Multi-Resolution Dynamic Contrast Enhanced MRI for Improved Kinetic Modeling

W. S. Kerwin[1]

[1]Radiology, University of Washington, Seattle, WA, United States

Introduction

Dynamic contrast-enhanced (DCE) MRI has been used to investigate contrast agent kinetics in oncology [1], myocardial perfusion [2], and carotid atherosclerosis [3] among other applications. The reproducibility of kinetic modeling depends heavily on the accuracy of the arterial input function (AIF) [4], which requires high temporal resolution imaging for proper characterization. On the other hand, for tissue characterization, temporal resolution is often not as important as spatial resolution. We therefore sought to develop a "multi-resolution" method that samples the AIF with higher *temporal* resolution and the tissue dynamics with higher *spatial* resolution.

Methods

We programmed a 3T MRI scanner (Philips Achieva) to alternate between full k-space acquisitions and central k-space acquisitions as illustrated in Fig. 1. For all acquisitions, central k-space lines were used to generate high temporal resolution images via keyhole reconstruction and these images were used for AIF extraction. High spatial resolution images were generated only from the full k-space acquisitions. Using this approach, the keyhole images were sampled at twice the frequency of the full images. The sequence was evaluated on subjects with carotid atherosclerosis using an interleaved 2D spoiled gradient echo sequence similar to that described in [3], with a keyhole factor of 25%.

We also evaluated the acquisition protocol using a computer simulation of DCE-MRI in which a bi-exponential blood curve was assumed and tissue uptake was simulated for v_p ranging from 0-50% and K^{trans} ranging from 0-0.3 min^{-1} (Fig. 2). For each pair of parameters, k-space simulations were conducted in which all concentrations were updated for each TR and Gaussian noise was added to simulate an SNR of 20. A standard protocol was simulated with a temporal resolution of 10 seconds and compared to the new multi-resolution sequence in which a 25% keyhole acquisition was added between each full acquisition. The latter sequence produced a 6.25 second sampling interval for the AIF and a 12.5 second tissue sampling interval. Measurement reproducibility was then assessed by calculating the kinetic parameters from the resulting images while varying the bolus arrival time.

Results

Figure 3 shows simulated data from the computer model. Using the simulated data, both the standard sequence and the multi-resolution sequence provided similarly accurate estimates of the kinetic parameters (Table 1), showing regression lines versus truth that are very close to the line of unity. The recorded standard deviations for v_p and K^{trans} correspond to approximately 5-10% measurement variability. The standard deviation for v_p was significantly smaller ($p<0.001$) for the multiresolution method as compared to the standard method. The standard deviation for K^{trans} was also smaller using the multi-resolution imaging method.

Table 1.

	Regression line	Pooled SD	Max SD
v_p (%)			
Traditional	y = 1.06x - 0.3	0.76	1.31
Multi-res	y = 1.05x – 0.2	0.45	0.59
K^{trans} (min^{-1})			
Traditional	y = 1.04x + 0.02	0.0082	0.0134
Multi-res	y = 1.05x + 0.02	0.0071	0.0090

Conclusions

This analysis shows that improving the temporal resolution of the AIF estimate can improve DCE-MRI reproducibility even if the temporal resolution for tissue is somewhat reduced. We attribute this observation to the fact that accurate determination of the bolus arrival time is critical for accurate determination of the kinetic parameters. The sequence developed for this purpose is similar to others proposed for high temporal resolution DCE-MRI [5-7], including keyhole and TRICKS, with one important advantage. In this method, k-space data for the high spatial resolution images are sampled as compactly as possible in time, thus minimizing any blurring. For applications such as carotid atherosclerosis, minimizing blurring is critical to ensure that the high intensity signal from the vessel lumen does not corrupt the smaller intensity variations in the adjacent wall. Application of this protocol in vivo showed suitable kinetic modeling results. The impact of the improved reproducibility on these in vivo results is yet to be determined.

References

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