Rapid non-contrast enhanced 4D dMRA using Golden Angle Radial Acquisition and KWIC Reconstruction at 7T

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TARGET AUDIENCE: Researchers interested in MR angiography and clinical utilities at Ultra high field

INTRODUCTION: Ultrahigh magnetic fields benefit arterial spin labeling (ASL) techniques by offering increased intrinsic SNR and prolonged tracer half-life determined by the longitudinal relaxation time (T1) of blood. Recently, non-contrast enhanced 4D dynamic MRA (dMRA) has been successfully developed at 3T which combines ASL with a multi-phase segmented TrueFISP (or SSFP) readout[1,2]. Pilot studies have been carried out to develop 4D dMRA at 7T[3]. However, due to SAR limitations at 7T, low flip-angle gradient-echo (or FLASH) readout was used, resulting in lengthy scan times (e.g., >=10min) even with parallel imaging. This limits potential clinical utilities of this technique at 7T. The purpose of the present study is to develop a rapid, reliable 4D dMRA technique at 7T by using 3D stack-of-stars golden angle radial acquisition in conjunction with k-space weighted image contrast (KWIC) reconstruction to achieve high spatiotemporal resolution within a short scan time.

METHODS: All scans were carried out on a Siemens 7T Magnetom using a 24-channel Rx and single channel Tx head coil (Nova Medical, Wilmington, MA, USA). Global B0 shimming and local B1 calibration were performed prior to all scans. The 4D dMRA sequence consisted of continuous 3D FLASH readout following slice-selective or non-selective inversion pulses (i.e., FAIR technique for spin labeling). A dynamic 3D radial stack-of-stars sampling with an in-plane view angle increment of $\theta g=111.25°$ (golden angle) was utilized. First-order flow compensation was applied in slice and readout directions. A pre-saturation pulse was applied in the image slab before labeling to suppress the background signal. A slab of 40x1.5mm sections was acquired. The other imaging parameters were as follows: FOV=256mm, voxel size= $1\times1\times1.5mm^3$, TE/TR=3.6/7.2ms; FA=12^o; 300 views per slice. Total scan time was 4 minutes. Golden angle radial strategy, in conjunction with k-space weighted image contrast (KWIC) reconstruction, permits flexible temporal resolution[4,5]. 20 views (core views) at the center region of k-space with 160 total views were empirically chosen for reconstruction of each phase, which achieved the temporal resolution of approximate 150ms in this study. For comparison, a standard Cartesian based non-contrast dMRA scan with FOV=$220\times165mm^2$ and voxel size =$1.1\times1.1\times1.5\ mm^3$ was also carried out. 19 phases with a temporal resolution of ~100ms were acquired. Parallel imaging was applied with rate 3 GRAPPA, and the total scan time was 9 min. Five healthy volunteers and an AVM patient (13yr F) participated in this study.

RESULTS: Dynamic MRA images with both Cartesian and radial acquisitions were successfully obtained from all the subjects. Figure 1 shows the MIP dMRA images at different phases with Cartesian (a) and radial (b) acquisitions. The dynamic filling of labeled blood through the Circle of Willis and its branches was depicted. Compared to Cartesian-based dMRA, radial-based dMRA shows better delineation of small and distal arteries without obvious streaking artifacts. Comparable SNR ($p=0.32$) were obtained in the big branches of Circle of Willis from Cartesian (SNR=92.85±15.82) and radial (SNR=104.28±10.49) dMRA. However, significantly higher SNR ($p<0.05$) was acquired in the small arteries using radial acquisition. Meanwhile, significantly higher CNR ($p<0.05$) was obtained from both big and small arteries in radial-based dMRA. Figure 2 shows the MIP images of Cartesian- and radial-based dMRA at 6 representative phases from one AVM patient. One can clearly see the passage of the labeled blood flowing from the feeding arteries (red arrows) through the nidus (green arrows), and then into a superficial draining vein (yellow arrows), matching well with digital subtraction angiography (DSA) results (Fig. 2c). Compared to Cartesian-based dMRA, radial dMRA shows improved delineation of arteries, AVM lesion and the draining vein.

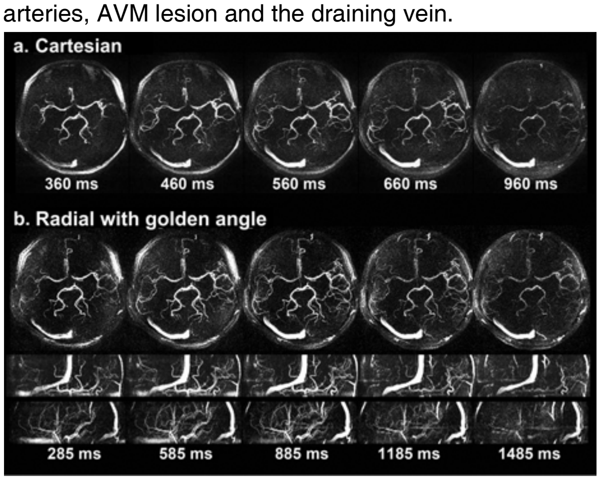

Figure 1 The MIP dMRA images from a respective subject with Cartesian (a) and stack of star radial acquisitions (b).

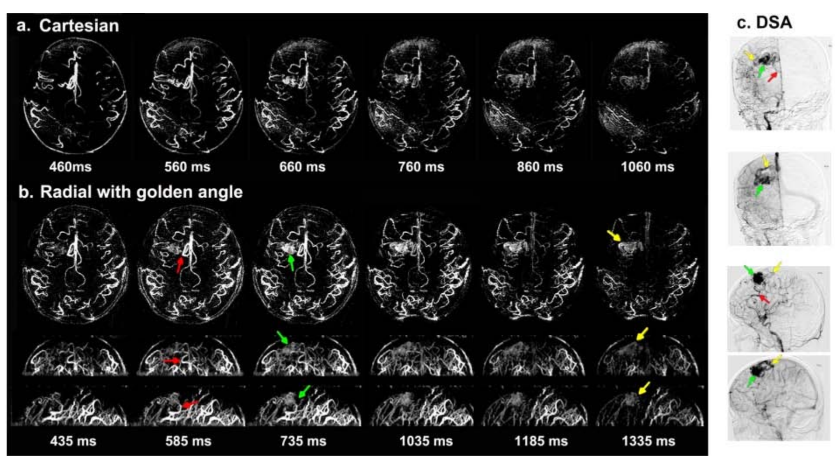

Figure 2 The dMRA images with Cartesian (a) and radial (b) acquisitions from a AVM patient (13 yrs, female), DSA results (c) are shown on right for comparison.

DISCUSSION: Time-resolved non-contrast enhanced 4D dMRA with 3D Stack of Stars golden angle radial acquisition was successfully implemented at 7T. Compared to standard Cartesian-based dMRA, golden angle provides the advantages of shorter scan time (less than half scan time of Cartesian-based dMRA with iPAT=3) as well as improved delineation of distal arteries. Preliminary data on an AVM shows promising results that the draining veins can be better delineated using radial acquisition. Non-contrast dMRA with 3D dynamic golden angle radial acquisition and KWIC reconstruction is a promising technique at 7T with reduced scan time and patient discomfort as well as potentially reduced motion.

REFERENCE: 1. Yan et al Radiology 2010, 256:270-9; 2. Bi et al MRM 2010, 63:835-41; 3. Metzger et al., ISMRM2013, no. 1292; 4. Song et al MRM 2004, 52:815-824 5. W. Lin, et al, Magn Reson Med 60:1135-1146