Utilization of Principal Component Analysis for Improved Perfusion Measurements in Highly Undersampled Radial DCE-MRI

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Introduction

Using an undersampled radial imaging technique for dynamic contrast-enhanced (DCE-) MRI, both high spatial and high temporal resolutions could be achieved simultaneously [1]. However, streaking artifacts and low SNR become major issues with this strategy. Principal component analysis (PCA) had previously been suggested for reducing these artifacts [2]. However, the effect of such processing on measured tissue perfusion has not been evaluated. In this abstract, we systematically investigate the effects of PCA processing on the accuracy of model-based perfusion measures such as K^{trans} and v_e, and suggest a method that minimizes measurement error while effectively reducing image streaking and improving SNR.

Methods

K-space data of a simulation phantom shown in Fig. 1a was generated analytically for the Golden angle radial acquisition scheme [3]. The SNR of the data was made comparable to that normally observed in vivo. The arterial input function (AIF) was created according to the experimentally-derived functional form [4]. Tissue enhancement curves (TEC) based on this AIF were subsequently created from the Tofts' model (Eq. 1) and shown in Fig. 1b.

$$C_t(t) = K^{trans} C_p(t) \otimes e^{-\frac{K^{trans} t}{v_e}} \qquad (1)$$

where C_p is the tracer concentration in the blood plasma, K^{trans} is the volume transfer constant, v_e is the volume of the extravascular extracellular space. Each image of the dynamic series was reconstructed from 32 views, with 256 points per view, with a temporal resolution of 2 seconds. PCA was applied to the undersampled dynamic series. We investigated two scenarios: First, perfusion parameters (K^{trans} and v_e) were different for tumor rim and core regions; second, parameters were the same for both regions.

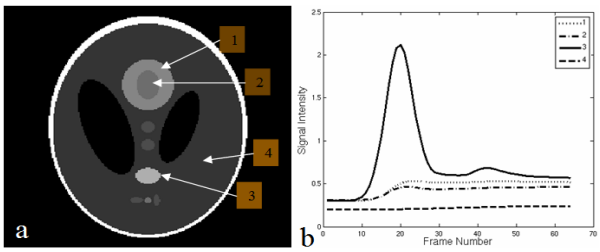

Fig. 1 (a) Phantom image. (b) Signal enhancement curves (1=tumor rim; 2=tumor core; 3=artery (AIF); 4=background).

Results

Figure 2a shows a plot of computed average K^{trans} and v_e values in the two regions of the tumor as a function of the number of principal components included (sequentially from highest to lowest eigenvalue) in the reconstruction of the dynamic series. The true values are as follows: K^{trans}_1 = 0.5 min^{-1}, K^{trans}_2 = 0.25 min^{-1}, v_{e1}= 0.4, v_{e2}=0.3. As more components are added, some have greater effect on average K^{trans} and v_e, while others do not significantly alter the values. Though some variability is observed for v_e, K^{trans} parameters quickly achieve stable plateaus close to the true values with a few key components. Fig 2b shows the first 20 spatial components (in decreasing eigenvalue). The four components that contribute most of the streaking artifacts (components 2-5) do not significantly alter K^{trans} and v_e (Fig. 2a). This allows their exclusion, resulting in reduced streaking without affecting accuracy. Other noise and streaking components can also be ignored. Fig. 3 shows histograms of region 1 (rim of the tumor). PCA results were generated using 1st, 6th, 7th, and 10th components. Fig. 4 shows histograms of K^{trans} and v_e values in the entire tumor when K^{trans} and v_e are identical in the two regions (K^{trans}_1 = K^{trans}_2 = 0.5 min^{-1}; v_{e1} = v_{e2} = 0.4). PCA results were generated using only the first component, the only component not dominated by streaking and noise. These results indicate that accurate pixel-wise computation of perfusion maps is possible with undersampled radial DCE-MRI followed by PCA processing.

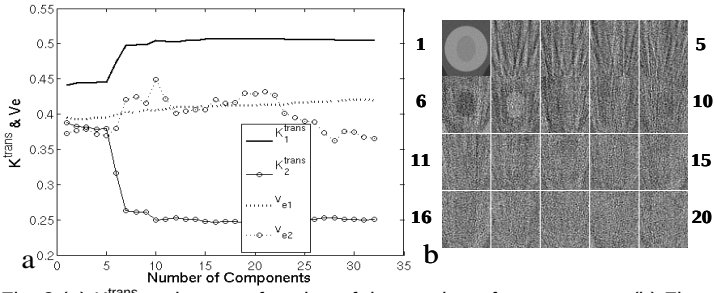

Fig. 2 (a) K^{trans} and v_e as a function of the number of components. (b) First 20 spatial components (increasing left to right and top to bottom). Components [1st, 6th, 7th, 10th] in which object's features can be recognized correspond to the most significant changes of K^{trans} and v_e shown in (a).

Discussion and Conclusion

PCA analysis can be used to reduce image streaking and to enhance SNR in an undersampled dynamic image series. However, it is not always obvious which components must be included to achieve these goals without compromising accuracy. Fig. 2 shows that the accuracy is highly dependent on the components. By excluding those components that predominantly contribute streaking and noise and do not significantly affect the average perfusion in a region, better accuracy could be achieved while minimizing contamination from streaking and noise artifacts.

Reference

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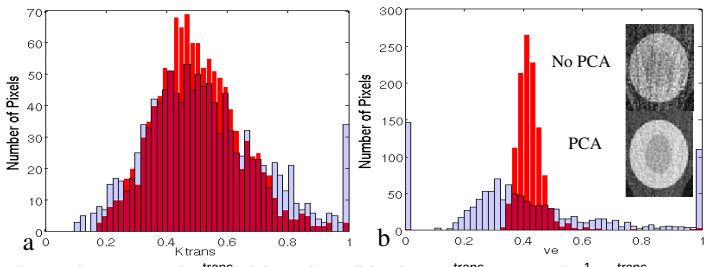

Fig. 3 Histogram of K^{trans}_1 (a) and v_{e1} (b) when K^{trans}_1= 0.5 min^{-1}, K^{trans}_2= 0.25 min^{-1}, v_{e1}= 0.4, v_{e2}= 0.3. Dark red represents PCA results; light blue without PCA processing. Images of the tumor at time frame 16 are also shown in (b) with and without PCA processing.

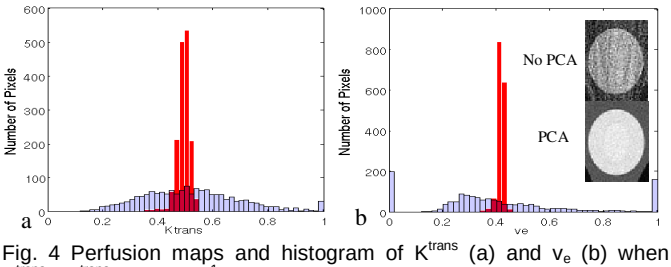

Fig. 4 Perfusion maps and histogram of K^{trans} (a) and v_e (b) when K^{trans}_1=K^{trans}_2= 0.5 min^{-1}, v_{e1}=v_{e2}= 0.4. Dark red represents PCA results; light blue without PCA. Images of the tumor at time frame 16 are also shown in (b) with and without PCA processing.