In vivo comparison of CSPAMM and DENSE for cardiac motion analysis

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Introduction

Tagging has shown great promise for analyzing cardiac motion patterns [1]. Two different methods have been proposed to utilize the phase associated with harmonic modulation of magnetization to enable tissue tracking. Using Displacement ENcoding with Stimulated Echoes (DENSE) [2] tagged magnetization is demodulated by decoding gradients permitting motion tracking from the signal phase. In contrast, HARmonic Phase (HARP) [3] analysis of Complementary SPAtial Modulation of Magnetization (CSPAMM) [4] data decomposes tagged data into its harmonic components during post-processing. In order to improve the signal-to-noise ratio, harmonic components can be combined with appropriate phase referring to peak-combination HARP as introduced in [5]. The relation between DENSE and HARP is illustrated in Figure 1 including the possibility of signal combination. Following the insight of the Fourier shift theorem, it has been argued that the information content of DENSE and HARP should be identical [6]. However, a formal comparison of DENSE and HARP has not been undertaken to date.

In this study, DENSE and HARP data were obtained consecutively in the same subjects and circumferential shortening, rotation and time-to-peak motion were evaluated with and without employing signal peak combination.

Methods

Eight healthy volunteers were imaged using 2D CSPAMM [3] and 2D DENSE [7] with identical scan duration (~14sec) using a Philips 1.5T system (Philips Healthcare, Best, The Netherlands). Data were read out using an EPI sequence with the following parameters: TR/TE/α = 30ms/5.3ms/20°, acquisition matrix of 96×42 (CSPAMM) or 48×40 (DENSE) reconstructed to 192×192, FOV of 320mm×253mm, slice thickness of 8mm. Tagging was applied using 2x lines (line distance: 8mm) employing two orthogonal imaging stacks.

Data were analyzed using TagTrack v.1.8 (GyroTools Ltd, Zurich, Switzerland). For DENSE the echo signal was shifted by 20.8% in k-space (corresponding to 8mm tag line distance), to create a phase image for conventional single peak HARP processing. For peak combined HARP processing two DENSE acquisitions were combined, shifting the echo peak and the anti echo peak in opposite direction in k-space. CSPAMM data were processed directly with the HARP method using the peak combination, and the conventional single peak method.

The mid-contour inside the left ventricular myocardium was tracked starting from an end-diastolic frame. Initial contours were identical for DENSE and CSPAMM data to reduce observer variability. The left ventricle was segmented into six equidistant sectors and resulting curves for circumferential length and rotation were fitted by a fourth order polynomial. Differences between both methods are presented in percentage of the average of the paired values.

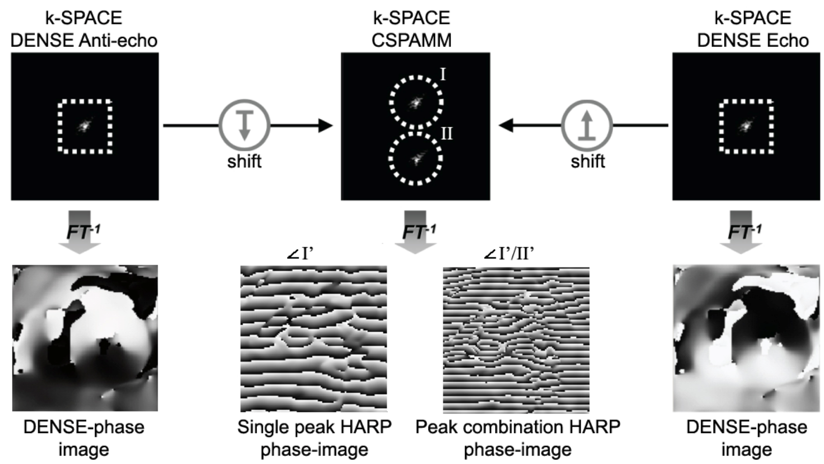

Figure 1. Relation between DENSE and HARP w/o and with peak-combination. The effect of the decoding gradients in DENSE imaging is reversed by shifting the stimulated echo and anti-echo peaks in k-space by the tagging modulation frequency resulting in a k-space representation equivalent to CSPAMM acquisitions. The HARP algorithm can then be used on the phase of either a single harmonic peak (I) or after complex division of both peaks (I/II) upon inverse Fourier transform.

Results

Table 1 gives a detailed overview of the mean difference ± one standard deviation between DENSE and CSPAMM acquisitions using the single peak HARP and peak combination HARP method. All values are shown in percentage of the average between DENSE and CSPAMM measurements. Measurements of the time-to-peak motion showed less variation than quantification of rotation and circumferential shortening. For all timing measurements the first standard deviation of the differences was within the range of the temporal resolution of the acquisitions.

	Time-to-peak rotation [%]	
	mean difference	standard deviation
HARP	0.0	15.8
Peak combination HARP	-1.61	16.6

	Amount of rotation [%]	
	mean difference	standard deviation
HARP	1.6	31.2
Peak combination HARP	1.1	32.9

	Time-to-peak circumferential shortening [%]	
	mean difference	standard deviation
HARP	-0.2	5.0
Peak combination HARP	2.6	9.4

	Amount of circumferential shortening [%]	
	mean difference	standard deviation
HARP	1.5	20.6
Peak combination HARP	2.8	19.1

Table 1. Mean difference between DENSE and CSPAMM acquisition as well as the standard deviation shown relative to the average of paired measurements. Data were analyzed using both the single peak HARP and the peak combination HARP method.

Discussion

This work has presented a direct comparison of CSPAMM/HARP and DENSE. Results indicate that both methods agree well when considering bias. The agreement between CSPAMM and DENSE was also confirmed when using the peak combination HARP method. However, considerable variation in individual values has been found when considering cardiac rotation. This may be explained by differences in breath hold position between the CSPAMM and DENSE acquisitions resulting in different cardiac levels being imaged. Since the direction and magnitude of rotation depends significantly on cardiac level, future studies need to incorporate navigator guided breath holding to ensure consistent breathhold levels. Global parameters such as time-to-peak motion were less sensitive to potential mismatches in slice positions. It is concluded that both CSPAMM and DENSE provide motion information with good agreement using HARP processing supporting theoretical considerations.

References

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