Simultaneous UHF quantitative T1 mapping and T2* weighted dynamic contrast imaging with applications to brain tumors

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Target audience – MR physicists, clinicians, oncologists

Purpose: The quantification of perfusion and permeability afforded by Dynamic Susceptibility Contrast (DSC) and Dynamic Contrast Enhancement (DCE) imaging are commonly used for the diagnosis and management of patients with brain tumors. These dynamic scans require high temporal resolution to adequately characterize the vascular and cellular properties of the tumor microenvironment. However many brain tumors, especially glioblastoma multiformes (GBMs) tend to be highly heterogeneous underscoring the need for improved spatial resolution. This desire for high spatial and temporal resolution can partially be addressed by the use of ultra-high field MRI as it can provide the extra sensitivity needed for higher resolution imaging. Here we present an accelerated, high-resolution inversion-recovery (IR) EPI acquisition that can be used simultaneously for DSC and DCE imaging at 7 T. IR methods with adiabatic inversion pulses are preferred at ultra-high fields because standard methods for DCE require accurate knowledge of the flip angle at every voxel in order to derive T_1 values that are converted into contrast agent concentration, and the spatially nonuniform B_1^+ field in the head at 7 T due to dielectric effects precludes this approach. Quantitative T_1 maps and T_2^*-weighted images can both be extracted from IR-EPI data, providing perfusion and permeability maps at high spatial and high temporal resolution that are inherently perfectly registered.

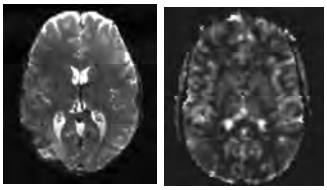

Figure 1 T2 weighted slice in tumor patient (left) CBV map in healthy control (right)

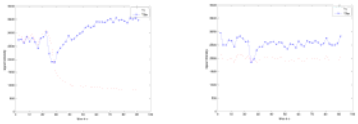

Figure 2 Dynamic T1 and T2weighted curves in tumor (left) and non-tumor(right) voxels

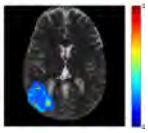

Figure 3 Area under the curve (tumor patient) extracted from the dynamic T1 maps

Methods: The IR-EPI acquisition method is based on a pulse sequence described previously (1,2). Briefly, the technique uses a broad-slab-selective FOCI adiabatic pulse (3) and a modified EPI acquisition where all slices are read-out sequentially during the inversion recovery (resulting in a distinct inversion time (TI) per slice), then after each IR the temporal order of the slices is permuted. This provides each slice with a range of TI values that can be used to fit the T_1 recovery and also extract the underlying T_2^*-weighted image. The single-shot 1.5 mm isotropic gradient-echo EPI protocol parameters were: TR/TE/matrix/BW/TI_{min}/fa. = 2070 ms/22 ms/128×128/1776 Hz/pixel/11 ms/65°, with a nominal echo spacing of 0.67 ms, acceleration factor *R*=3 (online GRAPPA reconstruction), 28 slices, and 177 measurements. After each IR, the slice order was permuted by 7 slices, resulting in 4 TIs measured per slice. The IR-EPI data was fit over a sliding window containing the 4 TIs using a Bloch simulation-based forward model as described in (2) to produce a time series of quantitative T_1 maps and T_2^*-weighted images with an effective temporal sampling of 2.07 s.

A glioblastoma patient and a control having given informed consent were imaged with a whole-body 7 T scanner (Siemens Healthcare, Erlangen Germany) equipped with body gradients and a custom 32-channel head receive coil array. During scanning a 0.1 mmol/kg body weight dose of Gd-DTPA (Magnevist) was delivered via at a rate of 3–5 ml/s. The CBF and CBV maps were generated from the T_2^*-weighted time series using the methods described previously (4), and the k_{trans} permeability and area under the curve (AUC) maps was generated directly from the T_1 images using the Tofts model implemented in-house in MATLAB.

Results: As seen in figures 1 and 2, we were able to use the dynamic T2 weighted images to generate parametric maps including those for CBV/CBF. Additionally, we created parametric maps based on the quantitative T1 imaging (figure 2) to created K_{trans}, v_e and AUC as seen in figure 3. These maps highlight the area of the tumor

Discussion: The technique discussed here allows us to acquire high spatial and temporal resolution dynamic contrast MRI images. By generating simultaneous quantitative T_1 and T_2* dynamic images after the injection of a contrast agent, we can calculate traditional DSC and DCE parameters such as CBV and CBF as well as k_{trans} and AUC. This more efficient scan using an accelerated EPI sequence at 7 T meets needs of both DSC (high temporal) and DCE (high spatial) and allows the creating of perfectly registered parametric maps. Further, this technique requires only a single injection and eliminates the need for the traditional T_1 mapping that is performed before standard DCE acquisition. The efficient use of IR pulses also reduces SAR. In high-grade tumors, the leakiness of the vasculature caused by disruptions in the blood-brain barrier lead of T_1 effects in addition to and opposing the T_2^* effects, often requiring the use of a "preload" for leakage correction, necessitating two injections [5]. Fitting of T_1 in the proposed technique may reduce the need for this preload, thus potentially reducing the total required contrast dosage. We plan on extending this acquisition to Simultaneous Multi-Slice EPI to increase temporal resolution and to allow for multiple echo times (6-10) which will provide T_2^* correction for the DCE and increased accuracy for DSC.

Conclusion: This novel approach to high spatial and temporal resolution dynamic contrast imaging at UHF can simultaneously quantify the perfusion and permeability in brain tumors.

References: [1] Renvall et al, Proc ISMRM 2014;22:4282, [2] Renvall et al, Proc ISMRM 2014;22:1488 [3] Hurley et al, MRM 2010 [4] Mouridsen et al, J Cereb Blood Flow Metab. 2014. [5] Boxerman et al, AJNR 2012 [6] Eichner et al, MRM 2014 [7] Setsompop et al, MRM 2014 [8] Olafsson et al, Proc ISMRM 2012;20:2068. [9] Xu et al, HBM 2012, [10] Grinstead et al, Proc ISRMRM, 2014;22:3215