-off threshold of 50% / 20% (TONE/SAT) was used. For comparison images were acquired with and without saturation and the contrast-to-noise-ratio (CNR) of the sagittal sinus was determined.

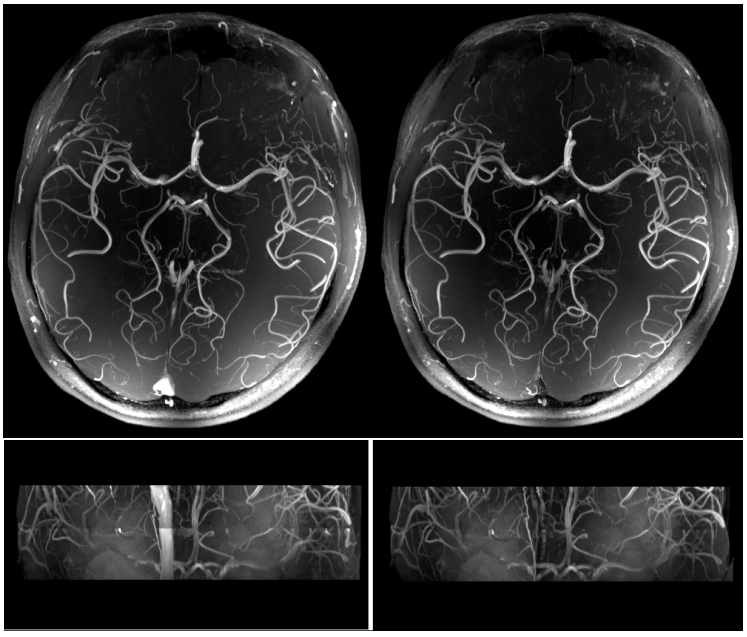

Fig. 1: Axial (top) and coronal (bottom) MIPs showing TOF MRA data with venous saturation pulse (right) and without (left). The suppression of venous signals is particularly visible in the sagittal sinus.

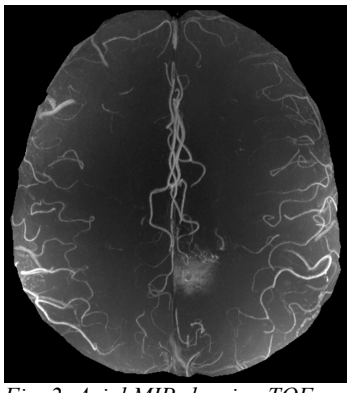

Fig. 2: Axial MIP showing TOF MRA data of the AVM patient (with saturation pulse).

Results and Discussion

Figure 1 shows axial and coronal MIPs of the acquired data where the reduction in CNR of the sagittal sinus by (131 ± 10) % is clearly visible. An application of the modified TOF MRA sequence in clinical routine is presented in figure 2. With the given sequence parameters TOF MRA data could only be acquired with VERSE optimization, as otherwise the legal SAR limits would have been exceeded by 130%. The VERSE algorithm reduced the SAR of the TONE/saturation pulse to approximately 67% / 35% of the original pulse. Nevertheless, even with the VERSE optimization the theoretical minimum TR of 23 ms could not be achieved.

With decreasing VERSE threshold the quality of the slice selection profile of both TONE and SAT pulse decreases. Since the slice profile quality of the SAT pulse is of minor importance, and since the SAT pulse contributes most to the overall SAR of the pulse sequence, this pulse particularly profits from the use of the VERSE algorithm. The measured TOF data show that through the use of the VERSE algorithm truly arterial MRA data sets can be acquired within acceptable total measurement times without perceivable loss of image quality (Fig. 1, Fig. 2).

References

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