Transit Time Imaging with Flow Encoding Arterial Spin Tagging (FEAST)

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Abstract Flow encoding arterial spin tagging (FEAST) is introduced as a technique to measure arterial transit time (ATT), which can be derived from the ratio between the perfusion signals acquired with and without appropriate bipolar gradients. The mean ATT from just below the Circle of Willis to the brain was approximately 1.1 and 1.4s for bipolar gradients with specific encoding velocity (Venc) of 29 and 8mm/sec respectively, and was shortest in the deep middle cerebral artery (MCA) territory. Clinical applications of FEAST demonstrated its utility in the diagnosis of cerebrovascular disease.

Introduction Arterial transit time (ATT) is a potentially important physiologic parameter that may indicate the recruitment of collateral flow sources in cerebrovascular diseases. Dynamic tracking of contrast agent has been used to assess transit time. However, absolute quantification of cerebral blood flow (CBF) and blood volume remains challenging in this approach. Arterial spin labeling (ASL) perfusion MRI provides direct and absolute CBF measurement that is quantifiable in classical units of ml/g/min. Most existing ASL approaches to assess transit time rely on multiple measurements at various delay times, thus are time consuming and vulnerable to motion artifact. We propose the use of flow encoding arterial spin tagging (FEAST) technique to measure transit time, which can be derived from the ratio between the ASL signals measured with and without appropriate bipolar gradients. We provide a theoretical framework and carried out an experimental validation during steady-state imaging on healthy subjects, along with clinical applications on patients with cerebrovascular disorders.

Theory The FEAST technique was developed using the continuous ASL (CASL) approach with a delay (w) between labeling and image acquisition (1). The CASL signal consists of two source contributions from the vascular and microvascular (tissue) compartments which can be differentiated by applying appropriate spoiler gradients. The transit time, δ, is the major factor in determining the proportion of the ASL signal in the two compartments, as more tagged blood water resides in the microvascular compartment with shorter δ and *vice versa*. An estimation of δ can be derived from the CASL signals acquired with and without bipolar gradients (ΔM' and ΔM) according to the following equations (2): $\Delta M = A\, f\, [\exp(-w/\mathrm{T1a})-\exp(-(\tau+w)/\mathrm{T1a})]$; $\Delta M' = A\, f\, [\exp(-\delta/\mathrm{T1a})-\exp(-(\tau+w)/\mathrm{T1a})]$ where f is CBF, τ is labeling pulse duration, T1a is the T1 of blood and A is a constant. Simulation demonstrates ΔM decays exponentially with w whereas ΔM' remains constant (Fig. 1A)

Methods MR scanning was performed on 1.5T GE Signa scanner, 14 healthy subjects were scanned during resting state using the standard quadrature head coil. Flow encoding bipolar gradients were applied along the slice direction in the CASL sequence. The amplitude of the gradients was 0 for odd pair of label and control acquisitions, and was 2.1 G/cm for even pair of label and control acquisitions. 5 slices (14mm thick with 2mm gap) were acquired sequentially from inferior to superior using a gradient echo EPI sequence (FOV=24cm, 40x64 matrix, TR=4s). 8 subjects were scanned using a pair of 8ms width bipolar gradients (Venc=8mm/s, TE=39ms) at three delays of 0.3, 0.6 and 0.9s, while the other 6 subjects underwent scans using a pair of 4ms width bipolar gradients (Venc=29mm/s, TE=31ms) at two delays of 0.45 and 0.7s. Each scan at a particular delay consisted of 120 acquisitions (8min). ΔM and ΔM' were obtained by averaging the odd and even number of difference ASL images respectively. Segmentation of transit time images into major vascular territories was performed using an automated ROI analysis (3). 6 patients with cerebrovascular diseases were also scanned using FEAST at w=0.8s with 8ms bipolar gradients along with FLAIR, diffision weight imaging (DWI) and the orignal CASL technqiue at w=1.5s.

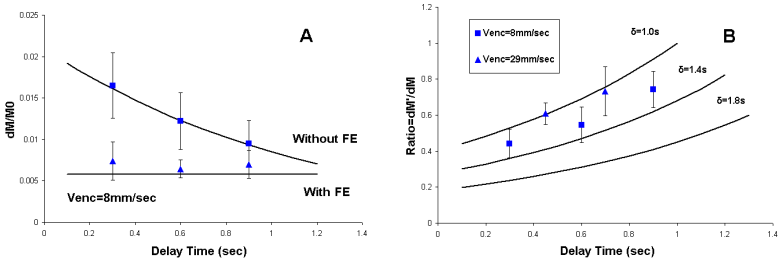


Fig. 1 Simulated curves and experimental samples displaying fractional ΔM & ΔM' signals (A) as well as the ratio of ΔM' to ΔM as a function of delay time (B).

Results and Discussion The global mean ATT was about 1.1 and 1.4s for the 4ms and 8ms bipolar gradients respectively (P=0.016), and was very stable across different delay times. As displayed in Fig. 1, the experimental results match well with the theoretical model. The measures of transit time under two conditions of bipolar gradients show very similar patterns of variation across vascular territories, with the shortest transit time in the deep MCA territories. This result is consistent with the neuroanatomy of cerebral blood supply since the deep MCA branches are closest and most direct branches of the internal carotid artery. Applications of FEAST on patients demonstrate it can detect transit time artifact in ASL perfusion images as well as provide additional and even more sensitive diagnostic information. Figure 2 shows a case study of a 30 year old stroke patient. Infarct is seen in the left MCA distribution in the DWI images. Transit time images indicate correspondingly prolonged transit time in the left MCA territory, suggesting perfusion in this region is maintained through collateral blood supply, and also explaining the transit related hyperintensity in the CASL CBF images. The FEAST technique should be a useful tool in both clinical and neuroscience applications.

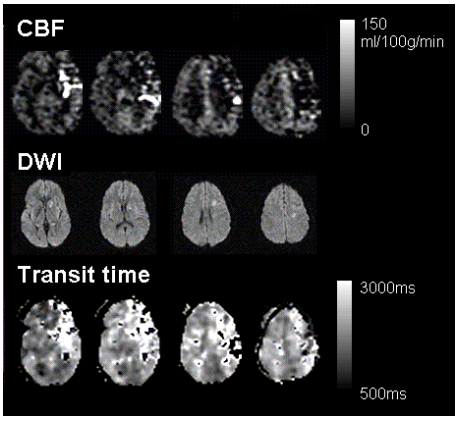


Fig. 2. CBF, DWI and FEAST transit time images of 30yrs female stroke patient.

References (1) Alsop DC&Detre JA *Radiology* **208**: 410-6; 1998. (2) Wang J et al. *MRM* **48**: 242-254; 2002. (3) Tatu L et al. *Neurology* **50**: 1699-1708; 1998.