Free-Breathing 3D Isotropic Whole Chest Non-Contrast MRA Using a Combination of Compressed Sensing, Parallel Imaging and a 3D Radial Phyllotaxis Trajectory: a Feasibility Study

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Target Audience: Scientists, researchers and clinicians who have interest in rapid free-breathing non-contrast whole chest MRA with isotropic spatial resolution.

Introduction: Three-dimensional (3D) imaging with balanced steady state free precession (b-SSFP) readout offers high blood-background contrast and is a valuable tool for non-contrast MR Angiography (MRA). It enables morphologic evaluation of the heart and thoracic vessels, which may be of value in the diagnosis of congenital heart disease or aortopathy. However, 3D non-contrast MRA is challenging due to the requirement of high spatial resolution for clear depiction of vessels of different caliber. Isotropic resolution is also highly desirable as it can enable arbitrary multi-planar assessment of the anatomy offline, with only a single image acquisition. The standard approach for 3D non-contrast MRA in clinical practice employs ECG triggering to avoid cardiac motion, and navigator gating to minimize the effects of respiration. However, this method suffers from long and unpredictable scan times (on the order of 10 minutes), which limit its clinical use [1]. A new approach for highly accelerated 3D non-contrast thoracic MRA within a single breath-hold has recently been proposed using parallel imaging with 32 element coil arrays and Cartesian sampling [2], However, the relatively long breath-hold times and the compromised slice coverage limit its clinical application in patients who are unable to complete a prolonged breath-hold. 3D radial trajectories represent an attractive alternative for free-breathing imaging due to their high robustness to physiological motion and to undersampling. Meanwhile, the incoherence of a spiral phyllotaxis arrangement of 3D radial readouts [3] also enables effective acceleration using compressed sensing. Moreover, when combined with self-navigated respiratory motion correction [4], such radial sampling offers the possibility of high acquisition efficiency. In this work, we demonstrate the feasibility of 3D isotropic free-breathing whole chest MRA in approximately 2 minutes using a joint multi-coil compressed sensing framework and a self-navigated 3D radial phyllotaxis trajectory with 100% acquisition efficiency. The proposed approach with isotropic spatial resolution enables simplified imaging acquisition and flexible retrospective image reformatting for multi-planar evaluation.

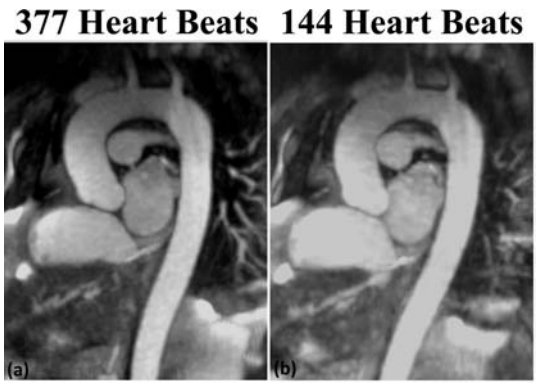

Figure 1. Reformatted thoracic MRA comparing results reconstructed using data from 377 (a) and 144 (b) heart beats.

Methods: A HIPAA-compliant and IRB-approved cardiac imaging protocol was performed in three healthy volunteers. An ECG triggered, T2 prepared and fat saturated b-SSFP sequence with 3D radial phyllotaxis sampling [3] was implemented on a 1.5T whole-body scanner (Siemens, Avanto) equipped with a 12 element body matrix coil. Relevant imaging parameters included: TR/TE=3.0/1.51ms, FOV= $(320\text{mm})^3$, base resolution=192^3, flip angle=90° and receiver bandwidth=898 Hz/Pixel. 32 radial spokes were acquired in each heart beat for a total of 377 heartbeats, corresponding to 12064 spokes. When compared to the Nyquist sampling requirement, the acquisition achieved an overall undersampling ratio of 20%. All the acquired data were first used to reconstruct a 3D dataset with matrix size 192x192x192 and isotropic spatial resolution (1.6mm^3) using 3D non-uniform fast Fourier transform (NUFFT). These results were considered as the reference for image quality comparison. A respiratory motion correction procedure was performed in radial k-space before image reconstruction, as described in [4]. A second reconstruction was also performed using acquired data from only the first 144 heartbeats, while discarding the rest of the acquisition. This corresponds to a total acquisition time of approximately 2 minutes. A joint multicoil compressed sensing framework [5] was employed to reduce the residual incoherent artifact by minimizing the following cost function: $d=\text{argmin}_d \{\|E\cdot d-m\|_2 + \lambda\|W\cdot d\|_1\}$, where E is the 3D NUFFT operator incorporating the coil sensitivities, d is the image to be reconstructed and m is the acquired radial k-space. W is the 3D wavelet transform and $\lambda>0$ is the corresponding regularization parameter, which was empirically selected in this work. Coil sensitivity maps were generated using low resolution images reconstructed from the central part of 3D radial k-space.

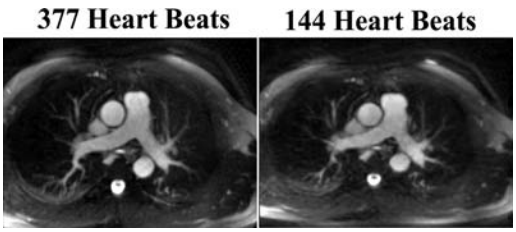

Figure 2. Axial view of the main, left and rightpulmonary arteries.

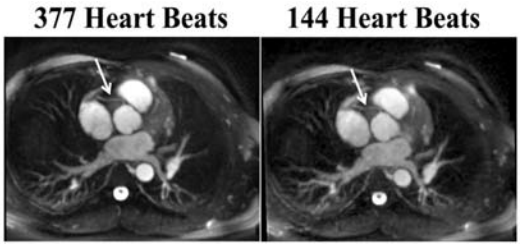

Figure 3. Reformatted datasets show the origin of right coronary artery and its proximal segment.

Results: Figure 1 shows a retrospectively reformatted view of the thoracic MRA reconstructed using data from 377 (a) and 144 (b) heartbeats. Figure 2 shows an axial view of the main, left and right pulmonary arteries reformatted using the same datasets as in Figure 1, while Figure 3 shows the origin of the right coronary artery and its proximal segment. Thin maximum intensity projections (MIPs) were used for all figure reformats. As shown in all three figures, the proposed reconstructions using multicoil compressed sensing allows for 3D whole chest non-contrast MRA in approximately 2 minutes (144 heart beats) with similar image quality when visually compared with the result obtained using data from 377 heart beats, of approximately 6-7 minutes duration.

Conclusion: This work demonstrated the feasibility of free-breathing isotropic whole chest MRA in about 2 minutes using a joint multicoil compressed sensing framework. The approach enables simplified image acquisition with large coverage, enabling assessment of the thoracic aorta and pulmonary arteries in a clinically acceptable scan time, as well as simultaneous visualization of the proximal coronary arteries, which may be of significant value for congenital heart disease and aortopathy. The isotropic spatial resolution also allows evaluation of the vessels in arbitrary planes. Future work will include qualitative evaluation of the approach against the established clinical reference approach and assessment of performance in clinical patients with various cardiac diseases.

References: [1] Srichai MB et. al Tex Heart Inst J 2010;37:58–65.[2]Jian Xu et al. JMRI 2012, 35:963–968 [3]Davide Piccini et. al MRM 2011, 66:1049–1056 [4] Davide Piccini et. al MRM 66:1049–1056 [5]Feng L et al. MRM 2013 Early View, doi: 10.1002/mrm/24980.