Highly Efficient Isotropic Whole-Heart Imaging using Radial Phase Encoding PAWS

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INTRODUCTION: Three dimensional (3D) whole-heart MRI has become an important acquisition in cardiac MRI. One of its main challenges is long acquisition times, required to achieve high spatial resolution while reducing image artefacts due to physiological motion. Here we propose to overcome these problems with a novel 3D interleaved bit reversed k-space sampling scheme. It is based on the undersampling properties of an interleaved Radial Phase Encoding (RPE) trajectory [1] to speed up the acquisition and Phase Ordering with Automatic Window Selection (PAWS) [2] to increase the navigator efficiency and reduce motion artefacts equally in both phase encoding directions. Volunteer scans show a significant decrease in scan time for RPE-PAWS compared to a respiratory gated Cartesian scan leading to fast 3D whole-heart MRI with high isotropic resolution.

METHOD: RPE combines Cartesian frequency encoding (FE) with a radial-like sampling pattern in the phase encoding plane PE_y – PE_z (Fig.1a). PAWS acquires data in several navigator windows (bins) (Fig.1b) and sampled k-space positions depend on the navigator signal. The final image is reconstructed using data from a combination of bins. Therefore the sampling pattern has to be defined such that adjacent bins contain complementary k-space information. We propose a new interleaved bit reversed sampling trajectory for RPE-PAWS (Fig. 1c) which yields a homogenous covering of k-space over time. Data acquisition finishes when one combination of two bins yields a completed k-space (in contrast to Cartesian PAWS, which is based on the combination of three bins). Two bins were used to achieve the shortest scan time[2].

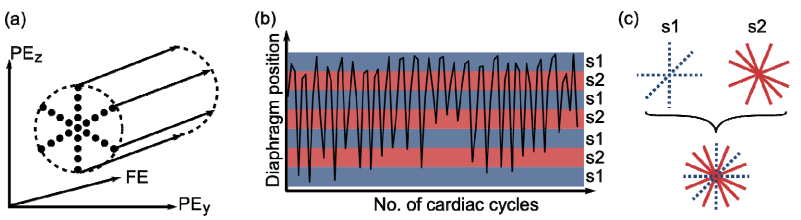

Fig. 1: (a) RPE sampling trajectory. (b) PAWS acquires data in bins covering the entire navigator amplitude. The final image is reconstructed using data from two consecutive bins. (c) s1 and s2 have complementary sampling locations and are recorded in a bit reversed order to achieve an evenly covering of k-space at all times.

Image acquisition: RPE-PAWS was implemented on a 1.5T MRI scanner (Philips Medical Systems, Best, The Netherlands). Eight healthy volunteers were scanned using a 32-channel coil. Relevant parameters include: b-SSFP sequence, FOV: $288mm^3$, isotropic resolution: $1.5mm^3$, T2 prep pulse (TE=50ms), fat suppression, flip angle: 90^o, TR/TE = 4.3/2.2ms, segmented approach (TFE factor = 24) with low-high profile order and an undersampling factor of 6. For reference purposes a gated Cartesian scan was also carried out with the same imaging parameters resulting in the same "nominal" acquisition time of 6.4min. The width of the individual bins for RPE-PAWS was 3mm, resulting in a 6mm gating window (after the combination of two bins). The same 6mm gating window was also used for the Cartesian scan with a SENSE factor of 6. Images were reconstructed using an iterative SENSE (RPE) and SENSE method (Cartesian) respectively[4]. The quality of the images acquired with the two methods was assessed according to apparent signal to noise ratio (aSNR) and vessel sharpness (VS) of the left (LCA) and right (RCA) coronary arteries.

RESULTS: Reformatted images of the RCA and LCA for two volunteers are shown in Fig. 2. The volunteer study led to an average increase in navgiator efficiency of 21% with maximum increment percentage of more than 90%. Moreover the presented sampling scheme allows for a further reduction in scan time of at least 25% by an increase of the undersampling factor from 6 to 8 without a visible loss in image quality (Fig. 2). This is due to higher acceleration factors which can be achieved with the presented sampling trajectory. A quantitative comparison between the images acquired with RPE-PAWS and with the gated Cartesian method resulted in a decrease of aSNR of 22% but an increase of VS for LCA by 17.1%. All other parameters did not exhibit a statistically significant difference.

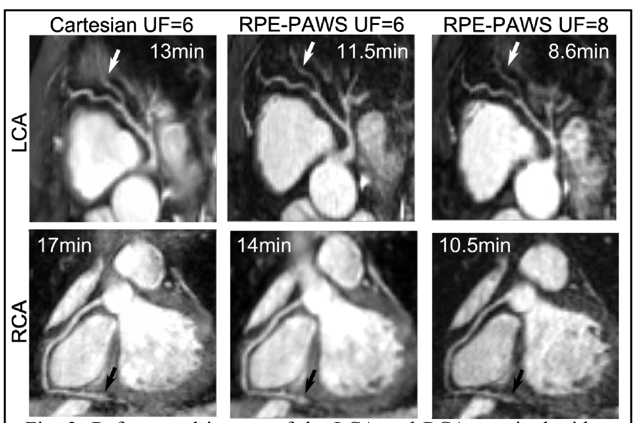

Fig. 2: Reformatted images of the LCA and RCA acquired with a gated Cartesian scan, RPE-PAWS with the same undersampling factor (UF) and with RPE-PAWS with an UF of 8. The total acquisition time for each scans is given in minutes.

CONCLUSION: RPE-PAWS provides a fast and highly efficient 3D whole-heart acquisition. The decrease in scan time compared to a gated Cartesian acquisition is due to a) the increase in navigator efficiency of the PAWS approach and b) the undersampling properties of the RPE trajectory. The homogeneous covering of k-space achieved with the interleaved bit reversed sampling scheme offers further advantages. In contrast to the original Cartesian PAWS approach presented by Jhooti et al.[2] image reconstruction is possible even if the scan has to be stopped prematurely resulting in angularly undersampled data. Furthermore the presented method does not just yield one high resolution image at a certain breathing position but allows for reconstruction of low resolution images showing the same volume at different respiratory motion stages. This provides dynamic information without an increase in scan time which can be used, for instance, for motion models in cardiac catheterisations[3].

REFERENCES: [1] Boubertakh R *et al.* Magn Reson Med. 2009;62:1331–1337. [2] Jhooti P *et al.* Magn Reson Med. 2000;43:470–480. [3] King AP *et al.* Med Image Anal. 2009 13:419–431. [4] Pruessmann KP *et al.* Magn Reson Med, 2001:46:638-651.