Segmented TOF MRA with Reduced Venous Saturation Pulses to Decrease SAR at 3T and 7T

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Purpose:

Time-Of-Flight (TOF) MR angiography has exhibited considerable improvement in image quality at very high and ultra-high magnetic fields because of the higher signal-to-noise ratio (SNR) and longer T1 relaxation time [1]. However, the specific absorption rate (SAR) of RF pulses increases quadratically with the magnetic field strength. A major contributor to SAR can be the tracking saturation pulse which is used to suppress venous signal in the TOF sequence. As such, saturation pulses are often omitted for human scans at 7T in order to stay within the SAR limit, leading to venous contamination in the TOF angiograms. We report a SAR-reduction technique by reducing the duty cycle of the saturation pulse with a segmented TOF sequence at 3T and 7T. Compared with the conventional TOF sequence, the segmented TOF sequence uses a considerably fewer number of saturation pulses, leading to SAR reduction.

Methods:

In conventional TOF sequences, one venous saturation pulse is applied before each excitation pulse (Fig. 1a). In our modified TOF sequence, the saturation pulse was applied for a group of excitation pulses. For example, one saturation pulse was applied for every 5 excitation RF pulses to reduce the SAR (Fig. 1b). In addition to SAR reduction, the segmented TOF sequence also provided more flexibility on protocol optimization, e.g., using a larger flip angle or shorter TR to improve the image contrast or reduce the total scan time.

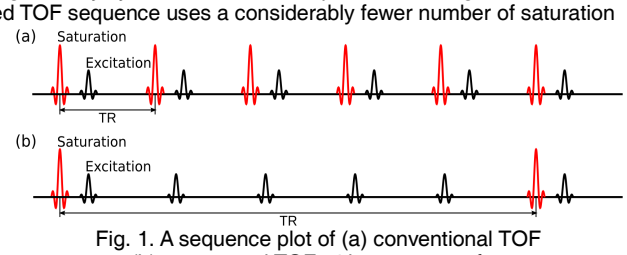

Fig. 1. A sequence plot of (a) conventional TOF (b) segmented TOF with segments of 5.

The segmented TOF sequence with venous saturation was implemented on a Siemens 3T Tim Trio scanner and a Siemens 7T Magnetom whole-body scanner. With the approval of the local Institutional Review Board (IRB), healthy volunteers were scanned on these scanners using segmented TOF and conventional TOF for comparison. For the scans at 3T, the segmented TOF sequence employed 5 excitations following each saturation pulse with a segment-to-segment TR of 80ms, while the conventional TOF sequence included a venous saturation pulse for each excitation. Other parameters for the two sequences were identical (FA=15°, TE=3.69ms). For the scans at 7T, the flip angle of saturation pulses was reduced, and duration was prolonged to further reduce SAR. Key acquisition parameters at 7T are listed in Table 1. Different number of segments was analyzed, including the conventional TOF (i.e., number of segment = 1). At both field strengths, the vessel-to-background-ratio (VBR) of segmented TOF and conventional TOF were computed and compared.

Results:

At 3T, the venous suppression effect of segmented TOF was similar to that of the conventional TOF. Venous VBR (vVBR) of segmented TOF was 0.63, which was not significantly different from vVBR of conventional TOF (0.62). Moreover, arterial VBR (aVBR) in segmented TOF was comparable to that of conventional TOF (3.87 vs. 3.72). With the segmented TOF, the reduced number of saturation pulses resulted in an 18% reduction in acquisition time (5'40" vs. 4'39"), while SAR was well within the safety limit.

At 7T, SAR of conventional TOF with saturation pulses was too high for human scan (361%, little variations among individuals).Therefore, the conventional saturation pulses cannot be employed for venous suppression. With the increased length of segments, the segmented TOF sequence resulted in a remarkable decrease of SAR (361%->174%->87%, from segments of 1->5 ->9). Within the safety limit, the substantially reduced SAR allowed for shorter TR, shorter acquisition time and higher aVBR, as shown by experiments No. 4 and No. 6 in Table 1.

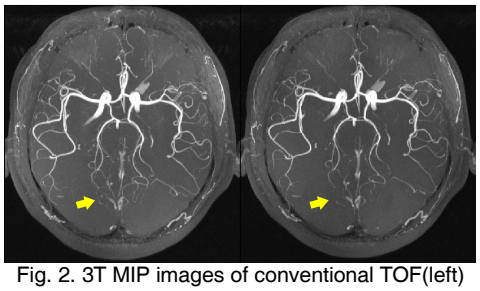

Fig. 2. 3T MIP images of conventional TOF(left) and segmented TOF(right).

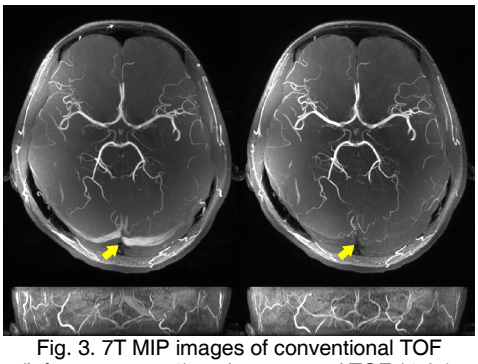

Fig. 3. 7T MIP images of conventional TOF (left, segments=1) and segmented TOF (right). with segments of 9 (right, No. 6 in Table 1).

Discussion:

Our results at 3T demonstrate that saturation pulses can be reduced with segmented TOF, without compromising venous suppression efficiency. The higher segment numbers, the shorter total acquisition time. In this study, the segment number can be up to 9, while vVBR is still at an acceptable level. Our experiment at 3T also indicates that the effective TR (the interval between excitations) should not be less than 15ms, with a FA of 15° . Shorter TR can lead to the saturation of tiny arteries, whose signal might be too weak to appear on MIP images, as shown by yellow arrows in Fig. 2.

Venous blood at higher magnetic field has a longer T1 relaxation time [3], which can be taken advantage of to reduce the number of the saturation pulses at 7T. In this study, a long segment length of 9 was used to further reduce the SAR without compromising the venous saturation efficiency, as shown by yellow arrows in Fig. 3.

Conclusion:

Our study demonstrated that a segmented TOF sequence with saturation pulse performs equally well as compared to a TOF sequence with conventional venous saturation. This segmented approach can considerably reduce SAR, making it possible to perform vein-suppressed TOF at 7T. Compared with the conventional method of venous suppression, this technique also offers more flexibility on protocol optimization, including shortening of the total acquisition time. The proposed approach eliminates a major obstacle to perform TOF MR angiography at 7T.

References:

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Table 1. Parameters and results of conventional TOF and segmented TOF at 7T *: not applied in scanning

No.	Segments	TR	FA	Duration and FA of Saturation Pulses	SAR	Acquisition Time	aVBR	vVBR
1	1	20ms	23°	3.48ms, 90°	361%*	2'33"	-	-
2	1	20ms	23°	-	67%	2'33"	3.80	3.43
3	5	100ms	23°	3.48ms, 90°	174%*	2'33"	-	-
4	5	67ms	23°	4.86ms, 50°	100%	1'44"	5.08	1.14
5	9	180ms	23°	3.48ms, 90°	87%	2'33"	3.69	0.60
6	9	116ms	23°	5.89ms, 70°	100%	1'39"	5.05	1.08