Quantification of Retinal Blood Flow Using a Pseudo-Continuous Arterial Spin Labeling Technique

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Introduction: Disorders of retinal vascular supply and growth have been implicated in many important visual disorders including age related macular degeneration [1], diabetic retinopathy, and glaucoma [2]. Measures of perfusion to the retina are currently derived primarily from optical techniques which relate dye transit or velocity distributions to blood flow. Alsop and Detre had previously observed that flow to the retina was readily detectable in their perfusion images [3]. In this study, we employed a recently developed strategy for continuous arterial spin labeling with a repeated series of short pulses to assess retinal perfusion [4]. We also report rigorous quantification of blood flow to the retina using multiple delay times, 3 Tesla imaging, and array coil reception.

Methods: Studies were performed on a 3.0 Tesla HD MR system (GE Healthcare Technologies) with an 8-channel phased array head coil on 5 healthy subjects with no history of retinal or choroidal abnormality. Labeling was performed with the pseudo-continuous ASL strategy [4]. An approximately axial image slice passing through the optic nerve heads was prescribed graphically based on the localizer image. The labeling slab was in the axial plane, approximately 5cm below the slice. This location labels blood in the carotid and other arteries below the Circle of Willis. Images were acquired using a 2D half Fourier single shot fast spin echo (SSFSE) sequence. Imaging parameters were Matrix=96x96, FOV=24cm, slice thickness=10mm Band width=20.83KHz, TE=36.5msec (minimum TE) and TR=7s . A long TR was selected to minimize any effects of the inversion pulses on blood magnetization for the next repetition; and a minimum effective TE was chosen to minimize the T2 contribution to the signal intensity. Image pairs (label & control) were acquired at post-labeling delays of 0.5, 0.75, 1, 1.25, 1.5, and 2.5 seconds. The pairs were repeated 20 times to improve signal-to-noise ratio by averaging. All of the imaging was performed with 7 inversion pulses whose timing was optimized to produce a very small signal from static tissue in order to successfully image retinal perfusion in-vivo. The volunteers were asked to fixate on a landmark and blink only during the silent periods of the sequence. Images were reconstructed offline with custom tools developed in the IDL programming environment. The signals in regions of interest drawn manually around the retina of each eye with respect to the post-labeling delays were fit to a single compartment model to measure arterial transit time. Because the literature suggest flow per cc of tissue to the choroid is extremely high, we allowed for the possibility of tracer outflow by modeling it as a transit time to account for additional loss of magnetization beyond the T1 of blood. Blood flow to the gray matter was calculated for comparison.

Results: Retinal perfusion images at various post-labeling delays are shown for one subject in figure 1.The combination of signal spatial location and dependence upon post-labeling delay provide strong support for the blood flow related nature of the signal (fig.2). Specifically ASL images at longer delays (1.25, 1.5 and 2.5 s) are clearly consistent with retinal perfusion. The perfusion signal was brightest near the fovea. The blood flow for the retina and gray matter was found to be 0.78±0.34 ml/mm2/min and 56.6±19.1 mL/100g/min. Arterial transit delay was 1120±224ms and 1098±240ms for retina and gray matter respectively. Outflow was found to affect the signal at longer post-labeling delays but the effect was small (table 1). There is also the possibility that the choroid has a different T1 than blood and there is no outflow.

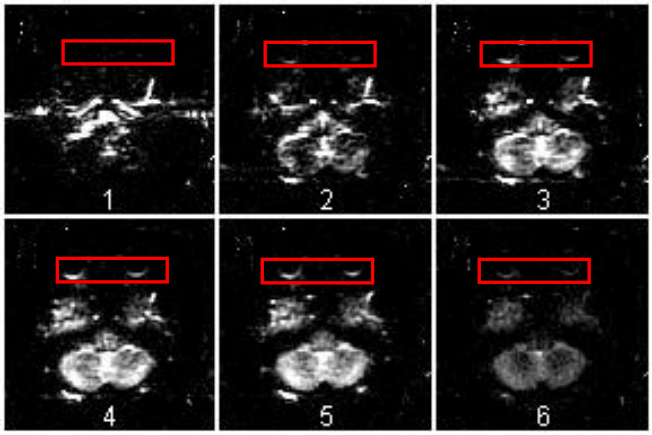

Figure.1. Single slice perfusion images obtained with background suppressed Pulsed-CASL technique. Images 1 to 6 in the figure correspond to post-labeling delays of 0.5 s(1), 0.75s(2), 1s(3), 1.25 s(4), 1.5s(5) , and 2.5s(6) respectively.

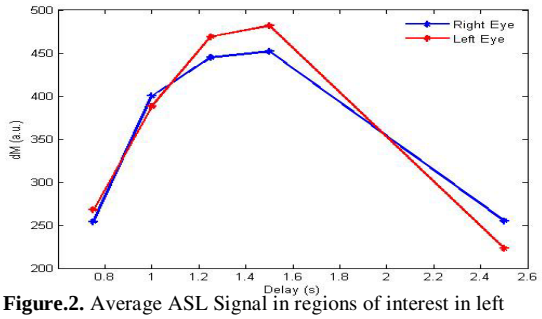

Figure.2. Average ASL Signal in regions of interest in left and right eye of a subject versus post-labeling delay time

Retina			
R_{1app} (s^{-1})	f (ml/mm2/min)	δ (ms)	$T_{out\ flow}$ (ms)
0.74±0.08	**0.78±0.34**	**1120±224**	**2200±211**

Table.1. Flow (f), Transit delay (δ), Time to outflow (τ) quantification results in Retina

Conclusion: The results of this study establish the feasibility of imaging and quantification of blood flow to the retina with contrast free MRI in humans and support the further characterization of the healthy and diseased retina with this method. This technique may also provide a unique window for the study of choroidal blood flow control and pathology.

References: [1] IOVS 1998; 39:385-390 [2] SOV 1998; 42:509-533. [3] ISMRM 2000, p.162 [4] ISMRM 2005, p.37.