Quantitative Accuracy of Temporally Constrained Reconstruction in Dynamic Contrast Enhanced MRI

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Introduction: Dynamic contrast-enhanced (DCE)-MRI is a powerful tool for evaluating tumor vascular response and assessment of antiangiogenic and antivascular therapeutics. High temporal resolution is needed to accurately determine tumor enhancement kinetics. One of the strategies to enhance temporal resolution is the undersampling of k-space data, including radially acquired schemes. Temporally constrained reconstruction (TCR) [1] has also recently been developed for dynamic MR imaging to achieve high image quality at high undersampling factors. However, whether this technique can achieve accurate quantitative MRI measurements has not been investigated. In this work, an enhanced simulation experiment was conducted to evaluate of the accuracy of TCR for the assessment of DCE-MRI perfusion parameters.

Methods: For the enhanced simulation study, a high SNR pre-contrast image was first acquired utilizing a 3D golden-angle radial sequence [2] on a Siemens 1.5T scanner as a template. Imaging parameters were as follows: TR=3.38 ms, TE=1.6 ms, flip angle = 25^0, 192 points readout, FOV=40x40 cm^2, 32 slices, 9000 projections total. Arterial input function (AIF) was simulated using an experimentally-derived model [3], and blood and tumor ROIs were manually added to the in vivo images (Fig. 1d). Tumor signal was subsequently generated using Toft's model with several different K^{trans} values. The imaging parameters for the simulation were same as above. Dynamic radial k-space data (2500 projections total) for the golden angle hybrid radial acquisition scheme [2] were generated from the modified images using NUFFT [4]. Normally distributed zero-mean complex noise with several different standard deviations were then added to the generated k-space data to examine the performance of TCR at different SNRs. The SNR was defined as the mean of the blood signal divided by the mean of the background (where signal is absent) in the pre-contrast magnitude images of the KWIC-reconstructed data set.

Images were reconstructed using three different methods. (1) Undersampled (US), in which 25 views were used to generate each image, corresponding to an undersampling factor of 12 from the Nyquist limit. (2) Temporal filtering (k-space weighted image contrast or KWIC) [5] with 25 views for the central region to achieve same effective temporal resolution. (3) TCR, using 25 views for each frame and reconstructed by minimizing the cost function:

$$\left\|F\overline{m}-y\right\|_2+\lambda\sum_{i=1}^{N}\left\|D_t(\overline{m}_i)\right\|_1 \qquad (1)$$

where $\overline{m}$ is the reconstructed image, N is the total number of time frames (100 for this simulation), F denotes the undersampled radial k-space sampling, y is the generated k-space data, and the coefficient λ weighs the temporal smoothness of the enhancement relative to the data fidelity term. In this work, the optimal λ was determined using the L-curve method [6]. D_t is the image intensity difference between adjacent time frames. $\|\ \|_1$ and $\|\ \|_2$ denote L_1 and L_2 norms.

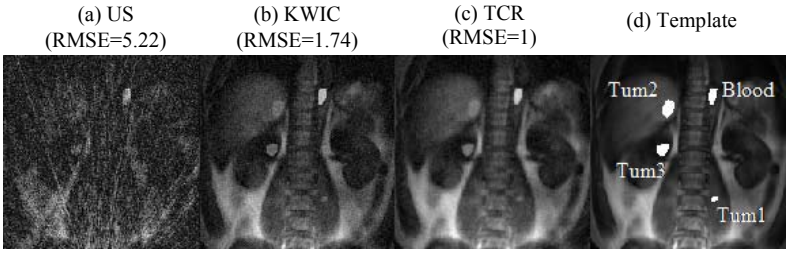

Figure 1. The reconstructed images using US, KWIC and TCR. (1d) shows the original image and the ROI masks for the blood and the three tumors (sizes: 107, 27, 159 and 111 pixels respectively).

Root means square error (RMSE) was computed by comparing the final reconstructed images to the original simulated image. Appropriate scaling factors for the reconstructed images were used to minimize RMSE error between the scaled images and the original simulated image [7]. All RMSE values were normalized to that of TCR. K^{trans} and v_e values were calculated on a pixel-by-pixel basis and compared to the true values.

Results: Figure 1 shows the reconstructed post-contrast images at SNR of 2.4 which is the noise level we typically observe in our *in vivo* data using the above imaging protocols. The TCR method had the lowest RMSE compared to the other methods. The median K^{trans} and v_e values and their standard deviations are shown in Fig. 2.

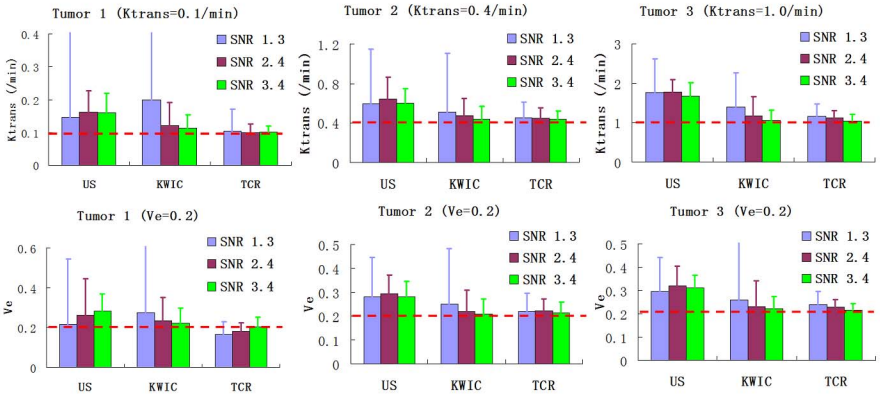

Figure 2. K^{trans} and v_e calculated using US, KWIC and TCR at different noise levels. True values are indicated by the red dashed lines.

Discussion and Conclusion: The temporal constraint used here exploits the expectation that the signal time course should be relatively smooth. While the k-space is initially highly undersampled in each time frame of the TCR image series, the final reconstructed image quality is high since the entire data set effectively contributes to the reconstruction of each image. Compared to KWIC and US methods, our findings indicate that the TCR method yields more accurate and precise perfusion measures, and is much less sensitive to differing amounts of image noise, K^{trans} values, and tumor sizes. These are all critical factors to consider when measuring changes in the perfusion parameters following treatment.

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Reference: 1. Adluru et al. Magn Reson Med 2007; 56: 1027-1036. ***2.*** Lin et al. Magn Reson Med 2008; 60:1135-1146. 3. Parker et al. Magn Reson Med 2006; 56: 993-1000. ***4.*** http://www.eecs.umich.edu/~fessler/code/ ***5.*** Song et al. Magn Reson Med 2004; 52:815-824. ***6.*** Hansen et al. Computational Inverse Problems in Electrocardiology. 119-142. ***7.*** Chan et al. Magn Reson Med 2011; [Epub ahead of print on 7 Jun 2011].