Phase Imaging of Brain Tumor Patients at 7T

K. E. Hammond[1], P. Mukherjee[2], S. M. Chang[3], J. M. Lupo[4], D. Xu[4], D. A. Kelley[5], D. B. Vigneron[4,6], and S. J. Nelson[4,6]

[1]University of California San Francisco/Berkeley (UCSF/UCB) Joint Graduate Group in Bioengineering, San Francisco, CA, United States, [2]Department of Radiology, UCSF, [3]Department of Neuro-surgery, UCSF, [4]Surbeck Laboratory of Advanced Imaging, Department of Radiology, UCSF, [5]GE Healthcare, San Francisco, CA, United States, [6]Program in Bioengineering, UCSF

Introduction: At high field both the signal-to-noise ratio and the B0 field distortions caused by iron-containing blood products (chiefly hemosiderin and ferritin) and venous blood are expected to scale, enabling the use of phase imaging to highlight abnormal vascularity in brain tumor patients. Hence phase could provide a clinically-relevant contrast different from magnitude contrast without requiring an additional scan. We tested this hypothesis on brain tumor patients receiving high resolution gradient echo scans at 7T and standard clinical exams at 3T. Phase is shown to have high potential for characterizing microvasculature and leakage in the blood brain barrier.

Methods:

Data Acquisition: Fourteen brain tumor patients giving informed consent received a high-resolution gradient echo scan at 7T (2D GRE, 512x512 matrix, 18cm FOV, TE/TR 11.4/30ms. 20° flip, 10 slices with 2mm/6mm slice thickness/gap, scan time 6.5 minutes) and a standard clinical exam at 3T (T2-FLAIR, T1-weighted SPGR and a post-Gadolinium injection SPGR). The 7T exam was completed prior to the 3T exam to ensure no contrast was present during the 7T exam. Patients were scanned on 7T and 3T whole body MR scanners (GE Healthcare, Milwaukee, WI) equipped with 8-channel phased arrays coils (from Nova Medical, Wilmington, MA at 7T and In Vivo, Miami, FL at 3T). Excitation was done using a head transmitter coil with active detuning at 7T and the body transmitter at 3T.

Data Processing: A complete phase map was created by centering the phase of each channel and combining phases using a confidence weighting of the coil sensitivity profiles[1]. This method minimizes noise by preferentially weighting the phase estimate from coils with high signal and hence low phase noise. The resulting image was uwrapped using PRELUDE[2]. Data processing took <3 min on a Sun Microsystems SunBlade 1500.

Data Quantification: Vessel widths were measured manually and histogram entropy in regions showing Gadolinium enhancement at 3T was calculated. Entropy indicates the degree of disorder in the histogram and captures the information content present in the data.

Results

- Venous vessels are 37% narrower on the phase than magnitude images ($P<0.001$, Wilcoxon signed rank test) but maintain similar vessel continuity. The vessel narrowing becomes more pronounced at smaller vessel sizes; in the periventricular microvasculature, vessels are on average 50% narrower (see figure 1).
- All six patients showing clear regions of Gadolinium enhancement at 3T had corresponding large phase shifts at 7T (see figure 2).
- In patients having received radiation treatment we noted regions of high magnitude and phase contrast distributed in a similar pattern to the treatment dose profile (see figure 3).

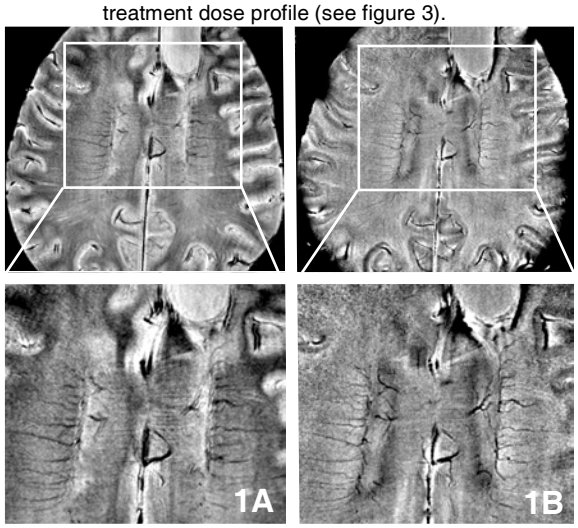

Figure 1. *Narrowing of microvasculature adjacent to a surgical resection cavity from (1A) magnitude to (1B) phase.*

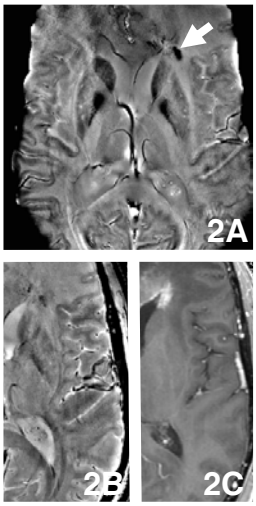

Figure 2. *Shift in (2A) 7T phase and (2B) magnitude coincident with (2C) 3T Gadolinium enhancement.*

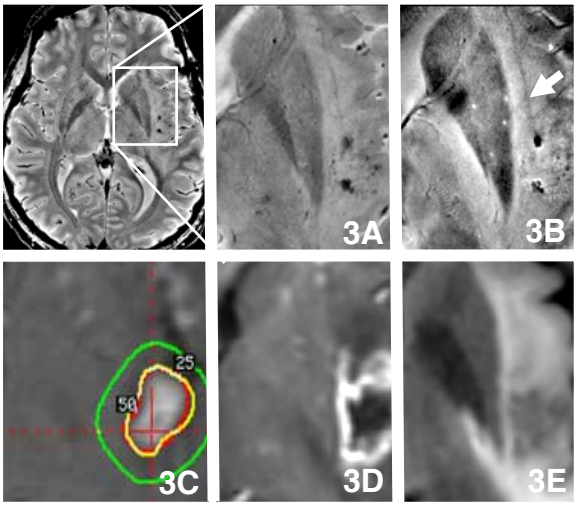

Figure 3. *Abnormal vascularity or micro-hemorrhage (arrow-head) adjacent to the claustrum (arrow) following (3C) gamma knife surgery as seen in (3A) 7T magnitude, (3B) phase, (3D) 3T post-Gadolinium and (3E) T2-FLAIR.*

Discussion: Phase highlights the presence of local susceptibility variations from blood products and iron-containing tissues. Magnitude is less sensitive than phase to susceptibility effects spread over multiple voxels because magnitude images show signal dropout only due to *intravoxel* dephasing. The presence of iron-containing blood products resulting from blood-brain barrier leakage in Gadolinium-enhancing regions could therefore explain why phase has more dramatic contrast than magnitude (see figure 2).

Vasculature has narrower apparent widths on phase than magnitude images because the susceptibility of deoxygenated blood shifts the field in opposite directions within and adjacent to the vessel. In the magnitude image, therefore, there is signal dropout both within and adjacent to the vasculature while in the phase image the bright adjacent tissue provides sharp contrast to the dark vasculature (see figure 1). A similar sharp contrast highlights dark spots likely resulting from hemosiderin and ferritin in intratumoral hemorrhage. The high contrast observed in regions of radiation treatment could be indicative of diffuse radiation effects (see figure 3). Establishing the source of these vascular phase shifts is an ongoing focus of our investigation.

Conclusion: Phase imaging of brain tumors at 7T provides additional clinically-relevant information to magnitude without requiring an additional scan. Phase contrast highlights venous vasculature and peritumoral leakage of blood products and may highlight diffuse effects of radiation treatment. Imaging abnormal vascularity in brain tumor patients is important for assessing tumor progression and the effectiveness of anti-angiogenic therapies.

References: [1] Hammond *et al.* Submitted to ISMRM 2007. [2] Jenkinson. *MRM* 49:193-197 (2003).

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