Assessment of cerebrovascular reactivity during breath holding by dynamic CBV-based MRI: Comparison with BOLD-based MRI

H-L. Liu[1,2], Y-Y. Hsu[3], J-C. Huang[2], W-C. Kwan[2], C-W. Wu[2], S. Mahankali[4]

[1]Dept of Medical Imaging and Radiological Sciences, Chang Gung Univ, Taoyuan, Taiwan, [2]MRI Center, Chang Gung Memorial Hospital, Taoyuan, Taiwan, [3]Radiology Department, Buddhist Tzu Chi General Hospital – Taipei, Taipei, Taiwan, [4]Dept of Imaging Physics, UT MD Anderson Cancer Center, Houston, TX, United States

Introduction

Vasodilatation caused by hypocapnic stress, such as breath holding, can be detected using the blood oxygenation level-dependent (BOLD) MR technique (1, 2). Recent works suggest that such contrast may play a significant role in the characterization of parenchymal glial neoplasms (3). In addition, the technique is sensitive enough to detect changes due to breath hold with short durations that are feasible for most of the patients (4). However, the precise underlying basis of the accompanying changes is relatively unclear since the BOLD signal is a complex outcome of various cerebral physiological parameters. Previous investigators have applied arterial spin labeling (ASL) methods to measure the dynamic cerebral blood flow change during hypocapnic stress and found patterns similar to those derived from BOLD measurements in healthy volunteers (2). However, ASL-based functional imaging generally requires long scan times and suffers from low signal-to-noise ratio. Most recently, a vascular space occupancy (VASO) - based functional MRI technique has been developed to dynamically detect signal changes related to variations in cerebral blood volume (CBV) (5). We, therefore, sought to investigate the sensitivity of this CBV-based MR technique in the detection of vasodilatation during different durations of breath holding and its clinical feasibility as compared with BOLD MRI.

Methods

Experiments were performed on a 1.5T Magnetom Vision (Siemens, Erlangen, Germany) clinical MRI scanner. For the CBV-based scan, a non-slice-selective inversion recovery (NSIR) gradient-echo EPI sequence was used for the VASO imaging, with TR/TE/TI = 2000 ms/9.3 ms/665 ms, slice thickness = 6 mm and in-plane resolution = 3 mm x 3 mm. An axial slice covering the thalamus was imaged. For the BOLD protocol, a gradient-echo EPI sequence was used with TR/TE = 2000 ms/ 60 ms, and the same resolution and slice location as the VASO. Two normal volunteers participated in this study. Each performed two cycles of breath holding after complete exhalation, starting initially with the 45-s natural breathing period, and guided later by a LCD goggle, for each experimental runs. In all, four runs were conducted, including 30-s and 15-s breath holding each for BOLD and VASO, respectively. Contrast-to-noise ratios (CNRs) of the BOLD and VASO signal changes were determined from the averaged time courses of ROIs draw within the thalamus. A similar protocol was also carried out in a patient with right frontal anaplastic astrocytoma to review clinical feasibility. Four cycles of 15-s breath holding was performed by the patient and the slice location was determined based on whole brain T1- and T2-weighted images. BOLD activation maps were generated based on two statistical thresholds, $p < 0.05$ and 0.0005, to match the same probability and similar activation volume, respectively, with VASO.

Results

Significant positive BOLD signal changes were noted in the ROIs drawn in both volunteers during both the 30-s and 15-s breath holding scans (mean = 4.9 and 2.2 %, respectively), which is consistent with previous findings (4). Averaged CNRs of the BOLD signal changes were 4.0 and 2.5, for 30-s and 15-s breath holding, respectively. Within the same ROI, VASO method was able to detect CBV related negative signal changes (mean = -3.1 and -1.8%, for 30-s and 15-s breath holding, respectively), and the averaged CNRs were 2.3 and 1.8. Averaged signal time course from the first breath hold cycle are shown in Fig. 1. To test clinical feasibility, a similar protocol was carried out in a solitary patient presenting with seizures (Figure 2). Axial, morphological, pre- (T_1W & T_2W) and post-contrast T_1W images demonstrated a solitary focal right frontal lesion that was subsequently proven histopathologically - after surgery - to be a WHO grade III anaplastic astrocytoma. Initial analysis of the BOLD data set in this patient revealed negative intra-tumoral signal changes consistent with previous findings (3). While the global pattern of the VASO functional map essentially mirrored that seen qualitatively with BOLD, the extent of intra-tumoral changes observed were of considerably lower magnitude. To account for the inherent sensitivity differences between the two techniques, the functional map generated from the BOLD data set was then re-thresholded to a lower p value which documented intra-tumoral changes similar to those observed with the VASO technique.

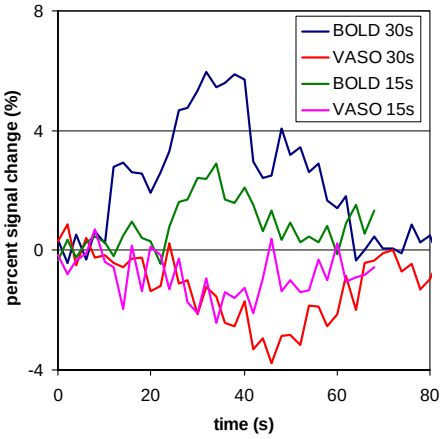

Figure 1 Time courses due to 30 s and 15 s breath holding in two normal subjects. Data was obtained from a ROI drawn with the thalamus. Time courses shown are from the 10 s prior to the start of breath hold.

Discussion

In agreement with the previous study by Lu et al.(5), CNRs of VASO were lower than those derived from BOLD. However, in the present study, CNRs of VASO were closer to BOLD (58 and 72% for 30-s and 15-s breath-holding, respectively) than their results from visual stimulation (~ 30%). Discrepancies between two techniques in the clinical case were likely resulted from the differences in sensitivity. However, given that CBV-based signal change is more directly related with the vasomotor response as compared to BOLD, it could potentially be more clinically relevant. Further studies at higher field strength (3T) involving larger samples of patients with varying histological grades of primary glial malignancy are presently underway.

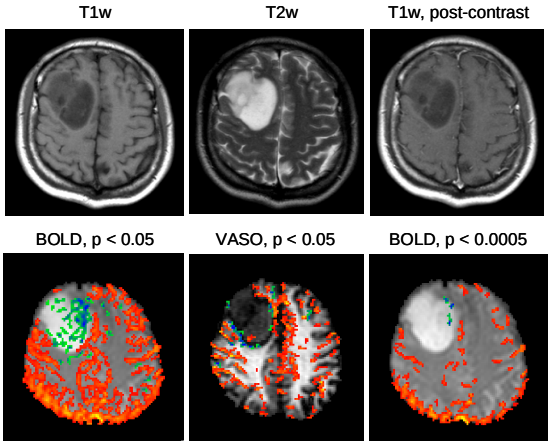

Figure 2 Morphological and functional MR images of a patient. Increases in signal (BOLD) or CBV (VASO) were shown in yellow to red color, while decreases in green to blue.

References

1. Stillman AE, et al. (1995). *Magn Reson Imag*, 13, 893-897.
2. Kastrup A, et al. (1998). *Stroke*, 29, 2641-2645.
3. Hsu YY, et al. (2004). *J Magn Reson Imag*,19,160-167.
4. Liu HL, et al. (2002). *Magn Reson Imag*, 20, 643-648.
5. Lu, et al. (2003). *Magn Reson Med*, 50, 263-274.