High-resolution Whole-brain DCE MRI of Brain Tumor using Constrained Reconstruction: Prospective Clinical Evaluation

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INTRODUCTION: Dynamic contrast enhanced (DCE) MRI is a powerful technique for mapping neurovascular parameters that are relevant to the assessment of brain tumor, multiple sclerosis, and other disorders. Conventional imaging techniques are limited by suboptimal spatial/temporal resolution and poor spatial coverage. Recently, sparse sampling and constrained reconstruction techniques have been employed in DCE-MRI to resolve these limitations [1,2]. In one study, whole-brain DCE with near-isotropic resolution was demonstrated using multiple sparsity constraints [1]. Here, we report a prospective clinical evaluation of this approach in brain tumor patients, where both the standard (clinical) and accelerated (experimental) scans were performed. Pharmacokinetic (PK) parameters (K^{trans}, v_p) are derived and image quality scores from experienced neuroradiologists were used to evaluate the anatomic images and PK parameter maps.

METHODS: Fifteen brain tumor patients were recruited, and imaged on a clinical 3T scanner. Clinical and experimental DCE-MRI were performed 15 minutes apart during the same examination. The clinical DCE-MRI had spatial resolution 0.9×1.3×7.0mm^3, FOV 22×22×4.2 cm^3, and the experimental DCE-MRI had spatial resolution 0.9×0.9×1.9mm^3, FOV 22×22×19 cm^3. Temporal resolution was 5 seconds for both scans. Both clinical and experimental scans were based on a Cartesian T_1-weighted SPoiled Fast GRadient echo (SPGR) sequence. The experimental scan acquired k_y-k_z phase encodes using a golden-angle Cartesian radial order [3]. The under-sampled data was then reconstructed using a constrained reconstruction scheme that utilized multiple l_1-norm constraints with very low weights, as described in Ref. [1]. To improve reconstruction speed relative to the work in Ref [1], we utilized an efficient augmented-Lagrangian method for solving the optimization problem, alternating direction methods of multipliers (ADMM) with variable splitting performed twice [4]. Reconstruction was implemented in MATLAB (Mathworks, Natick, MA) and run on a Linux workstation (24 core 2.5GHz, 128GB RAM). After reconstruction of the experimental scan, the images were registered to those of clinical scan, with 3 adjacent slices averaged in order to match the slice thickness of the clinical scan. Registered images and extracted blood-brain-barrier permeability maps (K^{trans}) were shown to two board-certified neuroradiologists (10 and 20 years experience respectively). Presentation order was randomized and raters were blinded to acquisition type. A 4-point Likert scale was used, where 3 = good, 2 = average, 1 = poor, 0 = non-diagnostic.

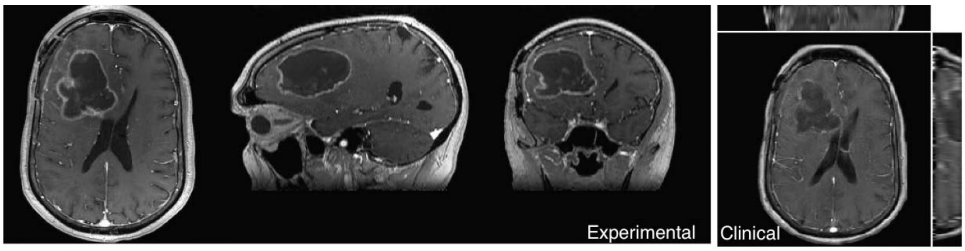

Figure 1 Volume coverage of the experimental scan (left) is significantly greater than that of the clinical scan (right), as demonstrated in this patient with a large 6cm GBM tumor.

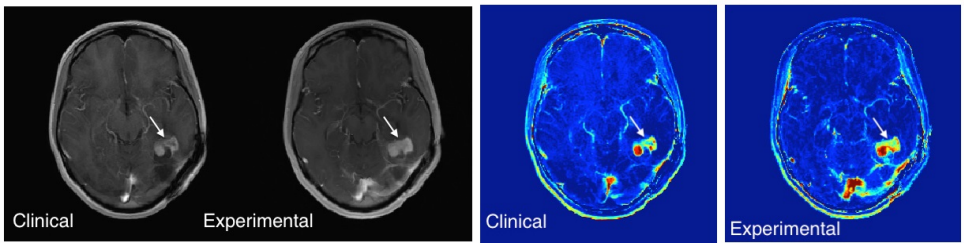

Figure 2 Image quality assessment was performed using spatially co-registered and resolution-matched anatomic images and K^{trans} maps, as shown here.

RESULTS: **Fig 1** shows the coverage of clinical and experimental scans. Post-contrast images are shown for a patient with a large glioblastoma (6cm diameter). The experimental approach was able to provide detailed depiction of the entire tumor and tumor boundary. The clinical scan provided incomplete spatial coverage, and the sagittal and coronal reformats had low resolution in the superior-inferior direction. In another case (not shown), the experimental scan captured 14 metastatic lesions, whereas the clinical scan captured only 4 due to limited spatial coverage. **Fig 2** shows spatially co-registered and resolution-matched anatomic images and K^{trans} maps for a glioblastoma patient, in the format that was used for presentation to radiologists. **Table 1** contains the radiologists' scores for the 1) anatomic time-resolved images for one key slice, 2) anatomic post-contrast images, and 3) K^{trans} maps. The average and standard derivation of the quality scores were calculated across the 15 patients. The experimental scan received higher image quality scores compared to the clinical scan, and this difference was statistically significant, with $p<0.001$ for all image sets.

Table 1 Radiologists' image quality scores.

	Clinical	Experimental
Time-Resolved	0.9±0.5	2.1±0.7
Post-contrast	1.1±0.4	2.3±0.6
K^{trans}	1.5±0.6	2.3±0.7
All combined	1.2±0.6	2.2±0.7

CONCLUSION: We have demonstrated a novel high-resolution whole-brain DCE-MRI method using constrained reconstruction that is clinically feasible. This method provides characterization of all abnormal tissues, a significant advance over the current clinical approach. This method also provides superior image quality and no apparent loss of diagnostic information compared to the current clinical approach.

REFERENCES: [1] R. M. Lebel, et al. MRM 71(2): 635–644, 2014. [2] L. Feng, et al. MRM 72(3): 701-717, 2014 [3] Y. Zhu, et al. ISMRM 2014, p. 4365. [4] S Ramani, et al. IEEE-TMI 30(3): 694-706, 2011