Simultaneous Measurement of DSC- and DCE-MRI Parameters using Dual-Echo Spiral with a Standard Dose of Gadolinium

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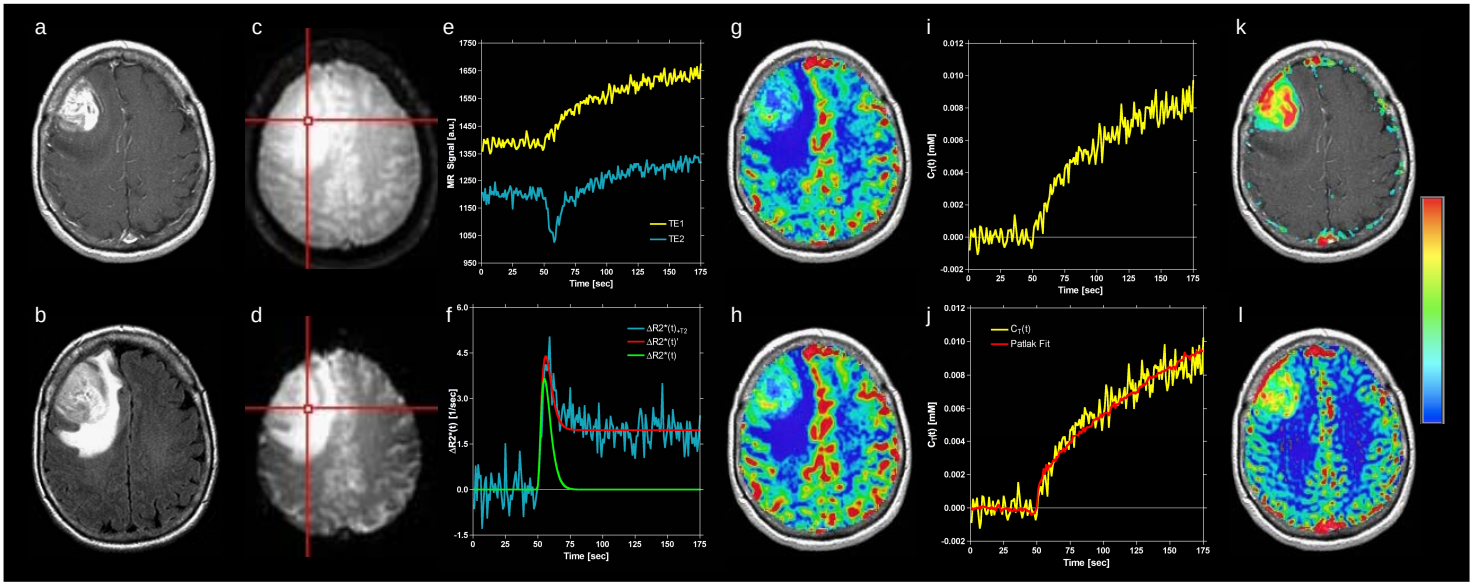
Introduction. Dynamic Susceptibility Contrast (DSC) MRI and Dynamic Contrast Enhanced (DCE) MRI are two non-invasive imaging techniques frequently employed to probe the angiogenic activity of brain neoplasms based on estimates of vascularity and vascular permeability [1,2]. It is well known that gadolinium exhibits simultaneous T1, T2, and T2* shortening effects in tissue, and these properties are uniquely exploited in DSC and DCE. In DSC, a concentrated bolus of gadolinium flowing through a tissue capillary bed induces transient signal loss through spin dephasing caused by vascular-extravascular susceptibility gradients [3]. In DCE, extravasation of gadolinium from intravascular to extravascular extracellular space results in dipole-dipole interactions between the unpaired electrons of the contrast agent and local tissue protons, which gives rise to signal enhancement through T1 shortening. However, the results of both DSC and DCE can be confounded by the opposing effects of gadolinium. Specifically, residual susceptibility effects compete with T1 shortening, which can confound DCE parameters, while dipolar T1 and T2 and residual susceptibility effects can confound DSC parameters [4-6]. We demonstrate here that DSC and DCE parameters, both corrected for confounding contrast agent effects, can be obtained simultaneously using a dual-echo spiral acquisition with a standard dose of gadolinium.

Methods. A prospective study was performed on four patients with high-grade intracranial tumors that underwent perfusion analysis. All studies were performed on a 1.5T GE CV scanner (GE Healthcare, Milwaukee, Wisconsin) equipped with 4 G/cm gradients. Pre-contrast T_1 and M_0 mapping was performed using an inversion-prepped, single-shot, spin-echo spiral-out sequence with the following parameters: FOV=22cm^2, matrix=96^2, slice thickness=5mm, skip=1.5mm, TE=11msec, TR=10000 msec, number of slices=13, 21 inversion times stepped linearly from 50-3550 msec. Perfusion weighted images were then acquired over the same slice prescription using a single-shot, dual gradient-echo, spiral-out sequence with the following parameters: TE_1=3.3msec, TE_2=42msec, TR=1100 msec, flip angle=72°, number of samples (reps)=180. A standard dose of Gadodiamide (0.1 mmol/kg, Omniscan) was injected at the 60th time point using a power injector. Post-contrast T1W images were then acquired using a conventional SE sequence over the same slice prescription with the following parameters: TE/TR/Matrix/NEX=10/450/256^2/2. Spiral image reconstruction was performed offline using custom software developed at our Institution.

Pre-contrast M_0 and T_1 maps were constructed by nonlinear least squares fitting of the inversion-prepped spiral data to the inversion recovery signal model. For DCE analysis, gadolinium concentration-time curves, $C_T(t)$, were constructed from $\Delta R1(t)$ curves corrected for T2* effects using the dual-echo signal time courses and a longitudinal relaxivity of 4.39 $s^{-1}mM^{-1}$ [1,4]. Plasma concentration-time curves, $C_P(t)$, were estimated by averaging three manually selected arterial input concentration-time curves and then multiplying by (1-HCT), where HCT was an assumed hematocrit of 0.45 [7]. DCE parameters Ktrans and Vp were then estimated on a voxelwise basis by non-linear least squares fitting of the Patlak model to the tissue concentration-time curves [8]. For DSC analysis, $\Delta R2^*(t)$ concentration-times, corrected for dipolar T1 and T2 and residual susceptibility effects, were constructed using a combination of the dual-echo time courses and a model that accounts for the first pass and residual susceptibility or dipolar T2 effects [5,9]. Estimates of rCBV were generated as the area under the corrected $\Delta R2^*(t)$ and were then normalized to the mean normal appearing white matter rCBV value. Estimates of CBF were generated from the maximum of the residue function obtained following singular value decomposition of the tissue and arterial input function concentration-time courses (the AIF was generated by averaging three manually-selected concentration-time curves). Finally, CBF estimates were cross-calibrated using a global scaling factor obtained by scaling normal appearing white matter CBF to 20 ml/100ml/min.

Figure 1: (a) T1+C, (b) FLAIR, (c-d) reconstructed first and second echo spiral images, (e) representative first and second echo MR signal time courses, (f) corrected $\Delta R2^*(t)$, (g) normalized rCBV, (h) cross-calibrated CBF, (i-j) uncorrected and corrected tissue gadolinium concentration-time curves, (k) Ktrans, (l) Vp.



Results and Discussion. Figures 1 a and b display post-contrast T1W and T2 FLAIR images for a patient with a high-grade brain tumor. Extravasation of contrast agent is apparent in the post-contrast T1W image. Reconstructed spiral images from the first and second echoes of the perfusion-weighted images are displayed in Figures 1 c and d, respectively, with representative signal time courses displayed in Figure 1e. Note the competing effects of gadolinium during and following the first pass of the bolus through the microvasculature. Figure 1f displays the corrected $\Delta R2^*(t)$ concentration time curve (green) used to calculate the normalized rCBV (Figure 1g) and cross-calibrated CBF (Figure 1h) estimates. Note that these estimates are no longer confounded by dipolar T1 and T2 and/or residual susceptibility effects. Figures 1i displays a tissue gadolinium concentration-time curve calculated from the first echo time series of the dual-echo acquisition. By using both echoes of the dual-echo time series confounding T2* effects are removed from the gadolinium concentration-time curve, as shown in Figure 1j. Estimates of Ktrans and Vp obtained from Patlak model fitting (red curve in Figure 1j) are displayed in Figures 1 k and l. Note that these estimates are no longer confounded by residual susceptibility effects. Similar results were obtained for each of the four patients included in the study. These results suggest that both DSC and DCE parameters can be obtained simultaneously using a dual-echo acquisition method with a standard dose of contrast agent. Future modifications will include incorporation of parallel imaging (e.g., spiral SENSE). Additional studies are planned to compare DCE estimates obtained with the newly described method to those obtained from the traditional DCE time series of T1W spoiled gradient-echo images collected for several minutes.

References. 1. Li et al., JMRI 12:347-357 (2000), 2. Harrer et al., JMRI 20:748-757 (2004), 3. Rosen et al., MRM 14:249-265 (1990), 4. Kim et al., MRI 22:307-314 (2004), 5. Paulson et al., Proc ISMRM 15th (2007), 6. Quarles et al., Proc ISMRM 14th (2006), 7. Murase MRM 51:858-862 (2004), 8. Ewing et al., MRM 50:283-292 (2003), 9. Johnson et al., MRM 51:961-968 (2004)

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