Whole-Heart Imaging Using Undersampled Radial Phase Encoding and a 32-Channel Cardiac Coil

R. Boubertakh[1,2], P. G. Batchelor[1], S. Uribe[1], T. S. Sørensen[2], M. S. Hansen[3], R. S. Razavi[1], and T. Schaeffter[1]

[1]Division of Imaging Sciences, King's College London, London, London, United Kingdom, [2]Centre for Medical Image Computing, University College London, London, London, United Kingdom, [3]Institute of Child Health, University College London, London, London, United Kingdom

Introduction: Whole-heart isotropic non-angulated cardiac MR is becoming an important protocol in simplifying MRI [1]. Subsequent reformatting of any slice of interest can be obtained from the 3D volume for qualitative and quantitative cardiac analysis of cardiac function. This removes the need of time-consuming slice planning by a skilled operator. The main problem of these acquisitions is the need for respiratory navigation in order to compensate for the breathing motion. This leads to rather long acquisition times, particularly when acquiring high image resolutions and/or using small respiratory navigator windows. The acquisition time can be reduced by undersampling the *k*-space data in combination with parallel imaging techniques [2]; but usually acceleration factors from 4-6 can be applied [3]. In this work, we present a 3D radial phase encoding scheme where *k*-space data are radialy acquired in the phase encoding plane *ky-kz*, and on a Cartesian grid along the readout direction. For undersampled data, radial encoding presents advantageous aliasing and motion properties compared to Cartesian sampling. In combination with an rf-coil array with high number of elements (32-channel), we show that high acceleration factors (R=12) can be obtained without significant loss in image quality by applying an iterative SENSE reconstruction [4]. Image quality, measured as signal to artifact and contrast to artifact levels, were computed and compared to a fully sampled radial acquisition.

Methods: A 3D acquisition, which combines both radial and Cartesian sampling of *k*-space, was implemented. Radial phase encoding was performed in the *ky-kz* plane, where the location of each phase encoded sample lies on a radial line (Fig. 1.a). The readout was always acquired in the same direction (Fig 1.b) along a Cartesian grid.
The sequence was implemented on a Philips Achieva 1.5T scanner (Best, the Netherlands) and healthy volunteers were scanned using a 32-channel cardiac coil. An end-expiration respiratory navigated volume covering the whole-heart was acquired at end-diastole in the sagittal orientation using a segmented balanced SSFP sequence (flip angle 90°, TR/TE = 4.5/2.17 ms, TFE factor = 24) with fat suppression, T2 preparation and an acquired isotropic voxel size of 1.74×1.74×1.74 mm^3. Two fully sampled data sets were obtained using a 6mm and 12mm gating windows. The *k*-space data consisted of 143 radial profiles and 144 samples/profile. From the fully sampled radial *k*-space raw data, undersampled data were simulated for different acceleration factors. The undersampling was done by skipping radial profiles along the angular direction (Rθ acceleration factor) and leaving out phase encode samples along every radial line (Rp acceleration factor) (Fig 1.c-d). The total acceleration is then the product of both factors: R=Rθ×Rp. Two undersampling factors were used: R = 8 (Rθ=4, Rp=2) and R = 12 (Rθ=6, Rp=2). Iterative SENSE reconstruction was implemented in Matlab with pre-conditionning and no regularization. The coil sensitivities were estimated from the central region of *k*-space and all reconstructed images were compared to a standard gridding reconstruction and the fully sampled radial images.

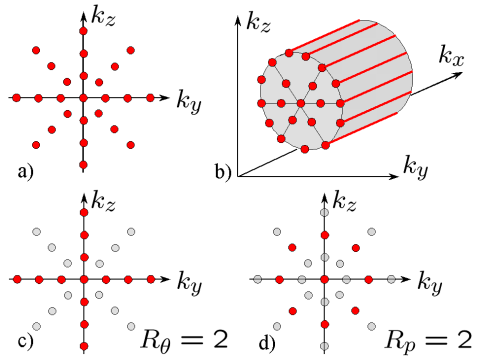

Figure 1.Sampling pattern for radial phase encoding acquisition: a) the sampled data (red dots) in the *ky-kz* plane, b) 3D *k*-space. Readout (*kx*) is always in the same direction. Data are undersampled by leaving out radial profiles (Rθ accelearation factor) and/or by leaving out samples along each radial profile (Rp accelearation factor).

Results and Discussions: Coronal views and reformatted images in the short-axis and four chamber views are shown in Figure 2 for both fully sampled and undersampled patterns for the 6mm gating window. A significant improvement in image quality is observed for the iterative SENSE reconstructions compared to gridding, with a strong reduction in aliasing artifacts. Quantitative evaluation of the image quality was performed by measuring in selected regions of interest (background, muscle and blood pool, circle ROIs in Fig 2.a) the signal to artifact as well as the contrast to artifact levels. The signal to artifact level was measured as the ratio between the average signal in the blood ROI and the standard deviation in the background. Table 1 shows that for the iterative reconstruction, image quality does not significantly degrade compared to the fully sampled data set even for high acceleration factors.
For comparison, a 3D isotropic Cartesian acquisition with 2D-SENSE (R=2.0×1.5) and half-Fourier (0.625 factor) [5] covering the same field-of-view and with the same acquired voxel size requires an acquisition time of 2min 52sec, for a heart-rate of 60. The acceleration factor for this sequence is 4.8; a radial phase encoding with a 12 fold-acceleration would then lead to a 2.5 speed-up, for a scan time of just 70 sec.

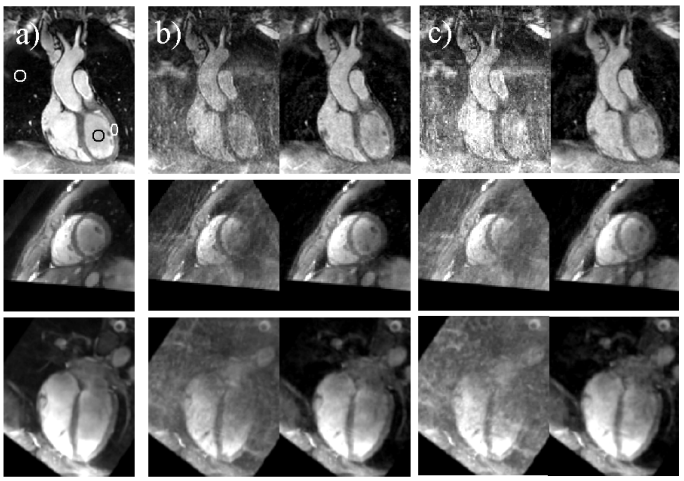

Figure 2. Coronal, reformatted short-axis and four chamber views (top to bottom): a) fully sampled radial, b) gridding (left) and iterative SENSE (right) for R = 8 (Rθ=4, Rp=2), c) gridding (left) and iterative SENSE (right) for R = 12 (Rθ=6, Rp=2).

	Fully sampled	Gridding R =8	Iterative SENSE, R=8	Iterative SENSE, R=12
Signal to artifact level	35.16	12.09	22.03	24.70
Contrast to artifact level	16.12	3.55	9.35	10.88

Table 1. Evaluation of signal to artifact levels in the blood pool and the contrast to artifact levels.

Conclusion: We have proposed a new 3D acquisition method combining radial phase encoding and Cartesian readout *k*-space sampling. Performing radial phase encoding in the *ky-kz* plane allows achieving high undersampling factors when used in combination with a parallel imaging. This sampling strategy is not limited to radial trajectories; any non-Cartesian sampling can be implemented, which opens the way to investigating new sampling patterns that present a better in-plane sample distributions, specifically in the center of *k*-space, which can further speed-up the acquisition time.

References:

[1] Sørenson et al, Circulation 2004, 110(2):163-169, [2] Pruessman et al, MRM 1999, 42:952-962 , [3]Nehrke et al, JMRI 2006, 23:752-756, [4] Pruessman et al, MRM 2001, 46:638-651, [5] Uribe et al, Radiology, *accepted.*