To TOF or Not To TOF; Nonenhanced MRA at 7T

S. Maderwald[1,2], J. M. Theysohn[1,2], O. Kraff[1,2], S. C. Ladd[1,2], M. E. Ladd[1,2], K. Wicklow[3], H. H. Quick[1,2], and E. R. Gizewski[2]

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

Introduction

To exploit the full potential of ultra high field MR systems, the sequences used at high field strengths have to be adapted to the specific features of high field imaging. High field systems potentially offer high signal-to-noise ratio (SNR) while the maximum applicable specific absorption rate (SAR) often limits the choice of imaging sequence parameters. The purpose of this study was to optimize and to evaluate 3D Time-of-Flight (TOF)-like non-contrast MR angiography techniques for display of the intracranial vessels with good background signal suppression and enhanced vessel conspicuity for imaging on a 7T scanner.

Methods

All measurements were performed on a whole-body 7 Tesla scanner (Magnetom 7T, Siemens Medical Solutions, Erlangen, Germany; gradient system 45 mT/m maximum amplitude and slew rate of 220 mT/m/ms). The imaging coil was a transmit-receive quadrature birdcage head coil (Invivo Diagnostic Imaging Corp., Gainesville, FL, USA). Three different gradient echo sequences (TOF, Volume interpolated 3D Flash (VIBE), magnetization-prepared rapid gradient echo (MPRAGE)) were compared in 9 healthy volunteers. Prior to scanning, written consent was obtained. In a previous study, imaging parameters for all three sequence types had been optimized (TE, TI, flip angle, and bandwidth) for high image contrast (vessel-tissue) and spatial coverage with a non interpolated resolution of 0.6*0.5*0.6 mm^3 (volume, 0.18 mm^3) and an acquisition time preferably below 15 minutes. The most promising protocol for each of the three sequence types was evaluated in this study (Tab.1). Two blinded senior radiologists rated in consensus: overall image quality, conspicuity of the small peripheral vessels in the source images and in the nearly isotropic maximum intensity projections (MIP), the character of artifacts, the resulting potential quality loss, and the suppression of the background. In a final step, we drove the parameters for the TOF sequence to still higher resolutions (volume, 0.13 mm^3), just to show the potential benefits and problems at 7 T.

Tab.1: Parameter	TOF	TOF high res	VIBE	MPRAGE
Repetition Time TR (msec)	57	62	12	2500
Echo Time TE (msec)	3.46	3.46	2.25	1.79
Flip Angle FA (°)	30	30	10	10
Bandwidth (Hz/pixel)	303	305	320	570
Field of View FOV (mm^2)	200*66.7%	200*66.7%	256*87.5%	256*87.5%
Acquisition Matrix (pixel)	384*223	512*247	512*376	512*376
Voxel Volume (mm^3) not interpolated	0.6/0.5/0.6	0.55/0.39/0.56	0.6/0.5/0.6	0.6/0.5/0.6
Acquisition Time (min:sec)	14:45	17:50	11:11	12:45
Inversion Time TI (msec)	0	0	0	1100

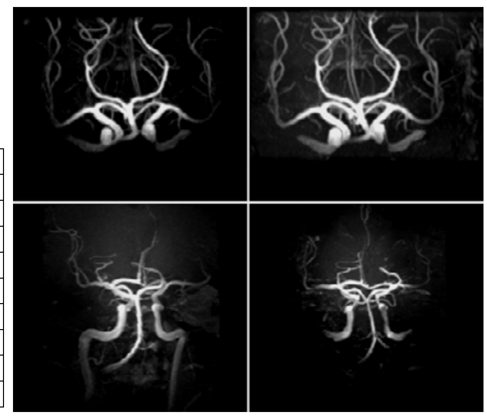

Fig. 1: MIPs. Upper row: TOF (left) and TOF high res; lower row: MPRAGE (left) and VIBE.

Results

All three imaging sequences were successfully performed in all 9 subjects, and the area of interest could be covered in less than 15 minutes by all three sequences. Even peripheral arteries were visualized well, subjectively similar to 1.5T as known from experience (not further evaluated). In the source images, the MPRAGE sequence achieved the best results; even the fine vessels and the vessels near the air-containing mastoid were depicted very well. Turbulence artifacts/intraluminal signal loss, which was a problem in the greater vessels (mainly the carotids) in TOF and VIBE, were less pronounced in MPRAGE. Due to the higher background signal (especially the fat signal near the orbit and clivus) in VIBE and MPRAGE MIPs, the MIP of the "conventional" TOF scored better in the skull base region. On the other hand, TOF provided the smallest coverage. The single small vessel borders of the "high resolution" TOF (0.13 mm^3) were more sharply defined even in the periphery when compared to the 0.6*0.5*0.6 mm^3 TOF, with an increase in acquisition time of only 18%.

Discussion

The non-predictability of the contrast features in 7 Tesla – due to modified T1 times, strong T2* effects and artifacts – and the limitations in field-of-view coverage by SAR restrictions, were the most challenging parts of this study. The TOF images were most prone to SAR limitations (larger flip angle); this is why TR had to be chosen much higher than desired; this reduced the optimally achievable background suppression. VIBE and MPRAGE can cover the whole brain in less than 15 minutes. Reduced coverage of the VIBE and MPRAGE sequences - in order to reduce the scan time - was not feasible, as prominent aliasing occurred in the slice selection direction. MPRAGE, due to its very good grey and white matter differentiation, seems attractive for navigation before tumor therapy due to its simultaneous good visualization of vessels and grey and white matter.

In conclusion, reducing SAR and scan time remains challenging in 7 T. New coil designs allowing parallel imaging will certainly be valuable contributions in the future, as they allow for parallel imaging strategies and render inherently higher SNR, which can be translated into reduction of scan time and SAR. The insights that were gained in this study (artifacts, contrasts) might be conveyed to other 7 T imaging protocols as well. 7 T seems able to render ultra high resolution TOF-like images within a reasonable imaging time. The accuracy of these new TOF-like sequences, of which MPRAGE performed especially well, should be evaluated in patients (stenoses, aneurysms), and the increase in TA for even higher resolution must be weighed against gain in diagnostic information.

Acknowledgement: This research was funded in part by the Dr. Werner Jackstädt Foundation, Wuppertal, Germany.