3D Whole Heart CSPAMM tagging in a single breath hold using k-t-PCA

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Introduction

Myocardial tagging techniques [1, 2] have shown great promise in assessing local wall motion abnormalities. Recent work has indicated the value of the method in stratifying patients for cardiac resynchronization therapy [3]. Three-dimensional data acquisition is a prerequisite for a comprehensive analysis of cardiac motion. The combination of reduced field-of-view and line tag preparation has permitted whole-heart 3D tagging in three consecutive breathholds in both healthy subjects and patients with infarcts [4].

In order to improve the robustness and simplify the protocols for 3D whole-heart tagging further, additional reductions in scan time are desired. Ultimately, data acquisition in a single breathhold is preferred removing any inconsistencies due to separate breathholds and varying heart rates.

In the present work, we investigate the benefits of the k-t PCA (principle component analysis) framework [5] for accelerating 3D tagging data acquisition. Using *in vivo* whole-heart 3D CSPAMM data it is demonstrated that up to 3.7-fold net scan accelerations can be achieved without compromising the accuracy of motion quantification.

Methods

Whole-heart 3D CSPAMM tagging data were obtained in healthy subjects using a Philips 1.5T clinical MR system (Philips Healthcare, Best, The Netherlands) with following imaging parameters: spatial resolution $3.8 \times 7 \times 7mm^3$, 14 slices, TR/TE = 7.0/3.2ms, 23 heart phases and 7mm tag-line spacing. In order to assess reconstruction accuracy, fully sampled data were acquired in three consecutive breathholds of 14 sec each. Pencil beam navigators were employed to ensure consistency among breathholds [4].

In order to simulate accelerated data acquisition, data were decimated using optimized sheared grid sampling patterns with undersampling factors of 5 and 8. Low-resolution training data were derived from an elliptical central area in k_y-k_z space with different total numbers of profiles ranging from 21-51. Accordingly, net reduction factors between 2.7 and 3.7 were achieved.

In image reconstruction, the training data representation in the spatial temporal frequency domain P(x,f) was decomposed into temporal basis functions B(f) corresponding to the principle components (pc) and spatially dependent weighting coefficients W(x) according to:

$$P(x, f) = W(x)B(f)$$

Following the notion used for *k-t* BLAST [6], the regularized least-squares solution of the reconstruction problem reads as follows [5]:

$$w_x = M_x^2 E^H (EM_x^2 E^H + \sigma I)^+ P_{alias,x}$$

with w_x denoting the unaliased weighting coefficients, M_x^2 referring to the diagonal elements of the signal covariance matrix in x-pc space, E to the encoding matrix, σ to the noise variance and $P_{alias,x}$ containing the aliased signals in x-pc space. The reconstruction algorithm was implemented in Matlab (The MathWorks, Natick, MA, USA). The reconstructed tagging data were analyzed using HARmonic Phase analysis [7] and circumferential shortening, circumferential strain and rotation were compared per slice with reference to values obtained from fully sampled data sets.
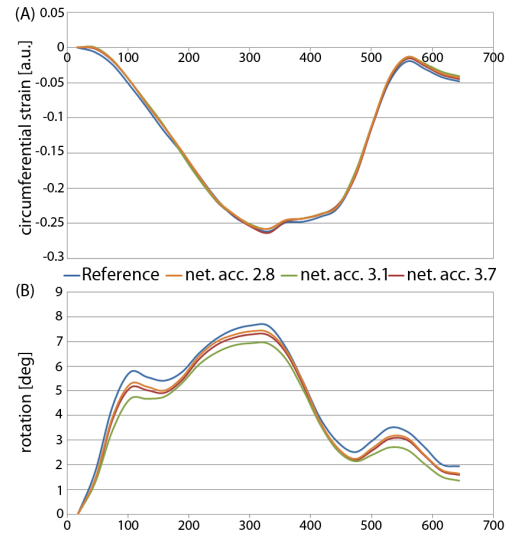

Figure 2: Circumferential strain (A) and rotation (B) from k-t PCA reconstructions with net acceleration factors of 2.8, 3.1 and 3.7 relative to values calculated from the fully sampled reference data.

# Training profiles	Nominal undersampling	Net undersampling	# Principal components	Error Circ. Strain [%]	Error Rotation[%]	Error Circ. shortening [%]
51	5	2.7	10	-1.0±3.0	-2.5±6.9	-0.9±3.4
37	5	3.1	10	-1.8±2.4	-6.6±6.9	-1.6±2.4
37	8	3.7	10	-1.8±3.4	-5.9±12.6	-1.8±3.6
51	5	2.7	15	-2.1±2.0	-3.2±6.2	-2.2±2.1
37	5	3.1	15	-2.3±2.6	-6.2±7.3	-2.4±2.5
37	8	3.7	15	-0.3±2.3	-7.5±11.3	0.2±2.6
51	5	2.7	20	-2.7±2.5	-3.1±7.1	-2.9±2.5
37	5	3.1	20	-2.7±2.4	-5.8±7.4	-3.1±2.9
37	8	3.7	20	-1.3±3.0	-5.0±11.5	-1.3±3.0

Table 1: Percentage error of circumferential strain, rotation and circumferential shortening from undersampled data relative to values calculated from fully sampled data for different combinations of training profiles, undersampling factors and number of principal components used in k-t PCA image reconstruction.
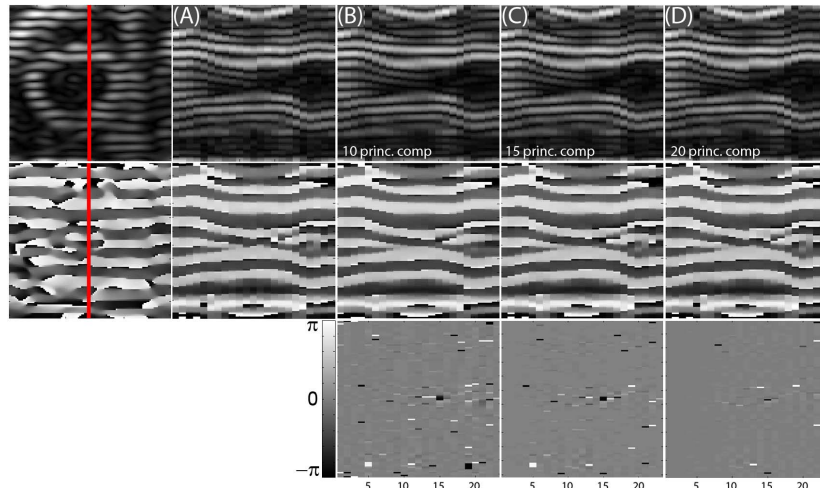

Figure 1: Magnitude (top row) and phase images (middle row) of profiles taken along the line shown in the short-axis view during systolic contraction. Images were reconstructed from fully sampled data using all principal components (A), 10 principal components (B), 15 principal components (C) and 20 principal components (D) along with phase difference error maps (lower row).

Results

Figure 1 shows the temporal evolution of one image profile taken from a center slice reconstructed with 10, 15, 20 principal components as well as a reference. It is seen that cardiac motion is well depicted by as few as 10 principal components. Figure 2 shows results of HARP tracking for circumferential strain and rotation in a single center slice comparing datasets with net accelerations from 2.7-3.7. Twenty principal components were used for reconstruction. Table 1 summarizes percentage errors of maximal circumferential shortening, maximal circumferential strain and maximal rotation obtained from undersampled data acquisition relative to values derived from fully sampled data. The error in circumferential strain and circumferential shortening from undersampled data is less than 4% for 3.7-fold net undersampling. Rotational motion was found to be more sensitive with percentage errors on the order of 7%.

Discussion

This work has demonstrated that 3D tagging data exhibit a high degree of spatiotemporal correlations which can be exploited using the k-t PCA framework. The essential information can be captured by only a limited number of principal components, permitting 3-fold net undersampling. This will allow acquisition of whole-heart 3D CSPAMM data in a single breathhold, and hence eliminate the need for multiple breath-holding with the risk of stack misregistration.

References [1] Axel et al. Radiology 1989 ; [2] Fischer et al. MRM 1993; [3] Manka et al. Euro. Heart J. 2009; [4] Rutz et al. MRM 2008; [5] Pedersen et al. MRM 2009; [6] Tsao et al. MRM 2003; [7] Osman MRM 1999