Implementation of 3-SPAMM for Myocardial Motion Analysis with HARP

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Introduction Myocardial tagging combined with harmonic phase analysis (HARP) [1] has proven to be an accurate and fast method for the quantification of myocardial deformation. With complementary spatial modulation of magnetization (CSPAMM) [2] the DC peak can be suppressed by acquiring a second measurement with phase-shifted tagging modulation and subtracting this from the first measurement. A filter is used to extract the first harmonic peak in k-space for HARP analysis. Recently, a method was presented [3-4] to eliminate both the DC and the negative harmonic peak by adding at least four SPAMM acquisitions with phase-shifted magnetization modulations, thus enabling HARP analysis without (or with only mild) filtering. In order to minimize motion artifacts, all measurements should ideally be acquired within one breath-hold, but this is often difficult to achieve in practice. In a separate abstract [5], we present the general theory of a method that allows suppressing of two peaks in k-space with only three acquisitions, thus allow the scan to fit within a single breath-hold. In this work, we present the performance analysis of this new method in human breathheld cardiac tagging.

Methods As introduced in [5], it is possible to separate N harmonic peaks by acquiring only N SPAMM measurements with different tagging modulations. Briefly, the 1-dimensional situation is illustrated in figure 1. Due to the Fourier-shift theorem, the harmonic peaks in k-space exhibit different phases depending on the shift in image space, whereby the corresponding harmonic peaks in opposite positions in k-space are complex conjugated. Two-dimensional displacements are encoded by two 3-SPAMM measurements in two orthogonal spatial directions. Theoretically, no filtering is needed for HARP analysis. However, in practice, slight motion can lead to incomplete signal cancellation, and filtering is also useful for maintaining an adequate signal-to-noise ratio for tracking and strain analysis. Myocardial 3-SPAMM images from a healthy volunteer were acquired at the equatorial level in one breath-hold on a Philips 1.5T scanner (Philips Medical Systems, Best, NL). An EPI-sequence was used applying slice following [4] (FOV:330mm, matrix:128x39, reconstructed matrix:256x256, EPI-factor:11, cardiac phases:20, temporal resolution:30, ramped flip angles, total scan time:19s). In order to obtain the same SNR to validate the performance of 3-SPAMM compared to CSPAMM, two 3-SPAMM and three CSPAMM measurements were acquired and averaged. Each tagging direction on the equatorial level was acquired in a separate breath-hold using a slice following EPI-sequence with the same parameters as above. Total scan time for both breath-holds was 33s.

A midwall contour consisting of 72 landmark points was tracked throughout the cardiac cycle using HARP incorporating peak combination [4]. The performance of HARP analysis was examined by varying the filter radius and determining the number of correctly tracked points.

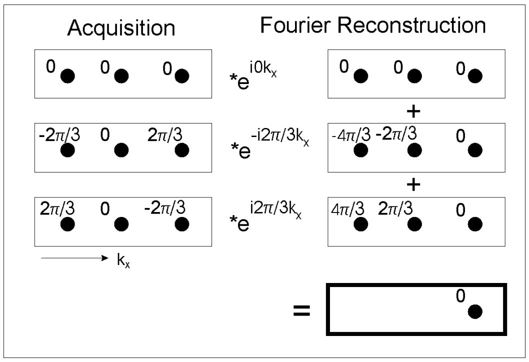

Figure 1: Encoding and Decoding of 3-SPAMM. Dots represent the harmonic and DC peaks in k-space, and the numbers indicate the corresponding phase, as a result of shifts of the tagging pattern.

Results Fig. 2 shows the circumferential shortening for the 3-SPAMM acquisition in a single breath-hold for 8 different myocardial sectors (HARP-filter radius: 21 pixels). The number of points (out of 72) tracked correctly throughout the cardiac cycle for a varying HARP-filter radius is shown in Fig. 3. For CSPAMM, tracking fails completely as soon as signal from the anti-echo leaks into the filter. With 3-SPAMM, tracking is possible in principle without the use of any filter and thus allowing maximal strain resolution. However, due to limited SNR, tracking performance degrades for larger filter radii (e.g. filter radius>25 pixels for 3-SPAMM acquisition without averaging, Fig.3).

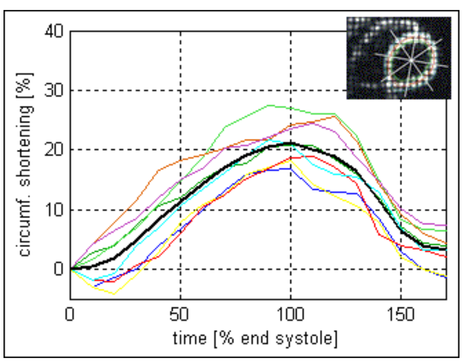

Figure 2: Circumferential shortening for 3-SPAMM in one breath-hold. HARP-filter:21px

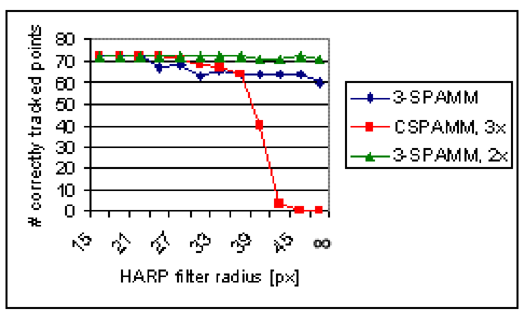

Figure 3: Number of correctly tracked points (out of 72) for varying HARP filter radius

Conclusion 3-SPAMM could be implemented to acquire tagged myocardial short-axis images in one breath-hold. With CSPAMM, filtering is always necessary for HARP analysis, whereas maximal strain resolution can be achieved with 3-SPAMM at the expense of SNR in the tracking result. Since there is no (or little) interference from the anti-echo, a smaller tagging modulation frequency can be used to gain SNR, and the size of the HARP filter can be chosen solely based on SNR considerations.

References [1] Osman NF, et al., 1999, MRM 42(6): 1048-60. [2] Fischer SE, et al., 1993, MRM 30(2): 191-200. [3] Epstein FH, et al. MRM 2004;52(4):774-781. [4] Aletras AH, et al. JMR 2004;169(2):246-249. [5] Tsao J, et al., (submitted), Proc ISMRM [4] Ryf S, et al. 2004, Proc SCMR: 451