Peak-Combination HARP for Increased Reproducibility of Tagging Analysis

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Introduction

Myocardial tagging combined with HARP (1) is a powerful method to quantify myocardial motion of healthy and diseased hearts. HARP extracts one of the first harmonic peaks in *k*-space produced by SPAMM (2) or CSPAMM (3). Using the displacement-encoded phase contrast, any point on the myocardium can be tracked. However, the phase information of MR images is susceptible to nonidealities, such as B_0 inhomogeneity, chemical shift, flow, etc. These effects are accentuated with longer readouts and at higher magnetic fields. Thus, the phase of HARP images can be adulterated, leading to incorrect tracking of the myocardium. In this work, we propose to correct this problem by using both the positive and negative first harmonic peaks. In the images from the two peaks, the HARP phase (i.e. from tagging) have opposite signs, while the additional phase arising from nonidealities have the same sign. Thus, by phase subtraction of the two, the HARP phase is added while the spurious phase is eliminated

Methods

Tagging measurements: CSPAMM images with a tag-line distance of 8mm were acquired in phantom and in six healthy volunteers on a 1.5 T Scanner (Intera, Philips Medical Systems, Best, Netherlands). The tag lines were applied in two directions and separate images were acquired for each tagging direction. CSPAMM images were acquired with a conventional EPI sequence (EPI-factor: 13, FOV: 380mm, matrix: 128x39). Twenty cine frames with a temporal resolution of 35 ms were acquired. In each volunteer, two CSPAMM scans were acquired in the same position in two separate breath holds.

HARP evaluation: For each scan, the endo- and epicardium were manually selected in an end-diastolic frame. The centerline calculated from epi- and endocardium was then HARP-tracked conventionally with different selections of the peaks and with peak-combination HARP. The centerline was divided counter-clockwise into eight sectors relative to the position of the anterior junction of right and left ventricles. rotating counterclock-wise. The circumferential fiber-shortening (cFS) of each sector and of the entire circumference (=centerline) were calculated over the cardiac cycle. Maximum cFS of the centerline and the sectors 4-6, where B_0 inhomogeneity was expected, were compared in each volunteer for the two scans and the different evaluation methods.

Peak combination HARP: CSPAMM image for tag direction 1 (without motion): $I_1 \propto (e^{i\cdot(k_1\cdot x+\varphi_1)} + e^{-i\cdot(k_1\cdot x+\varphi_1)})\cdot e^{i\cdot\beta(x,y)}$ where k_1 = spatial frequency of tag lines; φ_1 = phase at (*x*,*y*)=(0,0); $\beta(x,y)$ = additional phase originating from nonidealities such as B_0 inhomogeneity. Extraction of positive and negative peaks in k-space: $I_1^{\pm} \propto e^{\pm i\cdot(k_1\cdot x+\varphi_1)}\cdot e^{i\cdot\beta(x,y)}$, phase: $P_1^{\pm} = \pm(k_1\cdot x+\varphi_1)+\beta(x,y)$. Peak combination ("*"complex conjugate): $I_1^{PC} = \left(I_1^{+}\right)\cdot\left(I_1^{-}\right)^{*} \propto e^{i\cdot(2\cdot k_1\cdot x+2\cdot\varphi_1)}$ phase: $P_1^{PC} = 2\cdot(k_1\cdot x+\varphi_1)$. Note that *ß(x,y)* is eliminated in P_1^{PC}. The same procedure is applied to tag direction 2.

Results

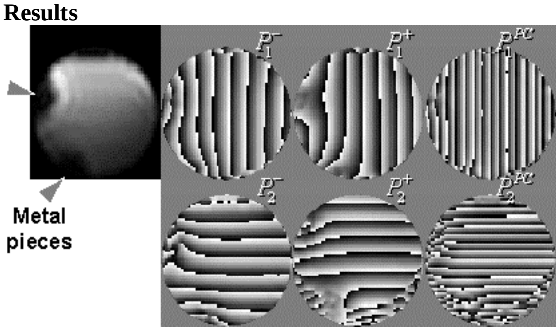

Figure 1: *Two small metal pieces were attached to a bottle phantom (T1: 1000ms) to produce an inhomogeneous B_0 field, which causes shifts in opposite directions in P^- and P^+. For P^{PC} the additional phase is eliminated.*

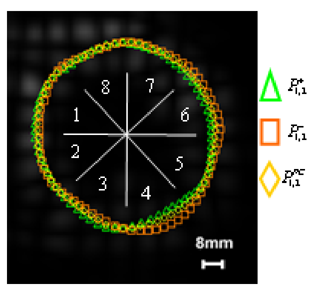

Figure 2: *Centerline at end systole evaluated with conventional HARP ($P^{\pm}$) and peak combination HARP (P^{PC}). The tracking depends on the peak selection (sector 4 to 6).*

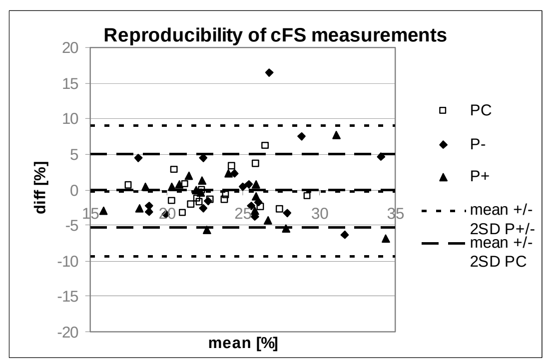

Figure 3: *Differences of two measurements for cFS in sectors 4-6. 95% confidence intervals for $P^{\pm}$ are almost doubled compared with P^{PC}*

HARP tracking can be adulterated by B_0 inhomogeneity which affects reproducibility of tagging evaluation. To measure a difference of 10% in segmental cFS (=2.5 absolute % points in cFS) with P^{PC} a sample size of 34 subjects is required compared with approximately 100 subjects for P^+ or P^- (at a level of significance of 5% and a power of 80%). Furthermore, the mean difference between repeated measurements of segmental cFS was -0.15% for P^{PC}, whereas the differences were -0.94% and +0.60% for P^- and P^+, respectively (not significant, ANOVA).

Discussion

Nonidealities such as B_0 inhomogeneity can lead to distortion of the image phase, which causes shifts in opposite directions in P^- and P^+, resulting in incorrect tracking and motion analysis in HARP (Fig. 2). With peak-combination HARP, the additional phase $\beta(x,y)$ is eliminated, thus improving the accuracy and reproducibility in HARP evaluation.

References

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