Accelerating brain DCE-MRI acquisition using an iterative reconstruction method with total generalized variation penalty: feasibility study

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Target audience: clinicians, physicists and other clinical professionals

Purpose

In dynamic contrast-enhanced magnetic resonance imaging (DCE-MRI) analysis, the temporal resolution in image acquisition is one of the key factors that affect the quantitative pharmacokinetics (PK) analysis accuracy. Studies have revealed that the calculation error of functional parameters increases as the temporal resolution degrades [(1)]. This study investigates the feasibility of improving temporal resolution for joint estimation of quantitative permeability and perfusion information using an iterative MR reconstruction method with undersampled k-space data in DCE-MRI.

Methods

Three patients' pre-treatment brain T1w DCE-MRI scans were selected. The images were acquired using a clinical 3D spoiled-gradient recalled echo (SPGR) sequence, and each set of scan consisted of multiple pre-injection volumes and 60 post-injection volumes, with a temporal resolution of 5.25s. All the data were saved for the following feasibility study: The undersampled k-space data of each volume was generated by sampling each slice's 2D k-space data with 32 non-Cartesian radial rays that were evenly distributed in the angular direction. This profile sampled about **11.5%** of the reference. The MR images were then reconstructed from the undersampled k-space data in a 2D fashion using the iterative regularized Gaussian-Newton (IRGN) method [(2)]. The nonlinear total generalized variation (TGV) regularization term was adopted to preserve the edge information while enabling the smoothness of low contrast regions in the image [(3)]. A maximum of 6 iteration steps was set in consideration of time consumption.

In the quantitative PK analysis, the CA concentration maps at each post-injection time point were calculated using dual flip angle method. A texture preserving variational denoising procedure was then implemented to minimize the noise effect in spatial domain of CA concentration maps [(4)]. With a published population-averaged arterial input function (AIF) [(5)], three quantitative PK parameters were estimated in voxel-by-voxel pattern using the two-compartment based PK models: permeability rate constant K^{trans} [(6)], and the perfusion parameters cerebral blood flow (CBF) and cerebral blood volume (CBV) [(7)]. For each of the investigated parameter, a pair of 2D distributions at a selected slice position was generated using reconstructed images and original images, respectively. Within the tumor region, the parameter's difference map was illustrated; for quantitative comparison, the parameter's average values from both distributions were evaluated, and the total relative error (TRE, Eq[1]) was calculated as the evaluation of a certain parameter's estimation accuracy. An upper TRE threshold of 0.15 was set to determine whether a parameter map was acceptable.

$$TRE = \frac{\sqrt{\sum_{x,y}[\mathrm{M}(x,y) - M_0(x,y)]^2}}{\sqrt{\sum_{x,y}[M_0(x,y)]^2}}$$

Eq[1]: TRE. *M(x,y)* is the parameter map estimated from reconstructed images, and $M_0(x,y)$ is the parameter map estimated from original images

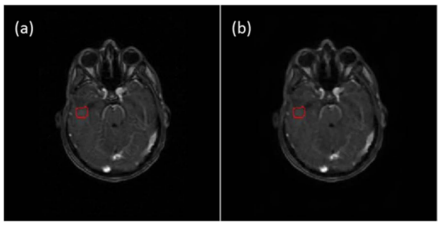

Fig.1 A comparison of original T1w image (a) and the reconstructed image (b)

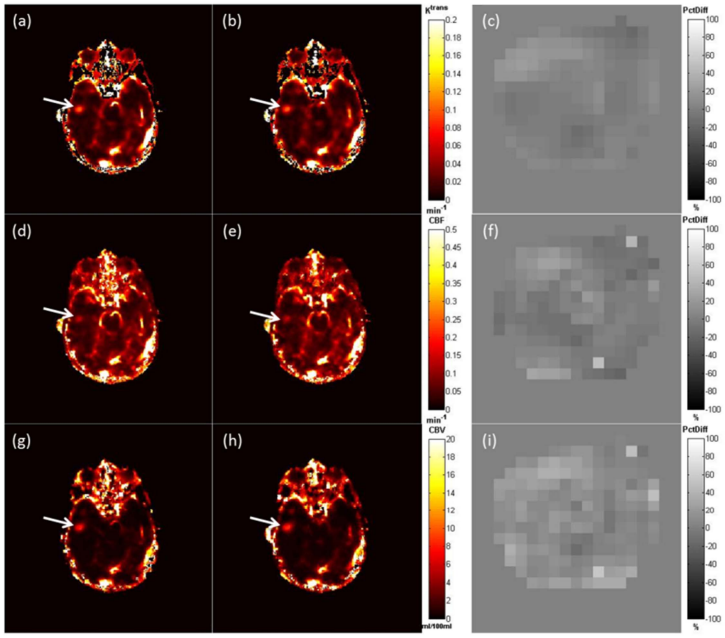

Fig.2 Left column: K^{trans} (a) , *CBF* (d) and *CBV*(g) calculated from original images; Middle column: K^{trans} (b) , *CBF* (e) and *CBV*(h) calculated from reconstructed images; Right column: K^{trans} (c) , *CBF* (f) and *CBV*(i) difference maps within the tumor region

Results

Figure 1 presents original T1w image (a) and the reconstructed image (b) at a selected position and time point of a chosen patient. Reconstruction time per image was about 30s. The tumor region is indicated by the red contour. Figure 2 shows the PK parameter map results. As demonstrated, the PK parameter maps estimated from the reconstructed MR images were morphologically similar to the corresponding ones estimated from the original MR images. The contrast features of the PK parameter distributions near the tumor region were preserved on the parameter maps estimated from the reconstructed image (indicated by white arrows), though minor discrepancies were observed at the tumor region edge. For quantitative accuracy evaluation of the parameter maps calculated from reconstructed images, Table 1 summarizes the differences of the parameters' average values and TRE values within the tumor region. The parameters were accurately estimated with <5% differences in terms of average value. All TRE values were acceptable.

Conclusion

With undersampled data at **11.5%** sampling ratio, the PK parameters of brain permeability and perfusion can be accurately estimated using the TGV based iterative image reconstruction method for quantitative DCE-MRI study. The feasibility of temporal resolution improvement using the investigated methods in clinical DCE-MRI study is promising.

References

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Table 1 Comparison of parameters in tumor calculated from reconstructed images. *Images shown are from Patient No.3

Patient No.	K^{trans}		*CBF*		*CBV*	
	Diff. (%)	TRE	Diff. (%)	TRE	Diff. (%)	TRE
1	+3.61	0.073	+0.90	0.079	+2.64	0.108
2	-2.07	0.081	+0.10	0.087	+3.45	0.121
3*	+1.17	0.062	+2.67	0.096	+4.64	0.131