An Iterative Self-Navigation Approach to Improve Image Quality in Subjects with Irregular Breathing in Whole Heart Coronary MRA.

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TARGET AUDIENCE: Scientist and clinicians interested in whole-heart coronary MRA and motion compensation techniques.

PURPOSE: Self-navigation (SN) has been introduced as a promising technique to perform respiratory motion correction in whole heart coronary MRA [1,2]. It has been demonstrated that this technique improves the ease of use and scan efficiency when compared to more standard navigator-gated approaches [3]. For conventional SN, the position of the heart extracted from the very first acquired data segment is used as reference position for the respiratory motion correction. However, as this reference is obtained during free breathing, a random position in the respiratory cycle is essentially chosen. Although good results have been reported with this methodology, a recent study performed in healthy volunteers with a 1D SN technique based on motion detection in superior-inferior (SI) projections demonstrated that the choice of end-expiration (end-exp) as respiratory reference position can significantly improve the image quality in comparison to end-inspiration (end-insp). This has been attributed to the more frequent occurrence of end-expiratory respiratory levels [4]. Even though end-exp has shown to be the most advantageous choice for a respiratory reference position in healthy volunteers, this may not necessarily apply to patients with less regular respiratory patterns. In addition, the standard SN technique only investigates the correlation between the reference SN profile and those acquired during the entire data collection and a mutual comparison among all SI projections is never performed. Due to these considerations, an approach that does not require a specific respiratory reference position might lead to improved results. In this work, we first test the hypothesis that end-exp might not be the most frequent respiratory phase in patients with irregular breathing patterns. Secondly, we present an iterative SN approach, which operates without the need of an explicit reference respiratory position. This algorithm aims at minimizing the total magnitude of 1D SI correction of the heart during the entire data collection period.

METHODS: Free breathing, self-navigated coronary MRA was performed in both healthy volunteers (n=11) and in clinical patients with suspected or confirmed cardiovascular artery disease (CAD) (n =25), after informed consent was obtained. Data acquisition was ECG-triggered to the most quiescent mid-diastolic phase (acquisition window ~100ms) using a segmented 3D radial trajectory [5] specifically adapted to SN by acquiring an additional readout oriented along the SI direction at the very beginning of each data segment [2]. Two different scanners (MAGNETOM Avanto and MAGNETOM Aera, Siemens AG, Healthcare sector, Erlangen, Germany) were used in this study. Parameters were set as follows: TR/TE 3.0-3.1/1.5-1.56ms, FOV $(220mm)^3$, matrix 192^3, voxel size $(1.15mm)^3$, RF excitation angle 90°, and receiver bandwidth 898Hz/pixel. In all cases, the entire data collection was performed during 377 to 610 heartbeats, dependent on the heart rate of the subjects. The respiratory position of the blood pool for each data segment was identified on the SI readouts using the algorithm for the automatic segmentation of the blood pool described in [2]. All the segmented respiratory positions for each volunteer/patient were stored in a vector as a representation of the respiratory breathing pattern of each specific subject during the SN acquisition. Subsequently, the mean (μ) and the standard deviation (δ) of the respiratory pattern were calculated for all subjects. To classify and compare each breathing pattern, all the respiratory positions above the value of $\mu+0.5*\delta$ were attributed to end-exp, whereas those below the value of $\mu-0.5*\delta$ were classified as end-insp. All the positions in-between were considered as “undefined respiratory phases”. As for the iterative SN algorithm, a quality index Q was designed in order to quantify the residual motion among all the acquired SI projections, and an iterative optimization algorithm was implemented. Specifically, Q was defined as the inverse of the average value of the cross-correlation of the vector containing all the combination of the SI projections. At each iteration step, all the SI projections were individually shifted within a predefined range of allowed shifts; large shifts were penalized by the algorithm. The iterative process was stopped when the combination of shifts that minimizes the value of Q was identified. Then, these shifts were applied for motion correction directly in k-space. All the datasets were reconstructed with the proposed iterative approach, by using the standard SN technique and end-exp as reference, and without motion correction for comparison for two separate groups: volunteers and patients. In all the reconstructed volumes, the percentage vessel sharpness (%VS) of the first 2 cm of the left anterior descending coronary artery (LAD) was computed as a measure of image quality using the approach described in [6]. A paired two-tailed Student’s t-test corrected for multiple comparisons was performed to quantify statistical significance.

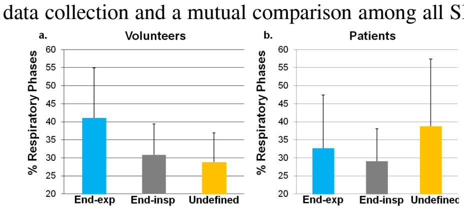

Figure 1: Percentages of respiratory phase occurrences in healthy volunteers (a) and clinical patients (b). The most frequent respiratory phase observed in volunteers was end-exp, whereas patients tended to stay predominantly in an undefined respiratory phase between end-insp and end-exp.

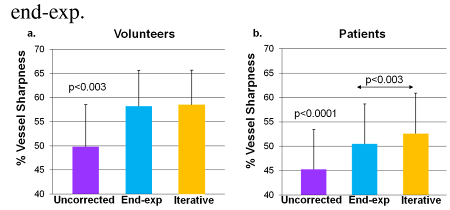

Figure 2: Computed %VS in healthy volunteers (a) and clinical patients (b). A significant difference was found between the datasets of clinical patients corrected with end-exp and with the iterative approach.

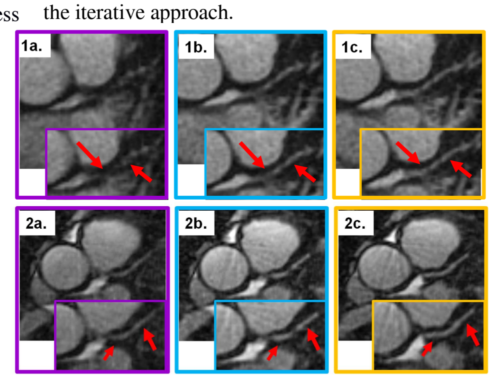

Figure 3: Example of reconstructed datasets in 2 different clinical patients (row 1 and row 2). A difference in image quality can be observed between the uncorrected datasets (column a), the datasets corrected with end-exp (column b), and the iterative method (column c). A slight improvement in image quality can be noticed in (c), when compared with (b).

RESULTS: All the acquisitions and reconstructions were successful for all acquired datasets. The percentages of occurrences for the different respiratory phases are shown in Figure 1, both for healthy volunteers (a), and for clinical patients (b). While the most frequently observed respiratory phase was end-exp in healthy volunteers (41.1±13.8%), clinical patients were found to have a highest occurrence of “undefined respiratory phases” (38.8±18.6%). In Figure 2, the calculated values of %VS are reported, again both for healthy volunteers (a), and clinical patients (b), respectively. The improvement in %VS was statistically significant for all the motion corrected datasets when compared to the datasets for which motion correction was not performed for both volunteers and patients ($p<0.003$ and $p<0.0001$, respectively). In healthy volunteers, no statistically significant difference was found between datasets corrected using end-exp as reference respiratory position or using the iterative approach. Conversely, in patients, the %VS was significantly improved using the iterative approach when compared to the datasets corrected using the end-expiratory phase as a reference ($p<0.003$). This improvement in %VS can be also noticed in many of the datasets by using a visual inspection (Figure 3).

DISCUSSION AND CONCLUSION: In this study, differences in the respiratory patterns of volunteers and patients were analyzed and reported using a respiratory self-navigated approach. While end-expiration is the most frequent respiratory phase in healthy volunteers, the average respiratory pattern measured in our group of patients suggests that “undefined” respiratory positions somewhere between end-exp and end-insp are most frequent. This confirms our above hypothesis that end-exp may not be the most frequently occurring respiratory position in patients with irregular breathing patterns. These findings may further help to discriminate between regular and irregular breathing patterns. The novel iterative approach for self-navigation described here has the advantage of being independent from the choice of a specific respiratory reference position. When compared to the standard approach, a significantly improved performance of this technique has been documented mainly in patients with irregular breathing patterns. In healthy volunteers, the iterative approach does not perform above and beyond the technique that favors end-exp as a reference position. In summary, this iterative approach significantly improves coronary MRA image quality in selected clinical patient cohorts.

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