Optimized Respiratory Reference Position for 3D Self-Navigated Whole Heart Coronary MRA

Davide Piccini[1,2], Gabriele Bonanno[2], Giulia Ginami[2,3], Arne Littmann[4], Michael O. Zenge[4], and Matthias Stuber[2]

[1]Advanced Clinical Imaging Technology, Siemens Healthcare IM S AW, Lausanne, Switzerland, [2]Department of Radiology, University Hospital (CHUV) and University of Lausanne (UNIL) / Center for Biomedical Imaging (CIBM), Lausanne, Switzerland, [3]Department of Information Engineering, University of Padova, Padova, Italy, [4]MR Application and Workflow Development, Healthcare Sector, Siemens AG, Erlangen, Bayern, Germany

INTRODUCTION: As demonstrated in several recent publications, respiratory self-navigation (SN) improves the ease-of-use, scanning time and temporal resolution in whole heart coronary MRA when compared to more conventional navigator-based approaches [1]. Using SN, respiratory motion information is directly extracted from the image data in k-space and used to suppress respiratory motion artifacts during image reconstruction. Similar to conventional navigator techniques, a respiratory reference position is selected at the very beginning of the image data acquisition [2, 3]. Correction of the subsequently acquired image data is then always performed relative to this original reference position. This setup allows inline motion detection and correction, thus providing both a real-time feedback on the performances of the SN algorithm [3] and an inline reconstruction of the dataset. Although good results have been reported with this standard methodology, the influence of the choice of the reference position on the final image quality has, to our best knowledge, not yet been ascertained. Respiratory reference positions from end-expiration or end-inspiration may be more suitable candidates since such respiratory phases represent pauses of the respiration and are characterized by a lower velocity of the heart. In addition, end-expiratory positions occur more frequently and less overall motion correction is needed as a result. Furthermore, the average or mean respiratory position may be advantageous as well, since respiratory motion correction over larger distances and related non-linear effects can be avoided. In this work, the relationship between the choice of the reference position for SN coronary MRA and objective image quality was investigated.

METHODS: Free breathing self-navigated whole-heart coronary MRA was performed in N=11 healthy volunteers, after informed consent was obtained and with approval of the institutional review board. Two different 1.5T clinical MRI scanners (MAGNETOM Avanto and Aera, Siemens AG, Healthcare Sector, Erlangen, Germany) were used in this study. Data acquisition was performed with a 3D radial trajectory implementing an interleaved spiral phyllotaxis pattern [4], which was adapted to self-navigation through an additional readout oriented along the superior inferior (SI) direction at the beginning of each interleave [3]. All measurements were segmented and ECG triggered. The acquisition window (~100ms) was placed in mid-diastole. The protocol parameters of the non slice-selective, T_2-prepared, fat-saturated, balanced steady state free precession (bSSFP) imaging sequence were set as follows: TR/TE 3.0-3.1/1.51-1.56ms, FOV $(220mm)^3$, matrix 192^3, voxel size $(1.15mm)^3$, radio frequency (RF) excitation angle 90°, and receiver bandwidth 898 Hz/Pixel. In all cases, a total of 11687 radial readouts were acquired in 377 heartbeats, with an overall Nyquist undersampling ratio of 20%. During post-processing, the algorithm for the automatic segmentation of the blood pool described in [3] was applied to all SI readouts to define all respiratory positions of the blood pool for each dataset. The vector containing the positions was sorted into a 50-bin histogram and analyzed in Matlab (The MathWorks Inc., Natick, MA). Mean (μ_i) and standard deviation (σ_i) of the respiratory positions vector were computed for each volunteer (i = 1... N). Offline motion detection, motion correction and reconstruction of all datasets were performed using four different reference respiratory positions: random, end-inspiration (end-insp), end-expiration (end-exp), and mean. Furthermore, one dataset was reconstructed without motion correction, for comparison. To represent the random respiratory reference position, the very first acquired SI readout of the scan was selected as in the standard SN approach [3]. The reference readouts for end-insp and end-exp were selected from the two extreme bins of the histogram, whereas the readout in which the position of the blood pool was closest to μ_i was chosen to represent the mean reference respiratory position. Using these reference positions, image reconstruction incorporating motion correction was performed prior to visual and quantitative image quality assessment. For this quantitative image analysis, a 2 cm segment of the mid portion of the left anterior descending coronary artery (LAD) was selected from all the reconstructed volumes. Percentage vessel sharpness (%VS) of each coronary segment was then computed using an approach similar to that described in [5]. Statistical comparisons were performed by means of a paired two-tailed Student's t-test with Bonferroni correction for multiple comparisons.

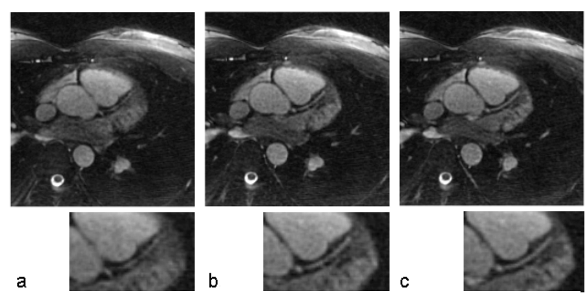

Figure 1: Example of image quality using different reference respiratory positions for the self-navigation algorithm. The image quality increases from the uncorrected reconstruction (a) to the corrected datasets using end-inspiratory (b) and end-expiratory (c) reference positions. A slight, but significant, improvement from (b) to (c) can also be noticed in the zoomed section of the mid LAD.

RESULTS: All acquisitions and reconstructions were successful for all datasets. A clear improvement in image quality could be observed in all motion corrected datasets with respect to those where correction was not performed (Fig. 1,a). In general, major differences in image quality among the corrected datasets (Fig. 1,b-c) could not be identified by visual assessment. The %VS of the mid-LAD (Fig. 2) reconstructed without motion correction was 49.8 ± 16.6 %. With motion correction and using the random reference, 58.1 ± 18.2 %VS was measured, while that from end-insp amounted to 55.8 ± 18.0 %VS, and that from end-exp to 58.2 ± 18.2 %VS, respectively. Using the mean value as a reference level, %VS was measured as 57.8 ± 18.9 %. The improvement in %VS of the mid LAD was significant for all the selected respiratory reference positions when compared to the datasets that were obtained without motion correction (worst case, end-insp: $p < 0.004$). The selection of an end-expiratory reference position led to a significantly improved %VS when compared to that of end-inspiration ($p<0.003$).

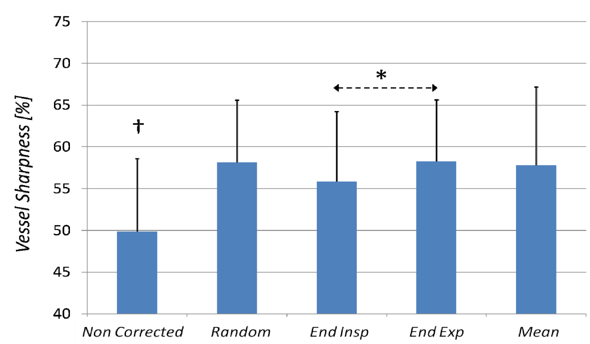

Figure 2: Mean and standard deviation of the vessel sharpness for all 11 volunteers. The increased sharpness with respect to the non-corrected reconstruction was statistically significant using all choices of the reference († $p<0.004$). Among the different reference positions, a significant difference in %VS was only found between the end-inspiration and end-expiration (* $p<0.003$).

DISCUSSION AND CONCLUSIONS: In the context of respiratory self-navigation for coronary MRA, a direct influence of the choice of the reference respiratory position on the final image quality was identified. However, a statistically significant difference in vessel sharpness was only measured between end-insp and end-exp. As the end-expiratory phase occurs more frequently, both the random choice and the mean of the reference position will be biased towards end-exp. This may explain the relative similarity of the findings. In conclusion, although the performances of the standard approach, where the reference respiratory position is chosen at the beginning of the measurement, are on average satisfactory, the choice of an end-exp reference could significantly improve image quality in individual cases. Starting the free-breathing SN acquisition with a short breathhold in end-expiration could thus be an easy solution to ensure both optimal image quality and inline feedback and reconstruction of the dataset.

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This work was supported by CIBM of the UNIL, UNIGE, HUG, CHUV, EPFL and the Leenaards and Jeantet Foundations.