Perfusion Imaging Using Velocity Encoding

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SYNOPSIS: A new strategy for MRI perfusion imaging is introduced here, which we call "Velocity Encoding Perfusion" (VEP). Echo planar imaging is used. Every shot is preceded by a tailored tagging pulse that saturates tissues in an adjacent slab by varying flip angles across the slab. The profile is also varied in time to create a sinusoidal oscillation of magnetization M_z. The velocity of flow depends on a time delay of tagged blood that arrives at the imaging slice and is detected by the phase and frequency of oscillations in the time-course series of images.

INTRODUCTION: The FAIR technique of MRI perfusion measurement was introduced in 1995 (1). Shortly afterward, derivatives of this technique were implemented on our 3T scanner with the goal of quantifying cerebral blood flow (CBF) (2). All these techniques derived CBF from a difference between tagged and untagged images. Averaging over time was used to improve SNR. The technique presented here uses a correlation method of detection introduced in our laboratory primarily for functional brain imaging (3). In all three versions of VEP introduced here, the M_z of tagged blood oscillates sinusoidally in time and its presence in an imaging slice is detected by correlating the signal with a sine and cosine at a known tagging frequency. The ratio of these components gives the phase shift that carries information about flow velocities, the sum of the squares is proportional to the square of the flow volume. In the first method, the frequency of the tagging oscillation varies across the slab. Figure 1 shows a snap image and a time course of a tagging signal. The slab was encoded perpendicular to the slice to show its profile. In the second method encoding was at a single frequency but with a different phase across the slab. This technique allows surrounding of any slice with two tagging slabs, encoded at different frequencies, to measure flow in two directions. The third technique, which is fast, encodes the tagging slab with a uniform phase that changes with every acquisition. The inversion recovery time (IR) is short. The fast blood tagged in the first shot will arrive at the same image acquisition with zero phase shift. Slower flowing blood will arrive a few acquisitions later with a different relative phase. This sequence operates under the assumption that moving blood will leave a tagging slice before the next tagging pulse is applied. A thinner tagging slice is required to avoid multiple tagging of the same blood volume. This technique runs with a TR as short as 100 ms and works well for time course analysis of flow.

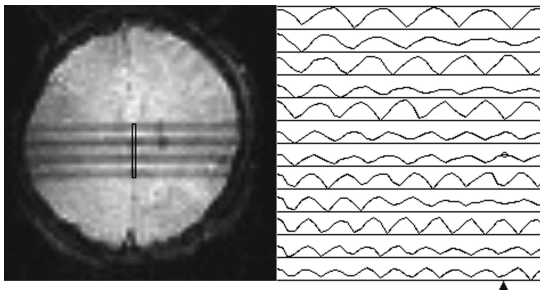

Fig. 1: Frequency modulation across the slab.

METHODS: All studies were performed on a Bruker Biospec 30/60 3T MR scanner. A balanced torque three-axis local gradient coil and endcapped birdcage rf coil optimized for human brain imaging were used. Image acquisition and rf tagging pulses were done off line on a computer equipped with a DATEL PCI-417G2 card, running Linux OS. Two D/A converters on the PCI card were used to create I and Q signals that were fed to a quadrature modulator to produce tagging pulses synchronously with the EPI sequence. These pulses were mixed in an rf combiner with standard rf pulses and sent to the transmitter. The flow maps were created from the time series of images using correlation techniques for phase encoding and Fourier transforms for frequency encoding tagging. The following acquisition parameters were used: 1) All sequences: TE = 27.2 ms, resolution 64 × 64, BW = 125 kHz, FOV = 20 cm, slice 1.5 mm. 2) Fast sequence: TR = 133 ms, IR = 50 ms, IR slab 1.5 mm, separated by 5, 10 or 15 mm, total acquisition time 60 s. 3) Frequency and phase encoding sequences: TR = 2 s, IR = 1 s, slab 10–70 mm, separation 2–10 mm, total acquisition time 4.5 minutes.

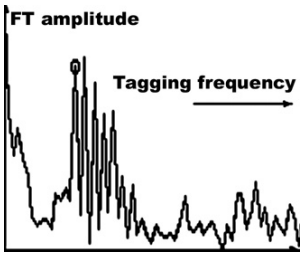

Fig.2 Velocity spectrum.

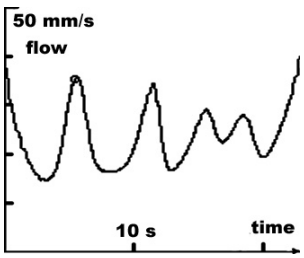

Fig.3. Velocity variation

RESULTS: Figure 2 shows a Fourier spectrum in a vessel for frequency modulation tagging. There are five different peaks depicting velocities in the vessel within 4.5 minutes of imaging. Dips between peaks confirm that the tagging method works. These frequencies were not used in tagging. Usually, for areas of uniform flow, only one velocity peak shows for a given pixel. The mystery was revealed after using a fast acquisition method with windowed correlation detection, 5 s wide, throughout the time course of images. Figure 3 shows that blood velocity in the vein varies from 15 to 40 mm/s. A 2.5 s window revealed larger variations in flow, but data were less reliable due to the lower correlation coefficients.

DISCUSSION: It has been shown that flow velocity encoding using tailored tagging IR pulses is possible. Results are in absolute units and the method is robust. Flow volume can be derived from the amplitude of oscillations in both slow methods with knowledge of T_1. In the fast method, the IR time varies with velocity, making the CBF measurement, but not the velocity measurement, less reliable.

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