Optimization of Venous Saturation Pulses for Time-of-Flight MR Angiography at 7 Tesla

Sören Johst[1,2], Karsten H Wrede[1,3], Mark E Ladd[1,2], and Stefan Maderwald[1]

[1]Erwin L. Hahn Institute for Magnetic Resonance Imaging, University Duisburg-Essen, Essen, Germany, [2]Diagnostic and Interventional Radiology and Neuroradiology, University Hospital Essen, Germany, [3]University Hospital Essen, Department of Neurosurgery, Germany

Introduction:

The visibility of the vasculature in time-of-flight (TOF) MR angiography (MRA) highly profits from increased field strengths [1]. However, the application of saturation pulses for suppression of the venous system is often not possible at 7T: To stay within the regulatory SAR limits, TRs need to be prolonged and high-resolution MRA data sets cannot be acquired in clinically acceptable acquisition times. Here, we use the variable rate selective excitation (VERSE) algorithm for both excitation and saturation RF pulses [2 - 5]. In this way, saturation pulses are applicable in high-resolution TOF MRA protocols, but still lengthen the total measurement time. Thus, saturation pulses were additionally optimized regarding flip angle and duration to meet SAR constraints and minimize total measurement time.

Material and Methods:

All measurements were performed on a 7T whole-body system (Magnetom 7T, Siemens, Erlangen, Germany) equipped with a 32-channel Tx/Rx head coil (Nova Medical, Wilmington, USA). The 3D FLASH TOF high-resolution protocol used flow compensation and tilt-optimized non-saturated excitation (TONE) across the slab. A saturation slab covered the entire area above the imaging slab (≥ 4 cm, gap 2 cm, applied every TR). The duration of the saturation pulses was varied between 1025 µs and 6000 µs to fit the pulses within given TR / SAR limitations. α_{SAT} was varied in steps of 5° from 10° to 60°. In the most superior slice of the imaging slab, the vessel-to-background ratio (VBR) (signal of sagittal sinus to surrounding tissue) was determined; the criterion for sufficient saturation was VBR ≤ 1. Saturation flip angles were optimized for TOF MRA protocols in volunteer scans (n = 7) with TR Є [20, 35] ms and α Є [15°, 25°]. The final clinical protocol [TR = 20 ms, TE = 4.34 ms, flip angle α = 20°, 112 reconstructed slices per slab (an additional oversampling of 14.3% was acquired), GRAPPA R = 4, partial Fourier 6/8 (read/slice), matrix 896 x 756, non-interpolated voxel size 0.22 x 0.22 x 0.41 mm^3, VERSE cut-off thresholds of 50% / 30% (excitation / saturation), α_{SAT} = 35°, and duration of saturation pulse 2.5 ms, resulting in an overall acquisition time per slab of 6 min 22 s] was applied in 23 patients with cerebral aneurysm, arteriovenous malformation (AVM), or Moyamoya syndrome (n = 12 / 7 / 4, respectively).

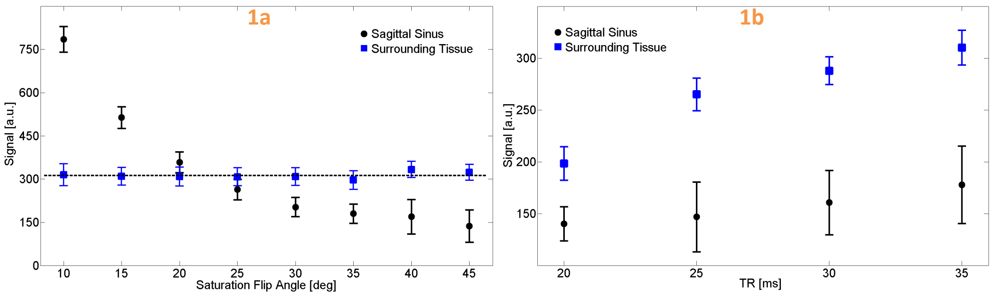

Fig. 1: Signal in sagittal sinus and signal from surrounding tissue:
a) *Variation of the saturation flip angle: for TR = 20 ms and α = 20°.*
b) *Variation of TR for α = 20° and α_{SAT} = 35°.*

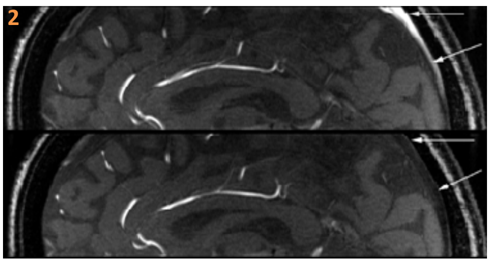

Fig. 2: *Sagittal view of TOF MRA without (above) and with venous saturation (bottom). TR = 20 ms, α = 20° and α_{SAT} = 35°.*

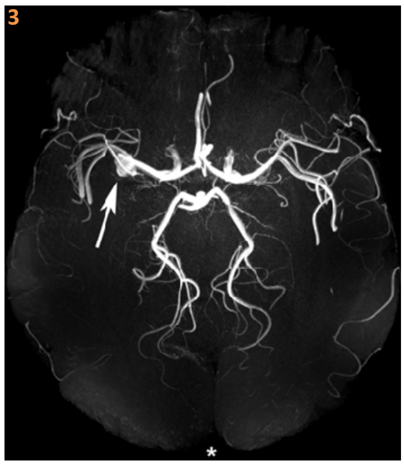

Fig. 3: *MIP of high-resolution TOF MRA using venous suppression (asterisk) showing aneurysm (arrow). TR = 20 ms, α = 20° and α_{SAT} = 35°.*

Results:

The fastest volunteer scans (TR = 20 ms) with α = 20° showed that saturation flip angles higher than α_{SAT} = 25° led to signals in the sagittal sinus smaller than the signal of the surrounding tissue (Fig. 1a). Therefore, α_{SAT} = 35° was chosen to assure that saturation would work for different head sizes and shapes. On average, a VBR of 0.53 ± 0.03 was achieved across the 23 patient exams (highest value 0.78 ± 0.22). No venous overlay was visible in any of the measurements (Fig. 2 bottom, Fig. 3). For α Є [15°, 35°], the determined optimal α_{SAT} = (α + 15°) was valid over a range of TR Є [20, 35] ms (Fig. 1b).

Discussion:

By optimizing the flip angle α_{SAT}, saturation pulses can be applied in a high-resolution clinical protocol using a short TR of 20 ms. Also, by making the duration of the saturation pulses a parameter that can be changed online, more flexibility in protocol creation was gained. As the highest measured VBR was about 0.8, the chosen α_{SAT} = 35° could be validated. An α_{SAT} = (α + 15°) is sufficient for suppression of the venous system in TOF MRA protocols in the parameter range α Є [15°, 35°] and TR Є [20, 35] ms, which is the range normally used at 7T [1, 5 - 7]. Instead of the standard 90° saturation pulse, only half the flip angle (or even less) is necessary, substantially ameliorating SAR constraints and enabling acquisition of high resolution in acceptable imaging time.

References: [1] Maderwald MAGMA 21:159-167 (2008); [2] Conolly JMagReson 78:440-458 (1988); [3] Johst ISMRM 2010, 2252; [4] Schmitter ISMRM 2010, 4424; [5] Schmitter MRM 2011 (in press); [6] von Morze MRI 26:1329-1333 (2008); [7] Hendrikse JMRI 28:1519-1526 (2008).