Brain Tissue Flow Measurement using Arterial Spin Labeling with Flow Discrimination by Cumulative Readout Pulses

Y. Wang[1], A. Payne[2], S-E. Kim[2], E. DiBella[2], and D. L. Parker[2]
[1]Bioengineering, University of Utah, Salt Lake City, UT, United States, [2]Utah Center for Advanced Imaging Research, University of Utah, Salt Lake City, UT, United States

Background

The Pennes' perfusion term in the Pennes bioheat transfer equation (BHTE) depicts the rate at which blood flow removes heat from a point and can play an important role in tissue heat dissipation. Because tissue perfusion is known to change over the course of a thermal therapy treatment [1, 2], the ability to perform multiple flow assessments to detect perfusion changes during magnetic resonance-guided high-intensity focused ultrasound (MRgHIFU) treatment is of high importance. In this work, we present a method to use arterial spin labeling (ASL) to determine the Pennes' perfusion term in brain tissue and evaluate performance as a function of various imaging parameters, such as flip angle (*FA*), bandwidth (*BW*), and resolution. The results indicate that the proposed technique could be applied in MRgHIFU to provide an efficient estimate of the Pennes' perfusion term. Although demonstrated on brain tissue, this technique could be applied to other tissue types.

Theory

The imaging pulse sequence is composed of IDOL magnetization preparation [3] followed by Look-Locker-like [4] readouts at multiple inversion times (*TI*) in a single scan. Since the signal perturbation due to the turbo-FLASH (TFL) excitation pulses changes as a function of flow velocity, multiple 2D TFL readouts with linear phase encoding ordering are employed to obtain flow-sensitive signals. The flow-dependent signal that is only due to the flow is obtained by the subtraction of control and tag images. Based on the flow-sensitive signal, an effective flow velocity mapping is fitted by modeling each slice by an average of *N* subdivision slices, where $N=D/(v\cdot TR)$, *D* is the slice thickness, *v* is the effective flow velocity, and *TR* is the time between two TFL excitation pulses. The modeling of control and tag images is the same except for the initial magnetization.

Methods

One volunteer subject was imaged using a 12 channel head coil on a Siemens 3T scanner. Transverse plane of a brain was imaged with the IDOL-prepared linear phase-encoding ordering TFL pulse sequence at a series of *TI* = [700, 1000, 1300, 1600, 1900, 2200] ms in a single scan. The tagging of the inflow was centered on the neck so that the heart is included in the inversion region, and the imaging slice was located at the corpus callosum. Altogether three measurements of tag/control pairs were acquired in 1 min. Other imaging parameters were *TR* = 3 ms, *FA* = [10° 15° 20°], pixel size = [1x1, 2x2, 4x4] mm^2, slice thickness = 3.5mm, *BW* = [220, 490] Hz/Px. An eight second time interval was introduced between the interleaved tag/control scans to avoid any impact from previous pulses. Pair-wise subtraction was performed to obtain the averaged flow-sensitive images. In addition, an exponential fitting was applied to the measured data series of difference signals to estimate flow velocity mapping.

Results

Flow-sensitive images at one slice location acquired at *TI* of [700, 1000, 1300, 1600, 1900, 2200] ms are shown in Fig. 1. The wash-out of bolus is visible as *TI* increases. A comparison of the performance of *FA* of 10°, 15°, and 20° is demonstrated on images acquired at *TI*=1300ms with 2x2 mm^2 in-plane resolution. As shown in Fig. 2, *FA* of 20° performs the best. The effect of *BW* on flow-sensitive signal is illustrated in Fig. 3. It is evident that signal-to-noise (SNR) of the image acquired at *BW* of 220 Hz/Px is higher compared to the image acquired at 490 Hz/Pixel. Furthermore, the effect of three different in-plane resolutions is presented in Fig. 4. Among three images, the image with resolution of 2x2 mm^2 appears to be a good tradeoff between the details in gray matters and the overall image SNR. Last but not least, the fitted relative velocity mapping is shown in Fig. 5. A high velocity is found in vein and slower velocities can be seen in gray matters.

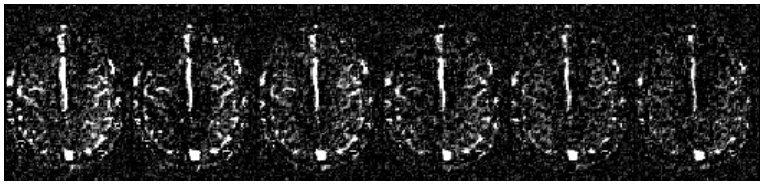

Fig. 1 Flow-sensitive images acquired at *TI* of [700, 1000, 1300, 1600, 1900, 2200] ms. Bolus wash-out is visible as *TI* increases. The large vein located at the bottom appears bright because the venous blood is labeled in IDOL tagging schemes.

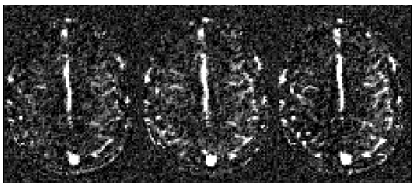

Fig. 2 Flow-sensitive images acquired at FA of 10°(left), 15°(middle) and 20° (right), with *TI* of 1300ms, 2x2 mm^2 in-plane resolution.

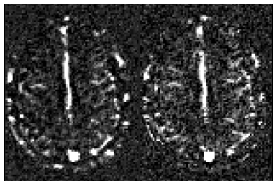

Fig. 3 Flow-sensitive images acquired at *BW* of 220 (left) and 490 (right) Hz/Px, with *TI* of 1300ms and 2x2 mm^2 pixel size.

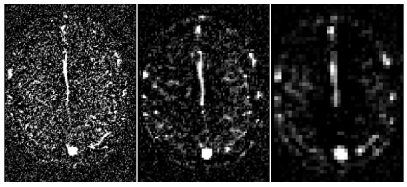

Fig. 4 Flow-sensitive images acquired at *TI* of 2200ms with in-plane resolution of 1x1 (left), 2x2 (middle), and 4x4 (right) mm^2.

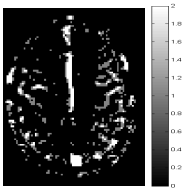

Fig.5 Fitted velocity mapping.

Conclusion

The results suggest that the proposed technique might be applied in MRgHIFU to provide an estimate of changes in the Pennes' perfusion term in a time efficient way. The results shown are based on image averaged over three repetitions only, and more repetition should lead to a higher SNR. Further investigation including more subjects is necessary. The tradeoff between the image acquisition time and the accuracy of effective velocity quantification need to be optimized such that the scan could be interleaved in an actual MRgHIFU study.

References

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Acknowledgments

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