A New Binning Approach for 3D Motion Corrected Self-Navigated Whole-Heart Coronary MRA Using Independent Component Analysis of Coils

Gabriele Bonanno1,2, Davide Piccini3,4, Bénédicte Maréchal1,3, Michael O. Zenge6, and Matthias Stuber1,2
1Radiology, University Hospital (CHUV) and University of Lausanne (UNIL), Lausanne, Vaud, Switzerland, 2Center for Biomedical Imaging (CIBM), Lausanne, Vaud, Switzerland, 3Advanced Clinical Imaging Technology, Siemens Healthcare IM BM PI, Lausanne, Vaud, Switzerland, 4Radiology, University Hospital (CHUV) and University of Lausanne (UNIL) - Center for Biomedical Imaging (CIBM), Lausanne, Vaud, Switzerland, 5MR Product Innovation and Definition, Healthcare Sector, Siemens AG, Erlangen, Germany

Introduction: Despite significant progress in navigator technology, respiratory motion correction remains a major challenge in coronary magnetic resonance angiography (MRA). In response to this challenge, one-dimensional self-navigation (SN) techniques have been developed that extract respiratory-induced motion of the heart directly from the imaging data themselves. SN approaches have shown similar image quality when compared to conventional diaphragm navigator gated (NAV) acquisitions, while affording 100% scan efficiency and improved ease-of-use. To account for three-dimensional motion of the heart, image-based SN approaches that exploit 3D radial trajectories have recently been introduced. These methods produce alias-free sub-images for each respiratory phase by combining (binning) data segments from different cardiac cycles (interleaves). From such sub-images, 3D motion parameters are estimated and used for motion correction during final image reconstruction. To bin interleaves in different respiratory phases, the NAV signal or the superior inferior (SI) displacement obtained from 1D-SN has demonstrated to be effective. However, the use of NAV requires additional planning and expertise, and 1D-SN still depends on the tracking of the ventricular blood-pool on a 1D projection image. Unfortunately, this projection does not only integrate the signal from the heart, but also that from other structures and anatomy (FOV). This unwanted background signal remains one of the major barriers for accurate respiratory motion tracking of the heart. To remove this barrier, we propose the following 2-step approach to take 1D-SN to 3D-SN. First, we extract the respiratory signal from independent component analysis (ICA) of the k-space center amplitude in all receiver coils and use it for binning and subsequent 3D sub-image generation. Second, we use an atlas-based segmentation of the heart for image-based motion detection without background contribution. In 11 healthy adult volunteers, the performance of this 3D-SN methodology was then quantitatively ascertained in comparison to conventional 1D-SN coronary MRA.

Materials and Methods: The proposed 3D-SN technique employs a 3D radial trajectory with an interleaved spiral phyllotaxis pattern, adapted to SN with an additional SI readout at the beginning of each interleave. A golden-angle increment is also used to rotate the spiral pattern from one interleave to the next (Fig.1A). To obtain a respiratory signal, the amplitude of the k-space center, obtained from the SI readout, is recorded for all interleaves and for all receiver coils (Fig.1B). Individual k-space patterns are then processed with ICA to extract the fluctuations related to respiration (Fig.1C). While this unit-less signal cannot directly be used for displacement measurements and correction, it can still be exploited to bin data for 3D sub-image reconstruction. The histogram of this signal is then sorted into 15 bins (Fig.1D). Uniform k-space coverage for each bin is promoted by the golden-angle phyllotaxis pattern. After discarding poorly populated bins (<15 interleaves), 3D sub-images from 10-11 respiratory phases can be reconstructed and used for final image reconstruction (Fig.1D). For motion detection, a sub-image (Fig.1E) is registered to the reference sub-image that is extracted from the most populated bin. However, prior to registration, an automated atlas-based segmentation is performed on this reference sub-image to automatically locate the heart within the FOV. As a result, a binary mask of the heart is applied to the reference sub-image (Fig.1F).

This is followed by a registration that aligns the remaining sub-images with the reference by means of a 3D affine transformation. Subsequently, all these transformed sub-images are combined to produce the final 3D motion-corrected dataset (Fig.1G). Free-breathing self-navigated whole-heart coronary MRA was performed in 11 healthy adult volunteers with ECG triggering on a 1.5T clinical MRI scanner (MAGNETOM Aera, Siemens AG, Healthcare Sector, Erlangen, Germany) with a total of 30 receiver coils. The acquisition window (~100ms) was placed in mid diastole. The protocol parameters of the 3D radial, non slice-selective, T2-prepared, SSFP imaging sequence included: FOV (220mm)3, voxel size (1.15mm)3, 12320 radial readouts acquired in 385 heartbeats. Each dataset was reconstructed offline in MATLAB with both the above-described 3D-SN algorithm and with a previously described 1D-SN approach. Quantitative image analysis was then performed on all 1D and 3D self-navigated images using the Soap-Bubble tool. For comparison, proximal, mid and distal coronary segments were analyzed and compared for 3D-SN and 1D-SN.

Discussion and Conclusion: We have developed and tested a new SN approach that enables 3D motion correction for free-breathing coronary MRA. This method uses independent component analysis of fluctuations of the k-space center amplitude among all receiver coils to distinguish respiratory phases. A respiratory signal is therefore directly obtained from the imaging data, while obviating the need for additional navigator signals or motion tracking of the heart on projection images. The proposed 3D-SN significantly improved V/S ratio and overall vessel visualization compared to the 1D-SN in healthy adult subjects.


Table 1 – Quantitative analysis of coronary artery segments. LM, left coronary (LCX), RCA and left anterior descending (LAD) segments were analyzed and compared for 3D-SN and 1D-SN. (*) indicates statistical significance of the Student’s t-test (p<0.05).

Figure 1 – Fundamental steps of the 3D-SN method. The k-space center amplitude is obtained at the beginning of each interleave and for all channels (A,B). From such signals a component related to respiration is extracted with ICA (C) and directly used to bin data in sub-images from different respiratory phases (D,E). Without the need for tracking of the heart, an automated atlas-based segmentation of the heart is then used to align the sub-images at the level of the heart with affine transformation. Combination of all registered sub-images provides a motion corrected, final image (G).

Figure 2 – Example reformats of the Right Coronary Artery. Improved overall depiction of the distal parts of the RCA can be observed on the 3D-SN image, when compared to a 1D-SN reconstruction (arrow).