Contarst-enhanced whole-heart coronary MRA in 5 minutes using radial EPI

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INTRODUCTION: Whole-heart coronary MRA is challenging due to the long data acquisition time on the order of 8-12 minutes. Interleaved EPI using Cartesian k-space sampling has been reported for reducing the scan time of whole-heart coronary MRA [1]; however, this method suffers from an increased sensitivity to motion artifacts [2]. The purpose of this work was to optimize a radial EPI [3] technique for contrast-enhanced whole-heart coronary MRA, with the goal of combining the scan efficiency of EPI with the motion insensitivity of radial sampling.

METHODS:
Sequence Design: A stack-of-stars radial trajectory was used for whole-heart coronary MRA. Fig. 1 shows the Radial EPI pulse sequence. Adjacent projections were sampled in each TR, and the full range of projections (0 to π) were sampled in each heart-beat in an interleaved fashion. Trajectory measurement [4] was used for correction of gradient delays. As shown in Fig. 2 (red arrows), combining all the projections during gridding leads to phase cancellation and corresponding signal voids in the images. We used a novel self-calibrating phase correction technique to compensate for this effect. K-space was split into n undersampled sections, each acquired at a particular TE. A low resolution fully sampled image was reconstructed at each TE from the central k-space region (shown as blue circles in Fig. 2) and the off-resonance phase was estimated from these images. This low resolution phase information was used to correct the corresponding undersampled high resolution data, and the multiple high resolution undersampled images (one for each TE) were combined by complex summation to give the final image (shown by the blue arrows). Variable density sampling was used in the kz direction [5] with the central kz partitions acquiring twice the number of projections as compared with the outer kz partitions. This variable density sampling in kz was compensated during reconstruction. The variable density sampling has two advantages: i) it leads to reduction of streaking artifacts, and, ii) it leads to better spatial resolution in the off-resonance phase map leading to better reconstructions.
Volunteer Imaging: 10 healthy volunteers and 1 patient were scanned on a 3T Trio scanner (Siemens Medical Solutions). Scan parameters were: 4 projections in each TR of 8.2 ms, flip angle = 30, readout bandwidth = 977 Hz/pixel, number of radial views = 288 or 144 depending on the kz value, partial Fourier of 5/6 in the kz direction, inversion-recovery preparation with TI = 200 ms, matrix: 256 x 256 x 60, voxel size: 1 × 1 × 2 mm^3, interpolated to 0.5 x 0.5 x 1 mm^3. 0.2 mmol/kg of Gd-DTPA was injected at 0.3 cc/sec.

RESULTS: Average imaging time for contrast-enhanced whole-heart imaging with the radial EPI technique was 5.6 ± 1.6 minutes with an average navigator efficiency of 43.3 ± 10.9 %. Fig. 3 shows reformatted coronary artery images using the radial EPI technique. Excellent depiction of all the major coronary arteries is seen. Quantitative evaluation of the radial EPI technique in healthy volunteers is shown in Table 1. Fig. 4 shows reformatted coronary artery images from 2 healthy volunteers acquired with radial (a ,b), and Cartesian (d, e) EPI techniques. The images in Figs. 4a and 4d are similar; however, the volunteer in Figs. 4b and 4e had an arrhythmia, due to which the Cartesian EPI images are corrupted by motion induced blurring. The radial EPI image for this volunteer (4b) shows excellent delineation of the coronary arteries, demonstrating the motion insensitivity of radial EPI compared with Cartesian EPI. Figs. 4c and 4f show images of the LCX and LAD in a patient using radial EPI (4c) and the corresponding X-ray angiogram (4f). The stenosis in the mid LCX (red arrow) and occlusion of the LAD (pink arrow), are clearly visualized in both images.

CONCLUSION: A radial EPI technique was developed for contrast-enhanced whole-heart coronary MRA in a scan time of approximately 5 minutes. Excellent delineation of the coronary arteries was seen in healthy volunteers and one preliminary patient study. Further clinical evaluation of this technique is currently underway.

REFERENCES: [1] MRM 61:1388-95. [2] JMRI 1:643-50 [3] MRM 42:324-34. [4] MRM 39: 999-04. [5] ISMRM 2007 # 307.

Table 1: Quantitative evaluation of the radial EPI technique.

Sequence (n = 10)	Imaging time (mins)	Navigator efficiency (%)	SNR	CNR	RCA length	LAD length
Radial EPI	5.6 ± 1.6	43.3 ± 10.9	24.4 ± 4.9	14.1± 1.7	9.3 ± 1.8	9.8 ± 2.4

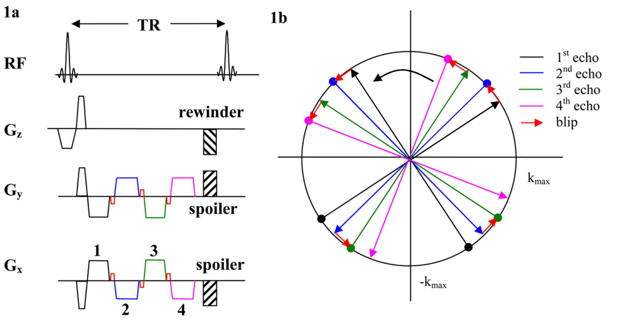

Fig 1. Radial EPI pulse sequence (**a**) & reordering scheme (**b**)

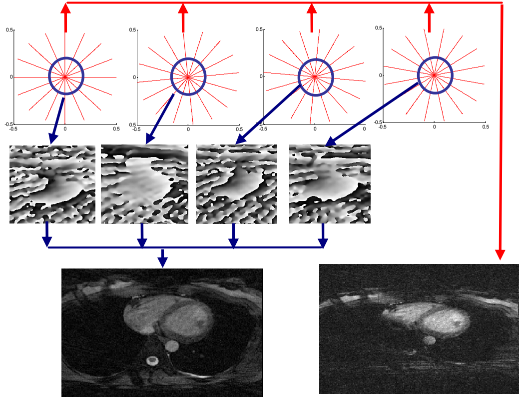

Fig 2. Schematic of the self-calibrating phase correction technique

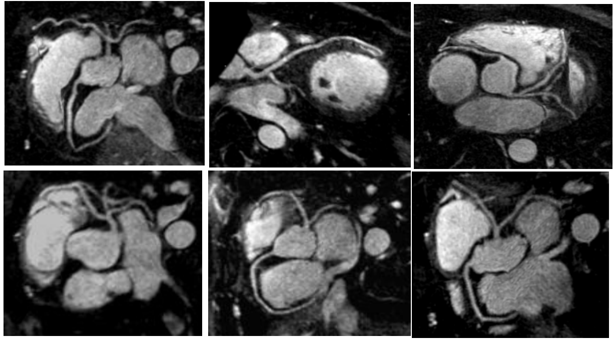

Fig. 3. Reformatted coronary artery images using the contrast-enhanced whole-heart Radial EPI technique

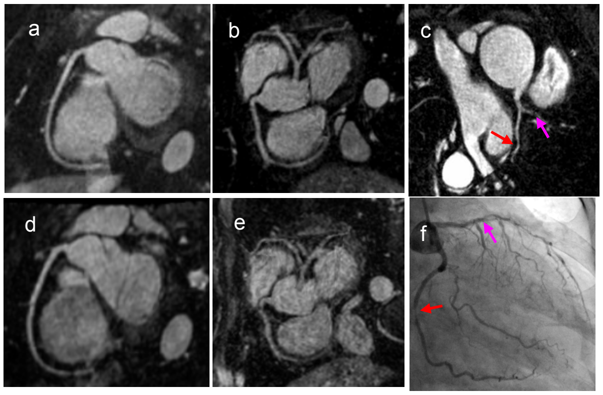

Fig. 4. Coronary images with Radial EPI (a ,b) and Cartesian EPI (d, e). Patient image using Radial EPI (c) and the corresponding X-ray angiogram (f).