

A Quantitative Comparison Between Slice-Followed and Non-Slice-Followed 3T bSSFP CSPAMM Myocardial Motion Tracking

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Introduction

Myocardial tagging ([1], [2]) has been extensively used for the detailed and quantitative investigation of myocardial motion. In particular, Complementary SPATial Modulation of the Magnetization (CSPAMM) [3] has enabled the analysis of motion and deformation throughout the entire cardiac cycle. Slice-followed CSPAMM was subsequently proposed to avoid effects of through-plane motion and to enable true myocardial motion tracking [4]. With recent advances in hardware and software, CSPAMM has also been combined with balanced Steady State Free Precession (bSSFP) imaging [5] at 1.5T, resulting in superior diagnostic performance when compared to a spoiled gradient echo signal-readout [6]. Simultaneously, a recent evaluation of bSSFP CSPAMM implemented at 3T showed significant improvement in contrast-to-noise ratio (CNR) and high accuracy of motion parameter measurements when compared to bSSFP CSPAMM at 1.5T [7]. However, and to our knowledge, a direct quantitative comparison of strain measurements with and without slice following at different anatomical levels of the heart has not yet been performed. Because of systolic base-to-apex long axis shortening, we hypothesize that there are significant differences in quantitative short axis strain measurements between slice-followed (SF) and non-slice-followed (non-SF) CSPAMM acquisitions. For these reasons, a 3T bSSFP CSPAMM technique was implemented with and without SF, validated in vitro, and quantitatively compared in vivo.

Materials and methods

A bSSFP CSPAMM sequence, with linearly increasing start-up angles (LISA) [5] was modified by adding slice-following capabilities as described in [3]. Two sets of phantom experiments were performed for comparing SF and non-SF. First, and to measure tag persistence, both SF and non-SF acquisitions were performed in a static phantom with a T₁ and T₂ of myocardium. Secondly, cylindrical phantoms (axis in anterior-posterior direction) with T₁ and T₂ of blood and myocardium were mounted on a periodically moving phantom that moved in parallel to B₀ with an amplitude of 2cm and a frequency of 1.083 Hz (i.e. mimicking a 65 bpm heart rate). These phantoms always moved in the same axial plane. The signal from a fiber optic light transmission periodically interrupted by the moving phantom was used as an external ECG to synchronize the CSPAMM acquisition with the phantom motion. The tagged slice was axial and localized in the center of the two cylinders. Cine CSPAMM imaging was then performed with and without SF. Using such a configuration, and using a static axial imaging plane as is the case for non-SF, the cylinders are expected to gradually move in and out of the field-of-view and a change in their diameter would be measurable as a direct consequence of through-plane motion. Finally, datasets from 10 healthy adult subjects were acquired at multiple anatomical levels of the heart with and without SF. All MRI was performed on a 3T clinical MRI scanner (MAGNETOM Trio, Siemens AG, Healthcare Sector, Erlangen, Germany) with the following acquisition parameters: TE/TR = 1.34/3.09 ms, radiofrequency excitation angle 12°, readout bandwidth 849Hz/Pixel and a temporal resolution of ~43ms. The matrix size was 84x256 (33% phase resolution), tag slice thickness and in plane resolution were set to 8mm and 3.8x1.3mm² respectively, with an acquired FOV of 320x320mm². In the moving phantom study, the thickness of the imaged slice was 50mm for SF and 8mm for non-SF. In the static phantom experiment, as well as for the in vivo scans, three short axis slices were acquired with varying imaged slice thickness: basal (30 mm), mid ventricular (25mm) and apical (30mm). Each CSPAMM acquisition was performed during a short 16 heartbeat breath hold. The visible area of the cylinders in the moving phantom study was measured in each cine frame to document the effect of through-plane motion on images acquired with and without SF. Datasets from the non moving phantom and from the in vivo acquisitions were used for SNR and tag-CNR calculations over time. For each volunteer, myocardial contraction was assessed using Harmonic Phase Imaging [8] (HARP, v4.1, Diagnosoft Inc., Palo Alto, CA, USA). Left ventricular circumferential strain and rotation were calculated for each of the three acquired slices. Statistical differences between the two methods were tested with a paired two-tailed Student's t-test at each time point.

Results

Without SF, the measured area of the moving phantom decreased to 8.3% of its original value. With SF, a constant area was measured for all cine frames with an overall standard deviation as low as 2%. The relative standard deviation of the SNR over time for the static phantom was 3.8% for non-SF and 3.7% for SF. The tag-CNR decrease between the first and last cine frame was 55.8±0% and 62.7±1.1% for non-SF and SF, respectively. However, the tags were well visible until the last cine frame which had a tag-CNR of 59±0 for non-SF and 52.5±0.2 for SF. In vivo, the relative standard deviation of SNR over time was lower than 6% for non-SF and <3% for SF. The tag-CNR decrease over time was 52.5±3.7 % for non-SF and 48.8±0.5% for SF (p=0.35). Consistent with the above phantom experiments, a high tag-CNR persisted throughout the entire cardiac cycle for both SF and non-SF. At the base of the heart, the HARP analysis unequivocally demonstrated significant quantitative differences between the two techniques. The circumferential strain during early and mid diastole (Fig. 1a) as well as the end-systolic rotation angle were significantly different (-4.5±1.6° non-SF and -3.3±1.6° SF at end systole, p<0.05). Consistent with these findings, and if through-plane motion is not accounted for, not always the same tissue is visualized throughout the cardiac cycle as demonstrated in Fig. 2, arrow. Even though the average values of circumferential strain did not show any significant differences between the two methods at the apex (Fig. 1b)), the difference in apical rotation during rapid early diastolic untwisting was still statistically significant (2.3±1.8° non-SF and 4.5±3.5 SF, p<0.05).

Discussion and conclusion

The phantom experiments clearly confirmed the effectiveness of SF 3T bSSFP CSPAMM, for which the tag contrast remained high on all acquired cine frames while the same tagged slice was always visualized despite through-plane motion. While SNR and tag-CNR between SF and non-SF remained high for all acquired cine frames, the area change observed on the tagged images acquired with non-SF clearly documented the inadequacy of the technique to account for through plane motion. SNR and CNR changes over time in both the phantom and volunteer study may be explained by the use of constant RF excitation angles, that do not account for T1 recovery of the tagged information. At the base, a significant underestimation of strain and overestimation of rotation was measured during early diastole if through-plane motion is not accounted for. Simultaneously, early diastolic rotation at the apex was underestimated without SF. Therefore, the hypothesis that there exist significant differences in quantitative short axis rotation and strain measurements between SF and non-SF CSPAMM acquisitions was tested positive.

References

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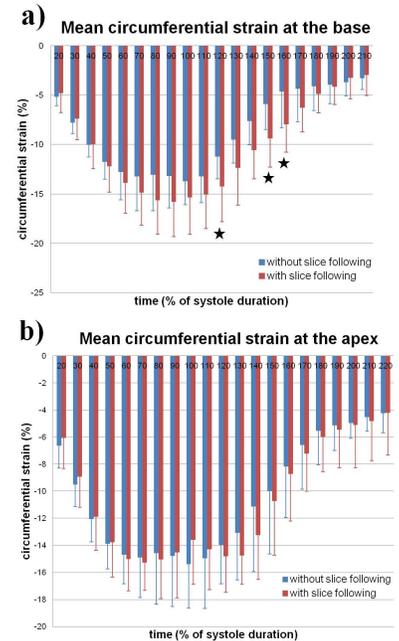


Figure 1. Mean circumferential strain at the base (a) and apex (b) of the heart over all 10 healthy volunteers. The stars indicate the time points where the comparison between the results obtained without and with SF were found to be statistically significant.

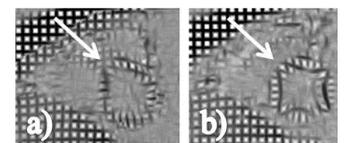


Figure 2. Significant anatomical differences on the basal slice in a volunteer without (a) and with (b) SF at end systole.