Phase-Based Vascular Input Function Validation Using Near-Simultaneous PET-MRI

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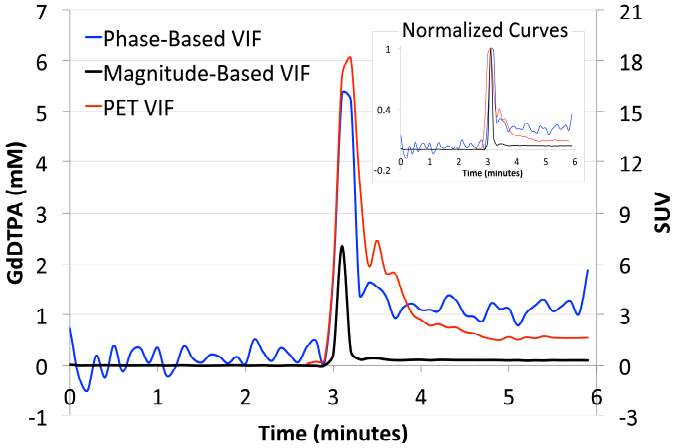
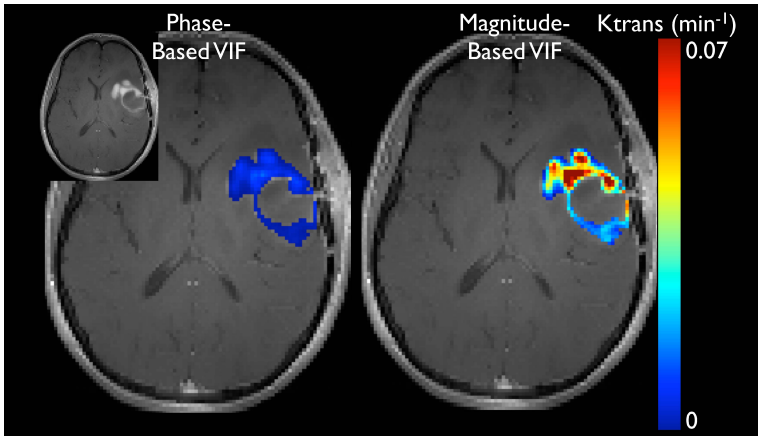
Introduction

An accurate quantification of the vascular input function (VIF) is essential for analysis of Dynamic Contrast-Enhanced (DCE) MRI data and estimations of K^{trans}, a metric for glioblastoma response to therapy. However, an accurate quantification of the VIF is confounded by several imaging-related limitations such as in-flow effects (that attenuate signal), the non-linear relationship between signal intensity and Gd-DTPA concentration at very high concentrations of contrast agent, and flip-angle dependencies [1]. The use of the phase data, which can be collected simultaneously with magnitude data during the acquisition, has been shown to be independent of many of these limitations, thus allowing for a more robust quantification of K^{trans} [2]. Moreover, additional imaging modalities with signals that are linearly related to tracer concentration can provide a comparison standard for dynamic MR data [2]. We have proposed (in a separate abstract submission this year) a method for validating PET arterial input functions using arterial blood sampling [3]. Assuming all the required corrections have been applied, PET has the advantage of providing accurate estimates of the actual radiotracer concentration in a particular voxel. Although Gd-DTPA and FDG have different overall distribution kinetics, they are likely similar during the first minutes following administration of the bolus, depending mostly on physiological parameters (e.g. cardiac output, cerebral blood flow, etc.). This may provide an alternative method to validate local estimates of the Gd-DTPA VIF. Here, we compare phase data-derived VIFs with magnitude data-derived VIFs as well as VIFs derived from a near-simultaneous PET acquisition with the goal of developing robust analysis approaches for DCE-MRI data.

Methods

Patients with newly diagnosed glioblastoma were scanned on a 3 Tesla imaging spectrometer (TimTrio, Siemens Medical Solutions, Malvern, PA) using the Siemens BrainPET coil. For the representative patient, a bolus of 5.34 mCi FDG was delivered at the start of the PET data acquisition, and continuously collected throughout acquisition of the MR data. The PET data were acquired in list-mode format. Corrections were applied to account for variable detector efficiency and dead time, random coincidences, photon attenuation and scatter and images were reconstructed with the standard 3D OP-OSEM algorithm. SUVs were determined from the radioactivity concentration in the tissue (MBq/ml), the administered dose and the patient's weight. A 0.1 mmol/kg dose of GdDTPA was injected at a rate of 5 cc/s ~ 30 minutes after the initiation of MR data acquisition and within 2.5 minutes of the DCE sequence acquisition. To derive estimates of measures related to permeability (i.e., K^{trans}), a voxel-by-voxel T1 map was derived using a variable flip angle (2, 5, 10, 15, 30 degrees) fast volumetric GRE acquisition, followed by a dynamic series employing two echo times (TE=2.73, 3.89ms) acquired at a 6s time resolution and 2.6 x 1.8 x 2.1 voxel resolution. The magnitude data were converted to concentration of GdDTPA from the standard relationship between T1 and signal intensity. The phase data were converted to concentration using Equation 2 in Ref. 1. K^{trans} estimates were derived from standard pharmacokinetic modeling of DCE-MRI data [4]. The bolus curves in the figure below were expressed on their respective concentration scales, but in order to compare tracer kinetics from each, they were aligned at the peaks and then normalized to their respective heights (pop-out). The area under the first pass peak (AUC_{FP}), post-bolus region (AUC_{PB}), and FWHM were determined.





	Magnitude-Based VIF	Phase-Based VIF	PET-VIF
AUC_{FP}	0.1228	0.2445	0.2552
AUC_{PB}	0.1056	0.5379	0.5844
FWHM	0.1113	0.2415	0.2556

Results & Discussion

PET-based measurements of the VIF can be compared to MR-based estimates of the arterial input function to qualify the use of an MR-based VIF using the complex data collected during a standard 3D SPGR DCE-MRI experiment. In the analyzed data set the MR phase-based VIF closely follows the dynamics of the PET VIF while the magnitude-based VIF has a lower peak concentration as well as attenuated wash-out kinetics compared to the other two VIFs. These data illustrate that dynamic arterial PET data may be used to validate MR measurements of VIF and that MR phase-based VIFs may provide a more accurate estimate of the vascular input function in DCE-MRI, a measurement that has strong effects on the variability in estimating K^{trans}. The results warrant further investigation of PET/DCE-MRI cross-validation techniques for this application.

References [1] Footit, MRM 63:772 (2010). [2] Korporaal, MRM 66:1267 (2011). [3] Chonde, ISMRM (2012). Tofts, JMRI 7:91 (1997).