Cerebral Blood Flow Quantification in Swine Model using Pseudo-Continuous Arterial Spin Labeling

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Introduction

Swine brain perfusion is a good model for that of human due to the similar proportions of grey and white matter [1]. Cerebral blood flow (CBF) maps can give great insight into disease states such as stoke and traumatic brain injury, both of which can be studied in a swine model with arterial spin labeling (ASL) MRI. Pseudo-continuous arterial spin labeling (PCASL) has higher tagging efficiency than pulsed ASL, and does not have the hardware constraints of continuous ASL [2]. Though PCASL has been developed and optimized for humans, there has been little to no work on optimizing PCASL methods for animal models. The swine model may have unique intracranial vasculature and dynamics that need to be considered for blood flow imaging. The purpose of this study is to determine the optimum parameters for PCASL acquisition and to measure cerebral blood flow and transit delay for the normal swine model.

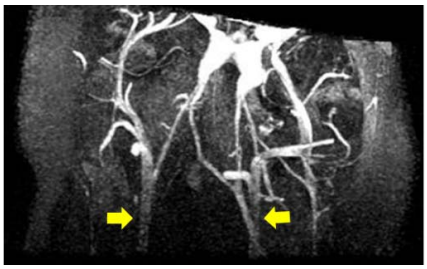

Fig. 1 *Anterior view of CE-MRA shows location of common carotid arteries (yellow arrows)*

Methods

Five female domestic pigs (25kg, 2.5-3 mos) were imaged in the following experiments on a 1.5T Excite HDx scanner with an 8 channel head coil (GE Healthcare, Waukesha, WI) in the Center for Biomolecular Imaging of Wake Forest School of Medicine. **Tagging Localization** In order to maximize tagging efficiency, the tagging plane should be perpendicular to the carotid artery; therefore a contrast-enhanced magnetic resonance angiogram (CE-MRA) was performed on one pig to determine the location and orientation of the carotid arteries (see Fig 1). **Arterial Velocity Measurement** A phase contrast (PC) image was collected at the location of the tagging plane (blue line, Fig 2) to determine the velocity of blood that will be labeled in the common carotid arteries for all subjects (there are no intracranial vertebral arteries in pigs). **Parameter Optimization** Bloch simulations were performed to optimize selected PCASL parameters (excitation gradient strength, excitation pulse width, B_1 field amplitude, and average gradient strength) in order to maximize the tagging efficiency of the blood for the measured range of velocities. **Acquisition** The tag and control images were taken perpendicular to the AC-PC line in order to minimize the number of slices required for full brain coverage, see Fig 2. The PCASL acquisition used 3D interleaved spiral FLASH, which applies a variable flip angle described in [3] and diffusion gradients for intravenous signal supression [4]. PCASL tagging duration was 1600ms and eight post-labeling delays (PLD) were applied [5] ranging from 100 to 2900ms with increment of 400ms. Imaging parameters included: 200mm FOV, 58mm slab thickness, 64x64x18 matrix size, image resolution of 3.1x3.1x3.2 mm^3, 40 control-tag pairs per PLD, with total scan time of 44 min. **Quantification** The T_1 of blood and the ratio of blood-to-white matter M_0 values are necessary for accurate quantification of CBF [6]. A T_1 map and a M_0 image were collected for two subjects who had a fresh blood sample in a vial next to their head inside the coil. A quantitative CBF map was created and normalized with a swine brain template [7].

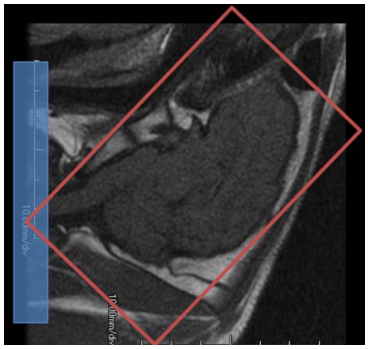

Fig. 2 *The tagging plane (blue line) is perpendicular to the carotid artery and the imaging volume (red rectangle) is perpendicular to the AC-PC line.*

Results

The range of velocities measured by PC in the swine is lower than the range of velocities that have maximal tagging efficiency using conventional human PCASL parameters. Figure 3a shows the range of the blood velocity through the common carotid arteries over the course of one heart cycle averaged for all subjects which demonstrates that the highest tagging efficiency should be in the range of 5-18 cm/s. Figure 3b shows the tagging efficiencies of the original and optimized parameters. The optimized parameters are 0.991 G/cm, 1033 us, 0.0356 G and 0.0667 G/cm for the excitation gradient amplitude, excitation pulse width, B_1 amplitude, and average gradient amplitude respectively (the original parameters were 0.8 G/cm, 800 us, 0.05 G, and 0.06 G/cm, respectively). The new parameters resulted in higher tagging efficiencies for blood flowing at 5-18 cm/s. Indeed, Fig 3a clearly demonstrates that this is the velocity range of most blood in the common carotid artery flowing through the tagging plane. The average T_1 of blood measured in the vile was 1546 ms and the blood-to-white matter ratio of M_0 was 1.25. Both of these values were used in the quantification of CBF for all subjects. Mean whole brain CBF and transit delay were 70.9 ml/100g-tissue/min and 1297ms, respectively. Figure 4 is an example of the CBF maps and transit delay maps normalized to the template [7].

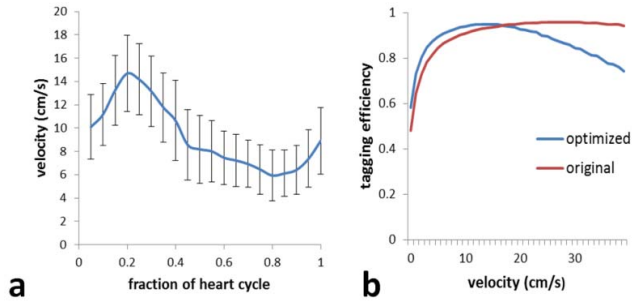

Fig. 3 a: *Mean ± standard deviation of blood velocity in common carotid artery measured with phase contrast imaging.* ***b:*** *Simulation results of the tagging efficiency over velocity.*

Discussion and Conclusion

There are many parameters and components of the PCASL procedure that required optimization in order for PCASL to work well in the swine model. The arterial blood velocity was measured to optimize tagging efficiency by adjusting acquisition parameters. Multiple post-labeling delays were collected so that the CBF quantification would be less sensitive to varying transit delays across the brain. The delay time pattern in pigs was not as variable compared to the known delay time pattern in humans and a shortened delay time for white matter was observed. The opposite pattern is observed in humans. Further study will be useful to better understand this result. Since the T_1 of blood and the blood-to-white matter ratio of M_0 values is directly used to quantify CBF, model-specific blood T_1 and the M_0 ratio of blood to white matter were measured for the quantification of CBF. Such considerations are necessary for the development of this new animal model of cerebral perfusion.

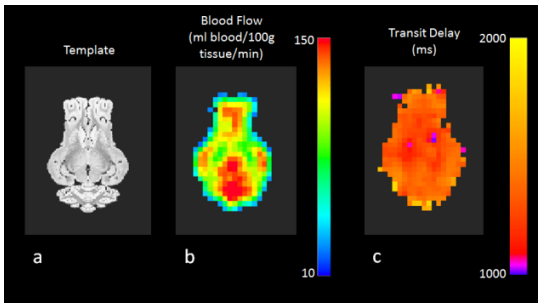

Fig. 4 *Template used for normalization (a). CBF map (b) and the transit delay map (c) normalized to the template*

References

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