Time-of-flight angiography in humans at 9.4T

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Introduction: Time-of-flight (ToF) angiography at ultra-high magnetic field strengths benefits from long tissue T_1 times that lead to a suppressed tissue background. On the other hand, SAR restrictions impose a limit on the actual flip angle that can be used. In the present study we explored the possibility to perform ToF measurements at 9.4T.

Materials and Method: Five subjects (age: 24-46y) volunteered to participate in the study, approved by the local ethics committee. MRI was performed at 9.4T (Magnetom, Siemens Healthcare Erlangen, Germany) equipped with head only gradients. A 16ch transmit array was used for transmission in CP-mode [1] and a 31 channel array for signal reception [2]. ToF imaging was performed slab-wise (2.4cm axial FOV) with a 3D gradient echo sequence, TR=20ms; GRAPPA 4/32 reference lines, voxel= 0.5x0.5mm; varying TE (3.8; 4.55; 10ms), slice thickness (0.4; 0.6mm), flip-angle (FA= 15-36°); duration of the excitation pulse (1024-4096µs). The acquisition time for each slab was between 1 ½-3 ½ min. Post-processing consisted of removal of scalp using BET (Brain Extraction Tool, FSL), and Maximum Intensity Projections across 40mm. The transverse signal component after N pulses (Fig. 1) was calculated from:

$$M_N = sinFA \cdot \left[M_{ss} + \left(e^{-TR/T_1} \cdot cosFA\right)^N \cdot (M_0 - M_{ss})\right],$$

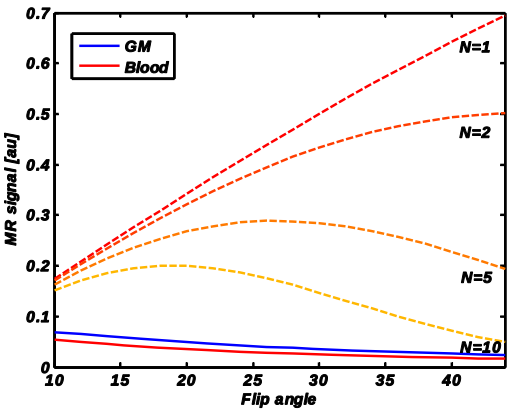

Fig. 1 Steady state MR signal as a function of FA for GM (T_1= 2.0s, blue) and blood (T_1= 2.9s red solid line) with a TR=20ms. The blood signal after N excitations is also shown (dotted).

M_{SS} and M_o are the steady state and initial magnetizations, respectively. T_1 times in Grey matter (GM) and blood at 9.4T were extrapolated [3].

Results and Discussion: Blood signal saturation occurs when the blood remains in the imaging slab for more than one TR and depends on the number of excitations (Fig.1). Assuming a velocity of 5-10cm/s, the blood traverses 0.5-10cm within 100-200ms. Therefore a reasonable FA value is 20-30° at 9.4T to avoid saturation of slowly flowing blood. Due to longer T_1 times at high field, the background suppression at 9.4T compared to 3T is ca 50% greater. The improved contrast-to-background ratio that we expected was hampered by SAR restrictions. Even in absence of suppression of the venous blood or magnetization transfer pulses, small flip angles of 14-16° yielded a SAR of 95-99% and poor image contrast (Fig.2A). By increasing the RF pulse duration from 1024 to 3072µs (4096µs) the maximal FA was 24° (32°), yielding an improved visibility of the arteries, and strong signal in the sagittal vein (Fig 2B). At 9.4T, the T_2 in arterial blood is similar to tissue (ca 40ms) while in venous blood it is substantially shorter (5-9ms dependent on the fractional oxyhemoglobin content, [4]). We found that lengthening the TE from 4.5 to 10ms was sufficient to suppress the venous blood in the sagittal sinus, without substantially compromising the visibility of the arteries (Fig. 2C).

References: [1]Shajan G et al., Proc. Intl. Soc. Mag. Reson. Med. 2 0 (2012): 308; [2]Shajan G et al., ESMRMB (2012) 351; [3]Rooney WD et al., MRM 57:308 (2007); [4] Lee et al., MRM 42:919 (1994)

Fig. 2. Maximum Intensity Projections across 40mm for axial (left) and sagittal multi-slab 3D ToF data sets acquired with FA/TE: A) 14°/4.55ms; B) 24°/4.55ms; C) 24°/10ms