High-resolution clinical 7T protocol for the depiction of cerebral vascular structures

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Introduction: High-quality pre-operative / pre-interventional images are essential for the treatment of intra-cerebral vascular pathologies. Digital subtraction angiography (DSA) is still the gold standard of the available imaging modalities, but with new ultra-high field MRI scanners, MR angiography (MRA) has the opportunity to become even more competitive. Especially the visibility of the vasculature in time-of-flight (TOF) MRA highly profits from increased field strengths [1]. The goal of this study was therefore to set up a 7T whole-brain examination protocol within a clinically acceptable overall acquisition time. Main targets of optimization were high-resolution TOF MRA and susceptibility-weighted imaging (SWI) data sets for the evaluation of the arterial and venous systems, respectively. For the TOF, the variable rate selective excitation (VERSE) algorithm [2-4] was used to ameliorate SAR restrictions.

Material and Methods: A 7T whole-body system (Magnetom, Siemens, Erlangen, Germany) equipped with a 32-channel Rx/Tx head coil (Nova Medical, Wilmington, USA) was used. The following modifications in sequence source code were enabled in all sequences: GRAPPA acceleration factors up to R = 8 in phase-encoding direction (2D), doubling of the number of acquirable slices. The VERSE algorithm was applied to the excitation pulses of the TOF sequence [2, 3]. In the MP-RAGE sequence the water sensitive inversion recovery (IR) RF pulse was replaced by a water-fat sensitive pulse with higher bandwidth. The clinical whole-brain protocol was optimized in 5 healthy volunteers and performed in 11 patients with cerebral aneurysm (N=5), arteriovenous malformation (AVM) (N=3), or Moyamoya syndrome (N=3). The protocol consisted of:
MP-RAGE: TR = 2500 ms, TE = 1.75 ms, TI = 1100 ms, TA = 4 min 58 s, GRAPPA R = 4, α = 8°, bandwidth = 570 Hz/px, 512 slices per slab, matrix 512 x 448, voxel: 0.53 x 0.53 x 0.53 mm^3. 3D SWI: TR = 29 ms, TE = 15 ms, TA = 13 min 34 s, GRAPPA R = 2, α = 15°, bandwidth = 160 Hz/px, 104 slices per slab, matrix 896 x 672, voxel: 0.25 x 0.25 x 1.5 mm^3. 3D FLASH TOF: flow compensation, tilt-optimized non-saturated excitation (TONE) across slab, TR = 26 ms, TE = 5.1 ms, TA = 8 min 16 s per slab, GRAPPA R = 4, α = 25°, bandwidth = 95 Hz/px, 112 slices per slab, matrix 896 x 758, voxel: 0.22 x 0.22 x 0.41 mm^3, VERSE cut-off threshold: 50%. 3 slabs (independent acquisitions, overlap 10 slices) to cover the entire brain were merged via weighted overlapping (Fig. 1) into a final 316 slice 3D dataset (Software FSL for CentOS; fmrib, Oxford, UK) using the OsiriX DICOM viewer (Pixmeo, Geneva, Switzerland) for MIPs and volume rendering. 2D TSE: TR = 6000 ms, contrasts = 2 (TE1 / TE2 = 11 / 95 ms), TA = 4 min 24 s, GRAPPA R = 2, α = 129°, bandwidth = 257 Hz/px, 43 slices, matrix 512 x 384, voxel: 0.5 x 0.5 x 3.0 mm^3. The overall quality of all sequences was rated by visual assessment by an experienced neuroradiologist on a three-point scale: 1 = poor / non-diagnostic, 2 = acceptable / diagnostic, 3 = excellent quality.

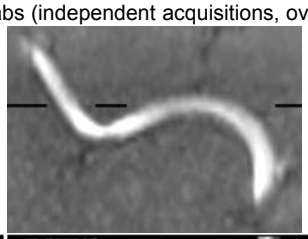

Fig. 1: *Excellent transition between adjacent slabs without discontinuities owing to weighted filtering is clearly depicted. Slab border is marked with black hairline.*

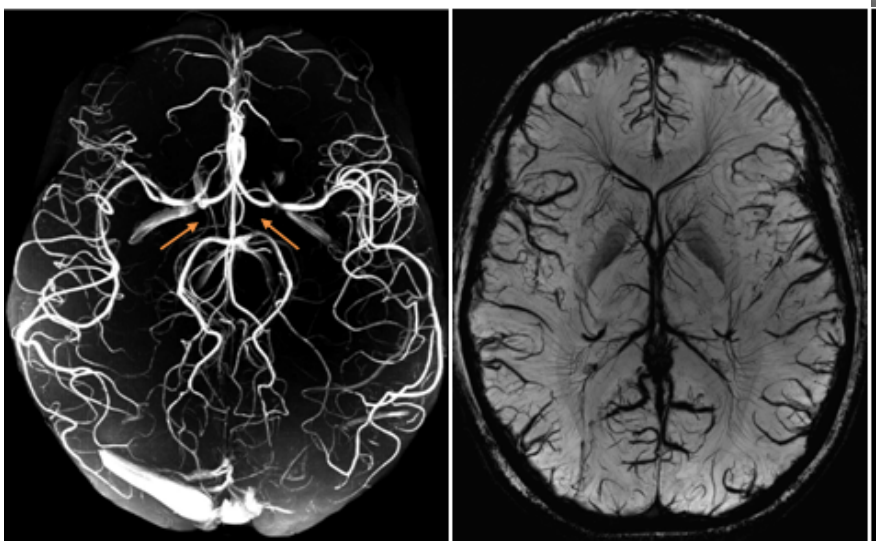

Fig. 2: *a) MIP of high-resolution whole-brain TOF MRI of a healthy female. Variant with absence of both posterior communicating arteries can be clearly seen (arrows). b) High-resolution SWI optimally depicts cerebral veins.*

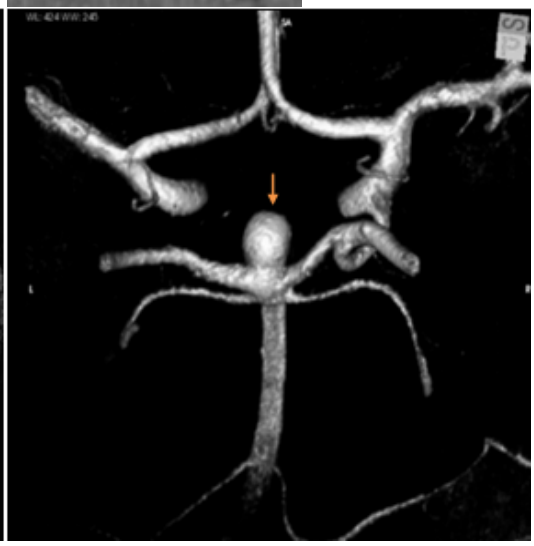

Fig. 3: *Volume rendering of TOF MRA in a patient with basilar tip aneurysm (arrow). Even small vessels are depicted with excellent quality. Also, absence of left posterior communicating artery is visualized*

Results: All volunteers and patients tolerated the examination well and could be successfully examined within 1 hour. All images were rated acceptable to excellent. The MP-RAGE provided clinical T1 contrast in ultra-high isotropic resolution. It is additionally perfect as a localizer for all other sequences due to the bright vessel depiction [1]. The water-fat sensitive IR-pulse allowed uniform inversion, without visible contrast changes e.g. in the cerebellum. The TOF sequence enabled MIP images (Fig. 2a) of the complete vascular tree with a voxel volume of smaller than 0.02 mm^3. The VERSE algorithm reduced the SAR of the TONE pulse by approximately 33% of the original pulse. Without use of VERSE (same sequence parameters and contrast), theoretically a reduction of slices per slab by a factor of 2/3 would be necessary. The SWI provided excellent T2* contrast, which is valuable for the delineation between arteries and veins (Fig. 2b). Finally, the double-contrast turbo spin echo completed the clinical 7T protocol with the PD/T2 contrast. The 43 slices permit (nearly) whole-brain coverage with adequate resolution for clinical diagnosis.

Discussion: This study shows a complete clinical 7T head protocol. Especially the high-resolution TOF MRA seems to show excellent results for depicting the cerebral vascular structures, e.g. a basilar tip aneurysm (see Fig. 3). The complete arterial vasculature of the brain is visible in a single 3D dataset. Combining oversampled slabs from independent acquisitions can reduce head motion artifacts, as only a part of the total scan has to be repeated if head motion occurs, potentially reducing scanning time. In the future, (dynamic) contrast-enhanced scans (with high temporal resolution) or arterial spin labeling may add additional information regarding the blood flow, especially interesting when depicting cerebral AVMs.

References: [1] S. Maderwald et al. MAGMA 21: 159-167 (2008); [2] S. Johst et al. Proc. 18th Ann. Meet. ISMRM 2010, 2252; [3] S. Schmitter et al. Proc. 18th Ann. Meet. ISMRM 2010, 4424; [4] S. Conolly et al. J Magn Reson. 78:440-458 (1988)