Imaging blood vessel volume in high grade gliomas at 3T using susceptibility-weighted imaging and dynamic susceptibility contrast perfusion MRI

J. M. Lupo[1], M. C. Lee[2], S. Cha[3,4], S. M. Chang[4], S. J. Nelson[2]

[1]UCSF/UCB Joint Graduate Group in Bioengineering, University of California, San Francisco, CA, United States, [2]Surbeck Laboratory of Advanced Imaging, Department of Radiology, University of California, San Francisco, CA, United States, [3]Department of Radiology, University of California, San Francisco, CA, United States, [4]Department of Neurosurgery, University of California, San Francisco, CA, United States

Introduction:

As clinical MRI scanners move to higher field strengths, traditional techniques to measure relative cerebral blood volume (rCBV) in brain tumors such as dynamic susceptibility-contrast (DSC) perfusion MRI become a challenge due to increased B_0 inhomogeneity and magnetic susceptibility differences at air-tissue interfaces that lead to signal drop out and large geometric distortions in echo planar imaging (EPI). Alternatively, the heightened susceptibility effects inherent at high field strengths can be exploited using the phase information contained in conventional gradient-echo sequences to create high resolution susceptibility-weighted venograms. [1] Thus, the need arises to develop a method to assess vessel density from susceptibility-weighted imaging (SWI) data and to evaluate the potential of this technique at higher field strengths compared to DSC MRI.

Methods:

T2*-weighted SWI and DSC MRI was performed on nine high-grade glioma patients (five grade III anaplastic astrocytoma and four grade IV glioblastoma), all of whom had received prior treatment. Images were acquired on a 3T Signa Echospeed scanner with EXCITE platform (GE Healthcare Technologies), equipped with an 8-channel phased-array coil (Medical Devices). High resolution T2*-weighted images were obtained prior to the injection of any contrast agent using a 3D flow-compensated GRE sequence with TE/TR=28/46ms, 20° flip angle, 24x24x6 cm^3 FOV, and 512x256x60 image matrix. Phase masks were constructed from the raw complex data of each individual coil element utilizing two methods: 1) conventional homodyne demodulation through complex division by a 64x64 low-pass filtered image[1] and 2) phase unwrapping using a 3D region growing algorithm[2] followed by high-pass filtering via subtraction of a smoothed unwrapped phase image[3]. The latter method was implemented in order to obtain an accurate representation of vessel volume in regions of tumor where large susceptibility differences can cause additional phase wrapping that often cannot be completely removed by the conventional method. The phase masks from each coil were then multiplied four times into the magnitude image of the corresponding coil and the resulting susceptibility-weighted magnitude images were combined by taking the sum of the coil images weighted by the corresponding coil sensitivity profile obtained from a low resolution PD-weighted fGRE scan. The perfusion imaging consisted of the injection of a bolus of 0.1 mmol/kg body weight of gadopentetate dimeglumine (Gd-DTPA) contrast agent at a rate of 5 mL/s. A series of 80 $T2^*$-weighted gradient-echo, echo-planar images were acquired during the first pass of the contrast agent bolus injection, with a TE/TR of 54/1500 ms, 35° flip angle, 26×26 cm^2 FOV, 128×128 acquisition matrix, and 4 mm slice thickness. Sensitivity encoding with a reduction factor of 2 was employed to both minimize the amount of distortion and allow a larger volume of coverage (13-14 slices) within the specified time resolution.

EPI volumes were registered to the SWI images through rigid body transformations and non-rigid B-spline warping through maximization of normalized mutual information[4] utilizing a pre-contrast, T1-weighted SPGR image as an intermediate distortion-free reference to co-register the images. The volume of interest was restricted to the joint FOV of the SWI and co-registered echo planar images. Minimum intensity projections (mIPs) of the SWI images were created at the same slice thickness and coordinates of the perfusion imaging. rCBV was calculated from the from the $\Delta R2^*$ curve of the dynamic data using non-linear gamma-variate fitting to correct for leakage, and then normalized to normal appearing brain tissue. Several gray and white matter ROIs were drawn for each patient based on the pre-contrast T1-weighted SPGR images, while post-contrast T1-weighted SPGR images and T2-weighted FLAIR images were used to manually define regions of tumor. The volume of SWI vessels in each region was determined and compared to perfusion rCBV values, using images obtained via method (1) for the gray and white matter vessels and method (2) for the tumor.

Results and Discussion:

The locations of elevated blood volume based on rCBV calculations within both normal brain tissue and tumor corresponded to regions of decreased intensity on the SWI images as shown in Figure 1, which demonstrates how well the two techniques compare for a heterogeneous tumor lesion. Figure 1a depicts an edematous region of tumor clearly visible on the T2-FLAIR with minimal vascularity confirmed by both low rCBV values and the absence of vessels on the SWI image. In Figure 1b, elevated blood vessel volume is observed within the contrast enhancing portion of the tumor with both techniques. Figure 1c illustrates the formation of macronecrosis within a contrasting enhancing rim region where DSC MRI fails to capture the presence of vessels surrounding this hypoxic region. Normal gray matter rCBV was approximately twice that of normal appearing white matter (2.25±.3) for all patients, but tumor rCBV values exhibited great variability depending on the ROI selected. The signal contrast between susceptibility-weighted vessels and neighboring brain tissue for gray matter and tumor regions were respectively 2.7 and 2.8 times higher than that of white matter.

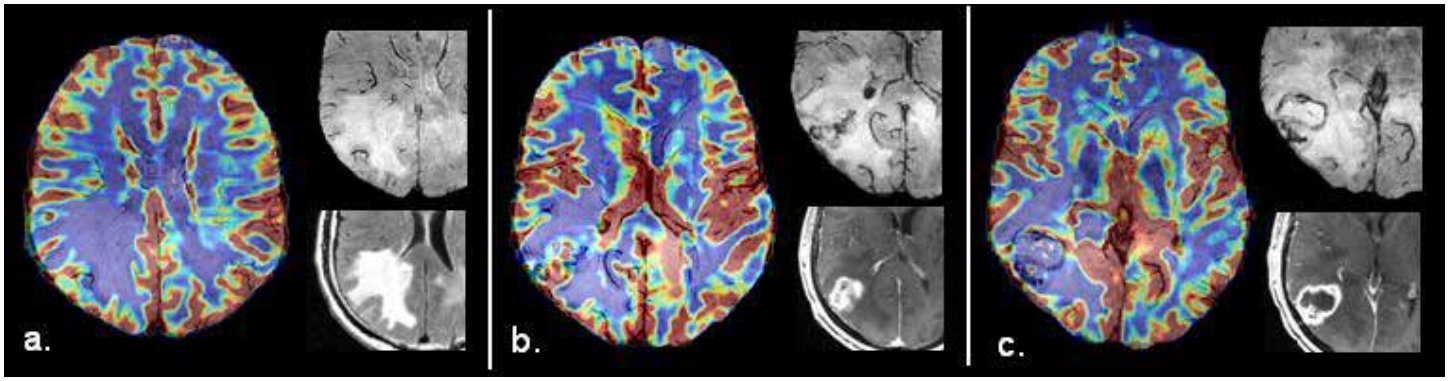

Figure 1: rCBV maps overlaid on SWI images (left), original SWI images (top right), and anatomical images (bottom right) for different locations (a-c) of a glioblastoma.

Conclusions:

SWI and DSC MRI are two drastically different but complementary techniques that can be combined to provide a more accurate assessment of tumor vascularity. SWI provides the added benefits of increased resolution and no geometric distortion, but suffers from long scan times and is incapable of evaluating vascular integrity. Future work will evaluate metrics that an be used to quantify blood volume from susceptibility-weighted images incorporating both the magnitude of signal intensity change in regions of vessels compared to surrounding brain parenchyma and the volume of space that this decreased signal occupies.

References:

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