Evaluation of Principal Component Analysis for Highly Undersampled Radial DCE-MRI

J. Guo[1], M. A. Rosen[1], and H. K. Song[1]

[1]Laboratory for Structural NMR Imaging, Department of Radiology, University of Pennsylvania School of Medicine, Philadelphia, Pennsylvania, United States

Introduction

Dynamic contrast-enhanced (DCE) MRI has been shown to be valuable in the assessment of tumors. Both the enhancement kinetics and structural features of lesions are important in tumor diagnosis, which require both high spatial and temporal resolutions. But there is a trade-off between spatial and temporal resolutions with conventional imaging techniques. It was demonstrated earlier that undersampled radial techniques can allow rapid imaging without sacrificing spatial resolution [1,2]. However, streaking artifacts and low image SNR can become more serious in highly undersampled datasets and could potentially affect measurement accuracy.

Principal component analysis (PCA) was earlier proposed for reducing streaking artifacts and enhancing image SNR [3,4]. In this work, we investigate the feasibility and accuracy of PCA for highly undersampled datasets for several different radial acquisition schemes in dynamic MR imaging: (1) A dynamic series in which the same set of view angles are acquired for each image (no angle interleaving); (2) Bit reverse scheme, in which the view angles of subsequent frames bisect those of prior images; and (3) Golden-angle scheme, in which a single angular offset of 111.25º advances subsequent view angles [5].

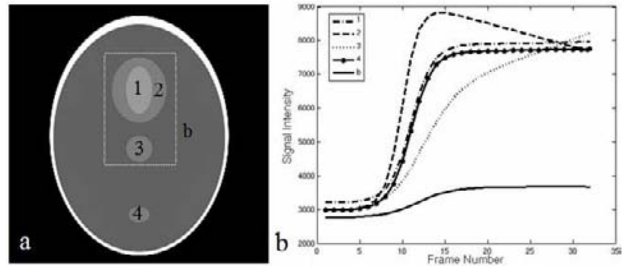

Fig. 1 (a) A simulation phantom with five ROIs (elliptical regions 1-4 and background b) which have different contrast response curves shown in (b). Local PCA was performed in the rectangular region shown in (a).

Methods

The simulated phantom shown in **Fig. 1a** was created with five different ROIs. The DCE-MRI data of the phantom were created analytically for the three different acquisition schemes. The response curves of signal intensities (**Fig. 1b**) were created for the ROIs according to the following equation [6]:

$$SI(t) = \frac{P_2 + P_5 \cdot t}{1 + e^{-P_4 \cdot (t - P_3)}} + P_1 \qquad (1)$$

where P_1 determines the baseline signal intensity, P_2 is related to the amount of signal enhancement, P_3 and P_4 are the approximate location and magnitude of the maximum slope, and P_5 is the terminal slope. There were 32 time frames in the dynamic series, and Gaussian noise was added to the images to yield SNR levels observed in vivo. Prior to PCA analysis, each frame was first subtracted by its average intensity [7]. PCA processing was performed locally in the rectangular region shown in **Fig. 1a**, and the signal intensity curves fit to Eq. (1) on a pixel-by-pixel basis. Parametric maps were subsequently created, and the normalized mean and standard deviation computed for each region. The degrees of undersampling, ranging from 256 to 32 views per image, were investigated.

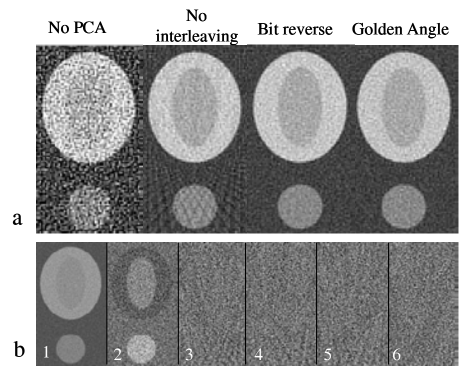

Fig. 2 (a) Images of the 16th dynamic frame, near the peak of the contrast enhancement. (b) The first six principal components for the Golden-angle scheme.

Results

Figure 2a shows the original and PCA-processed images at the 16th time frame for the three acquisition schemes. The noise is significantly suppressed for all three schemes after PCA processing. The streaking artifacts are effectively removed in the two angle-interleaved schemes (Golden-angle and bit reverse), while the artifacts remain visible in the non-interleaved scheme. In this simulation experiment, only the first 2 principal components were found to contain significant signal levels within the regions of interest, while the other components were either dominated by noise or streaking artifacts as shown in **Fig. 2b**. **Figure 3** shows the parametric maps of the terminal slope (P_5) from the Golden-angle data set showing regions of signal wash-out (red), plateau (blue), and continual increase (green). After PCA processing, the parametric maps are significantly improved. The normalized means and standard deviations (SD) of the five parameters in Eq. (1) from region 2 were calculated and shown in **Fig. 4** with and without PCA processing. With PCA processing, the mean values are relative stable for all undersampling factors, although the SD's steadily increase with higher undersampling. Without PCA, the mean values deviate from the true values, particularly at higher undersampling factors, and the SD's are much higher.

Discussion and Conclusion

Our results demonstrate that highly undersampled radial acquisition is amenable for PCA processing. PCA processing was effective in improving image SNR and in removing streaking artifacts in the two angle-interleaved schemes studied. Local PCA processing was used in this work because it is computationally more efficient and permitted the inclusion of fewer principal components. PCA in combination with Golden-angle or bit reverse scheme improves the quantitative estimation of parameters extracted from the images by removing the noise and artifacts. Our simulation experiments show that contrast enhancement dynamics of regions consisting of several different kinetic behaviors could be accurately assessed with local PCA analysis.

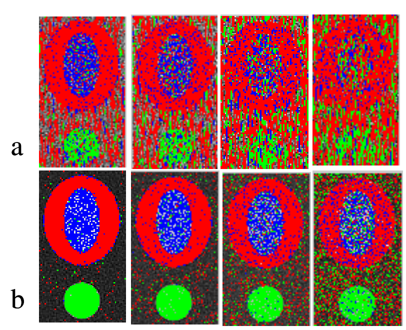

Fig. 3 (a) Parametric maps of the terminal slope (P5) without PCA processing of the Golden-angle acquisition scheme for various numbers of views per frame: (L to R) 256, 128, 64 and 32, respectively. (b) Corresponding maps following PCA processing, using the first two components.

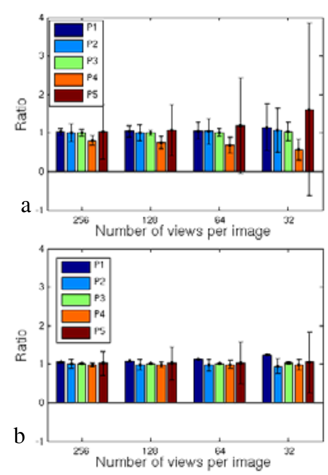

Fig. 4 The normalized means (ratio of measured vs. true values) and standard deviations of the five parameters in ROI 2 for the different numbers of views per image. (a) Without PCA; (b) With PCA.

Acknowledgements: NIH P41 RR 02305

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