Contrast Enhancement in TOF cerebral angiography at 7 Tesla under SAR constraints: trading between Saturation, VERSE and Magnetization Transfer RF pulses.

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INTRODUCTION. It has been shown that 3D time-of-flight (TOF) cerebral angiography can be obtained at 7T[1-2]. However, because of SAR limitations it is not possible to apply standard approaches often used at lower field to further suppress undesired signals, namely Saturation pulse (SAT) to target veins, and Magnetization Transfer (MT) to target background tissues. The goal of this work is to demonstrate TOF contrast enhancement at 7T using MT and/or SAT pulses without exceeding SAR limitations. For this purpose the VERSE principle was applied on excitation and SAT pulses [3,4], while MT pulses were only applied during a subset of k-space lines closest to the k-space origin. Furthermore, we investigated the background signal suppression obtained when applying SAT pulses for vein signal suppression. Our results indicate that VERSE SAT and sparse MT pulses successfully increase TOF contrast at 7T without exceeding SAR limits. Our finding also emphasize the MT effect carried by SAT pulses at 7T, which contributes to a greater flexibility in contrast versus SAR management.

Table 1: *SAR for different VERSE RF amplitude settings and number of MT pulses in k-space. κ_{SAT}=1/κ_{EXC}=1 are equivalent to no VERSE. Blue lines correspond to settings used in Fig. 2*

Excitation κ_{EXC}	Saturation κ_{SAT}	MT N_{MT}/N_{TOT}	SAR in % of MAX_{SAR}
1.0	1.0	100 %	319 %
1.0	1.0	off	115 %
0.5	1.0	off	108 %
0.5	off	off	11 %
0.5	off	9 %	31 %
0.5	0.25	off	49 %
0.5	0.25	9 %	69 %
0.5	0.25	24 %	100 %

METHODS. Healthy volunteers who signed an IRB approved consent form were imaged at 7T (Siemens, Germany), using a 16 channel transceiver coil. A VERSE algorithm [4,5] was implemented for excitation and travelling venous SAT pulses. The max amplitude of VERSE RF pulse was set to a fraction κ_{EXC} (or κ_{SAT}) of the max amplitude of initial excitation (or SAT) pulse. (VERSE was applied to all SAT pulses used in experiments). Initial pulse durations (T_{EXC}=1.5ms, T_{SAT}=3.8ms) were maintained, gradient slew rate was ≤100T/m/s. MT was applied sparsely [6], only during the N_{MT} centered k-space lines in phase (PE) and slab (SL) direction out of N_{TOT} total k-space lines. 3D TOF data were acquired with a) the original sequence with κ_{EXC} =1.0 (no VERSE) without venous SAT and without MT, and b) a modified sequence with κ_{EXC} =0.5, with venous SAT (κ_{SAT}=0.25) and with MT applied for N_{MT}/N_{TOT} =~9% of k-space lines. Imaging parameters: TR/TE=33ms/3ms, 4 slabs (24mm thickness), overlap: 25%, FOV=220x172x78mm^3, resolution=(0.5)^{3}mm^3, Grappa=3 (PE), partial fourier=6/8 (SL). SAR was expressed as % of the regulatory limit (SAR_{MAX}) for different RF pulsing schemes. MIP maps were generated in axial (full), sagittal and coronal (40mm thick) views. To compare the impact of SAT and MT on TOF contrast, an arterial Vessel to Background Ratio (aVBR) was computed in 3 more subjects (single slab, κ_{EXC}=0.5) by dividing signal intensity in the basilar artery by surrounding background signal. Similarly, a venous Vessel to Background Ratio (vVBR) was used to quantify venous signal suppression by dividing sagittal sinus signal with background tissue signal close to the sagittal sinus.

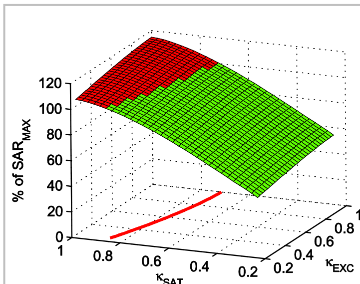

Fig.1: *SAR in % of SAR_{MAX} as a function of κ_{EXC} and κ_{SAT}.*

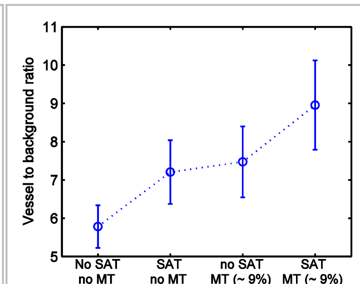

Fig.2: *aVBR determined in basilar artery with and without* MT, *with and without* SAT.

RESULTS. Fig.1 shows SAR as a function of κ_{EXC} and κ_{SAT}, with SAT_{MAX} indicated as a red line. Non-VERSE SAT pulses could not be used without exceeding SAR limits, as also shown in Table 1 listing SAR values for different pulse schemes. Fig. 2 shows the impact of using MT and/or SAT pulses on VBR based on in-vivo data. Interestingly, when using SAT only, the VBR increased by a similar amount than with sparse MT only, likely due to MT effects reported with SAT pulses [7]. SAR increases by 20% if only MT is used (N_{MT}/N_{TOT}=9%) and by 39% if SAT is used. Using both SAT and MT, the aVBR increased by 56% compared to using neither of the two pulses, while SAR increased from 11% to 69% of SAR_{MAX}.The corresponding gain in TOF contrast can clearly be appreciated on MIP images shown in Fig.3. When applying SAT and spare MT, venous signals are efficiently suppressed, as exemplified in the sagittal sinus, where the vVBR decreases from 3.8 to 0.4. Background signal suppression is enhanced facilitating small vessel visualization. A dramatic reduction in subcutaneous fat signals is a beneficial side effect of the relatively low VERSE gradient amplitude used in SAT pulses, resulting in a spatial shift of concomitant fat suppression that overlaps with the skin of the imaged slab [8], as long as appropriate gradient polarity is used.

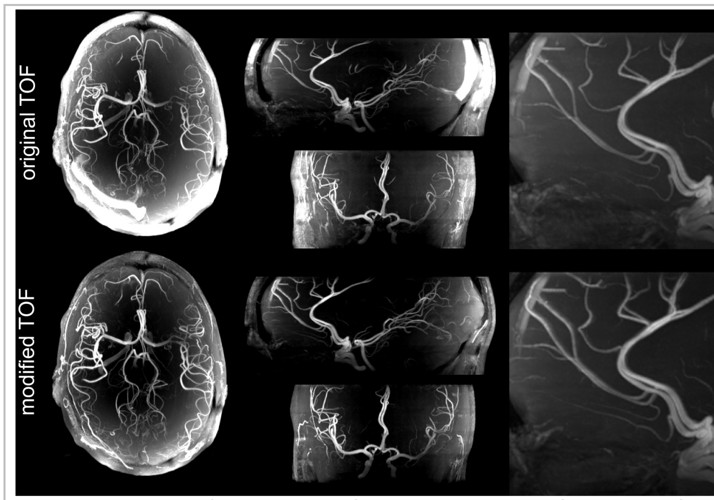

Fig.3: *MIP images of the original TOF (top) without VERSE, venous SAT or MT and the modified TOF sequence (bottom) with venous SAT and with MT.*

DISCUSSION.
In this report we demonstrate that significant gains in contrast and image quality (signal attenuation in veins, in background tissue and in subcutaneous fat; better visualization of small vessels) can be achieved in cerebral TOF at 7T by applying the VERSE principal to Excitation and Saturation pulses and by limiting the use of Magnetization Transfer pulses to a fraction of k-space coverage; we also show that both SAT and MT pulses contribute to background signal suppression. By contrast, with a standard sequence SAT and MT pulses could not be used because of SAR limitation, resulting in suboptimal vessel to background contrast. Even though the value or κ_{EXC} was not lowered below 0.5 to avoid excitation profile distortion due the intrinsic sensitivity of VERSE pulses to ΔB_0 [4,5], it was possible to substantially improve angiogram quality using RF pulse combinations that did not exceed 69% of SAR_{MAX}.

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