Flow ENhancement of Signal Intensity (FENSI): Validation of localized flow measurements

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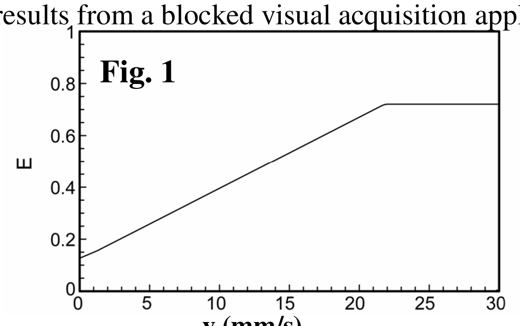
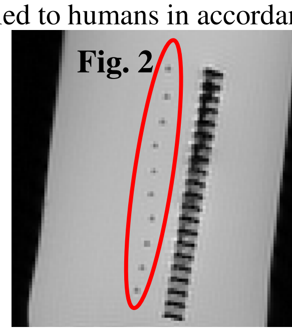
Introduction: The need to measure localized blood flow velocity is important for evaluation of the resting state blood flow of an individual, relating blood flow to disease states, and examining hemodynamic coupling of functional responses. Arterial spin labeling approaches offer quantitative information relating bulk flow of blood from a tagging plane into a slice [see 1 for a recent review]. Recently, velocity selective ASL methods have been proposed [2] that allow for restricting ASL signal to blood that has crossed a predetermined velocity threshold. In this work, we present a method called Flow ENhancement of Signal Intensity (FENSI) that gives quantitative information on flow velocities along with high spatial localization and directional sensitivity.

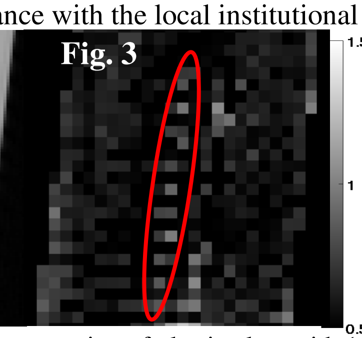
Theory: The FENSI method proposed here is based on the MR microscopy method of DESIRE (Diffusion Enhancement of SIgnal and REsolution) proposed by Paul Lauterbur in 1992 [3] and demonstrated experimentally recently [4]. The concept of the method is to saturate the spins within a small plane (also known as "hole burning" technique). By repeatedly saturating this region over a period of time, the signal void region grows proportional to the velocity of flow perpendicular to the saturation plane. The images are obtained by subtracting images with and without saturation. The enhancement of the resulting image is defined as the ratio of the signal intensity difference between an enhanced and an un-enhanced image to the intensity of the un-enhanced image. We consider an un-enhanced image an image obtained with only one tag (minimum saturation time). With this definition, the enhancement can be experimentally determined from the imaging sequence. This "experimental" enhancement is compared with the theoretical prediction. Assuming a 400 μm saturation plane inside a 1 cm slice, with 20 tags applied at 11 ms spacing and ignoring T1 effects, the curve shown in Figure 1 is obtained relating the theoretical enhancement of the signal to the velocity of the flow perpendicular to the saturation plane, assuming a 5% volume fraction of the flow.

Results: A phantom was constructed using a water-filled bottle and tubing of 0.86 mm inner diameter. The tubing was wrapped 10 times around a curved plastic plate with a distance between the tubing segments of ~8 mm. The FENSI saturation sequence was combined with a spin-echo EPI imaging sequence with a TE of 40 ms, a matrix size of 64x64, a field of view of 22 cm, and a TR of 2 s. It was implemented on a 3 T Siemens Allegra headscanner. With these parameters, in voxels containing tubing, a 5% volume fraction of tubing was obtained, consistent with literature values on microcirculation volume fraction. A syringe pump was used to maintain a flow with 1 cm/s average velocity in the tubing. A scan plane was set up perpendicular to the parallel tubing segments. A high resolution image was acquired in the tag plane and is shown in Figure 2. The results of the enhancement calculated from 20 averages of 1 tag and 20 tag images (first one of each discarded) are shown in Figure 3. As shown here, the velocity estimates in the tubing are very nearly 1 cm/s. The locations of the tube segments were determined by visual inspection of the flow image. The average velocity in the voxels with tubing was estimated to be 0.85 ± 0.07 cm/s.

Conclusion: FENSI provides an accurate way to measure velocities while being highly localized and directionally sensitive. This method will be applied to image microvascular circulation to reveal resting state blood flow, flow in disease, and as a tool for examining hemodynamic coupling of functional responses. Shown in Figure 4 are preliminary results from a blocked visual acquisition applied to humans in accordance with the local institutional review board.







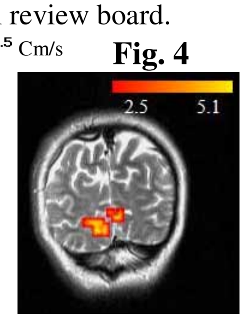


Fig 1. Enhancement vs. Velocity. **Fig 2.** High resolution image showing cross section of plastic plate with 10 tubes cut perpendicular, just to the left of the plastic plate. **Fig 3.** Map of flow in phantom. Note the 10 tubes showing up as brighter in the flow image. **Fig. 4.** Z-score map of application of FENSI to functional imaging in a blocked visual paradigm.

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