# Atlas-Based 3D-Affine Self-Navigated Whole-Heart Coronary MRA: Initial Experience in Patients


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**Introduction:** In coronary magnetic resonance angiography (MRA), 1D respiratory self-navigation (SN) techniques[1] have been shown to result in similar image quality as conventional diaphragmatic navigator-gated (NAV) acquisitions, while improving scan efficiency and ease-of-use[2]. To account for 3D motion of the heart, *image-based* SN approaches that exploit interleaved 3D radial trajectories have been introduced[3]. These methods use a respiratory signal to combine (bin) data segments from different interleaves in common respiratory phases, and generate undersampled sub-images for each of these bins. Subsequently, 3D motion parameters are estimated from the sub-images and used for motion correction during final image reconstruction. However, the signal originating from anatomical structures other than the heart in the field-of-view (FoV) may compromise accurate respiratory motion tracking, since both the generation of the binning signal and the estimation of 3D parameters are usually performed in image space[2,4]. To account for this unwanted background signal contribution, the following 2-step approach has recently been proposed[5]. First, a respiratory signal is extracted from independent component analysis (ICA)[6] of the k-space center amplitude in all receiver coils and is used for respiratory binning. Second, an automatic atlas-based segmentation[7] of the heart is used for image-based motion detection without background contribution. It has previously been shown that a) the respiratory signal extracted with the ICA is synchronous to the actual respiratory motion detected by the NAV signal[8], and that b), this 3D-SN methodology significantly improved vessel visualization and sharpness in comparison to 1D-SN coronary MRA[2] in healthy human subjects[5]. To take this to the next level, we have now applied the 3D-SN procedure in patients with suspected cardiovascular disease and show preliminary results in comparison to 1D-SN.

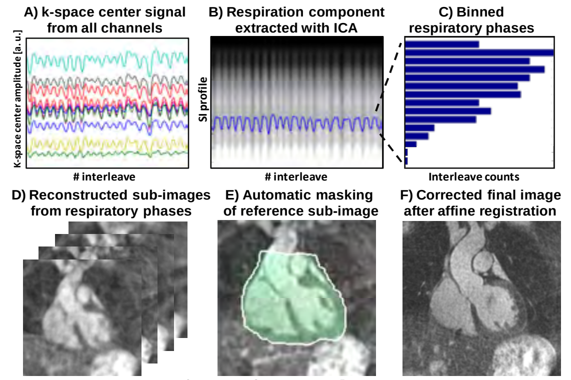
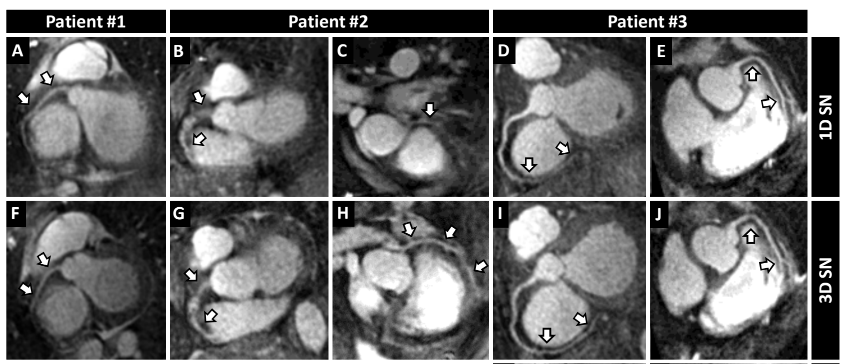



**Figure 1 – Main steps of the 3D-SN method.[5]** The k-space center amplitude is obtained at the beginning of each interleave and for all channels (A). From such signals a component related to respiration is extracted via ICA[6] (B) and directly used to bin data in sub-images from different respiratory phases (C,D). An automatic atlas-based segmentation[7] of the heart is performed on a reference sub-image to locate the heart within the FoV (E). Each sub image is then registered to the reference one at the level of the heart with affine transformation. Combination of all registered sub-images provides a final corrected image (F).

**Materials and Methods:** The proposed free-breathing 3D-SN technique implements a prototype 3D radial trajectory with a golden-angle interleaved spiral phyllotaxis pattern[8]. For motion correction[5], 10-11 sub-images were registered with a 3D affine transform and combined to produce the final corrected image (Fig.1). Whole-heart coronary MRA was performed in 9 patients with ECG triggering on a 1.5T clinical MRI scanner (Magnetom Aera, Siemens AG, Erlangen, Germany) with a total of 30 receiver coils. The protocol parameters of the 3D radial[8], $T_2$-prepared (TE $T_2$Prep=40ms), fat-saturated, bSSFP imaging sequence included: FoV $(220mm)^3$, voxel size $(1.15mm)^3$, 15-25 radial readouts/interleave acquired in 550-851 interleaves. Each dataset was reconstructed offline in Matlab both with the 3D-SN algorithm and with a previously described[2] 1D-SN approach. For quantitative comparison, coronary segments (AHA classification) were visualized, counted, and analyzed for vessel length, average vessel diameter and vessel sharpness (%VS)[9] on all 1D- and 3D-SN images. For statistical analysis, a paired two-tailed Student's *t*-test was used. For only one patient, x-ray coronary angiograms were available for comparison.

**Results:** Self-navigated image reconstruction was successful for all datasets. Offline processing time amounted to ~5min for 1D-SN and ~25min for 3D-SN with a non-optimized custom-built software. Coronary MR images showed good image quality after motion correction with 1D-SN (Fig.2A-E). By visual comparison, an improved delineation of proximal coronary arteries as well as better visualization of more distal segments was obtained when the same datasets were reconstructed with 3D-SN (Fig.2F-J, arrows). In a representative patient with confirmed healthy coronaries, 3D-SN images show a better depiction of the anatomy vs. 1D-SN with gold-standard x-ray angiography as reference (Fig.2I-L). Consistent with these visual findings, a trend for higher %VS was observed for all coronary segments with 3D-SN, while significant improvement was obtained for the right (RCA) and the left circumflex (LCX) coronary arteries (Tab.1). A total of 58/72 coronary segments were visualized by 3D-SN, whereas the 1D-SN technique allowed visualization of 50/72 segments. Vessel length and average diameter did not show significant differences between the two techniques.



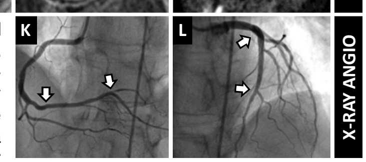



**Figure 2 – Example reformats of the right (A, B, D, F, G, I) and left anterior descending (C, H, E, J) coronary arteries in patients.** Good overall image quality is obtained with 1D-SN reconstruction (A-E, arrows). By comparison, improved depiction of proximal coronary segments and visualization of distal ones can be observed on the 3D-SN images (F-J, arrows). In patient #3 3D-SN images show a good depiction of the anatomy in comparison to 1D-SN and a longer contiguous segment of the RCA (I, arrows) with the x-ray angiography as reference.

| *Method:* | *1D SN* | *3D SN* | *1D SN* | *3D SN* | *1D SN* | *3D SN* | *1D SN* | *3D SN* |
|---|---|---|---|---|---|---|---|---|
| **Segment:** | **LM** | | **RCA prox** | | **RCA mid** | | **RCA dist** | |
| Visualized | 9/9 | 9/9 | 8/9 | 9/9 | 8/9 | 9/9 | 5/9 | 6/9 |
| Sharpness | 42.3 ± 9.3 | 47.3 ± 13.5 | 37.8 ± 12.6 | 39.6 ± 9.8 * | 37.4 ± 12.0 | 43.8 ± 12.6 * | 24.3 ± 10.4 | 34.6 ± 4.1 |
| **Segment:** | **LCX** | | **LAD prox** | | **LAD mid** | | **LAD dist** | |
| Visualized | 4/9 | 5/9 | 8/9 | 9/9 | 6/9 | 8/9 | 2/9 | 3/9 |
| Sharpness | 37.3 ± 1.2 | 46.8 ± 8.4 * | 40.6 ± 11.8 | 43.5 ± 8.8 | 40.6 ± 6.3 | 40.5 ± 10.2 | 31.3 ± 4.5 | 37.9 ± 4.6 |

**Table 1 – Quantitative analysis of coronary artery segments.** Left main (LM), LCX, RCA and left anterior descending (LAD) segments were analyzed and compared for 3D-SN and 1D-SN. (*) indicates statistical significance ($p<0.05$).

**Discussion and Conclusion:** A novel *image-based* SN approach for free-breathing coronary MRA was preliminarily tested in patients for the first time. The proposed technique enables 3D motion correction in a patient setting with 100% scan efficiency and without the need of additional navigator images. Future efforts will focus on improving robustness of the technique for inline implementation in order to enable 3D correction at the scanner. As for the image quality, it is worth noting that the patients were selected blindly with respect to coronary artery disease, therefore it may not be excluded that some coronary segments are invisible (stents, disease) even after optimal motion correction. In conclusion, the proposed 3D-SN technique demonstrates great promise to improve overall vessel sharpness and visualization when compared to conventional 1D-SN. Such improvements in motion correction may allow increased confidence in the detection/exclusion of stenosis for self-navigated coronary MRA[10]. Since this study was conducted in a small patient cohort, future work will focus on the analysis of a selected patient population with known or suspected coronary artery disease and gold standard comparison with state-of-the-art x-ray angiography.


**References: 1.** Stehning MRM 2005 **2.** Piccini MRM 2012 **3.** Bhat MRM 2010 **4** Pang MRM 2014 **5.** Bonanno ISMRM 2014 **6.** Hyvärinen IEEE-TNN-1999 **7.** Chefd'hotel IEEE-ISBI-2002 **7.** Bonanno Int MR Angio Working Group 2014 **8.** Piccini MRM 2011 **9.** Etienne MRM 2002 **10.** Piccini Radiology 2014.