

# ARTERIAL SPIN LABEL CBF MAPS CAN SHOW ABNORMALITIES IN CLINICAL PATIENTS WITH NORMAL BOLUS PERFUSION-WEIGHTED IMAGING: IDENTIFICATION OF THE "WATERSHED SIGN"

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**Introduction:** Bolus perfusion-weighted imaging (PWI) and arterial spin labeling (ASL) are two popular methods to evaluate hemodynamic abnormalities in a wide range of cerebrovascular diseases [1-3]. ASL is very sensitive to prolonged arterial arrival times, since the label decays with blood T1. This increased sensitivity may differentiate between truly normal hemodynamics and mild/bilateral abnormalities of CBF and arrival time. This study examines whether additional findings are seen on ASL images in patients with normal PWI.

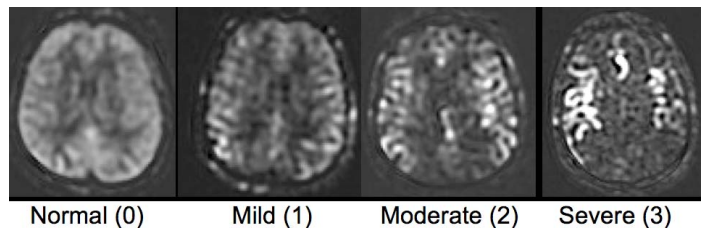
**Methods:** Patients signed prior written informed consent and the study was HIPAA compliant. Inclusion criteria included MRI ordered for known or suspected cerebrovascular disease. 139 consecutive patients met these criteria and had routine brain imaging at 1.5 T with both bolus PWI and ASL. Gradient-echo bolus PWI (2 min) was performed with single shot EPI (n=34, TR/TE 2s/60ms) or multiecho GRAPPA (R=3) parallel EPI (n=105, TR/TE 1.225s/(15,36,56 ms)) [4] and single-dose Gd. Post-processing using automated AIF detection and oSVD [5] yielded relative CBF, CBV, MTT, and normalized time-to-peak (Tmax) maps. Background suppressed 3D fast-spin-echo (FSE) pseudocontinuous ASL (pcASL) images (6 min) were acquired using a labeling period/post-label delay of 1.5s/1.5s [6].

PWI studies were first screened based on a final radiographic reading of normal. Then, these cases were examined by an experienced neuroradiologist to determine whether subtle PWI abnormalities were present. Based on pilot data, ASL often showed low signal in vascular borderzones (a finding we term the "watershed sign"). ASL images were reviewed by two experienced neuroradiologists in a blinded manner, who scored them on an ordinal scale from 0 to 3 (0=normal, 1=mild watershed, 2=moderate watershed, 3=severe watershed) (Fig 1). Disagreements were resolved by consensus.

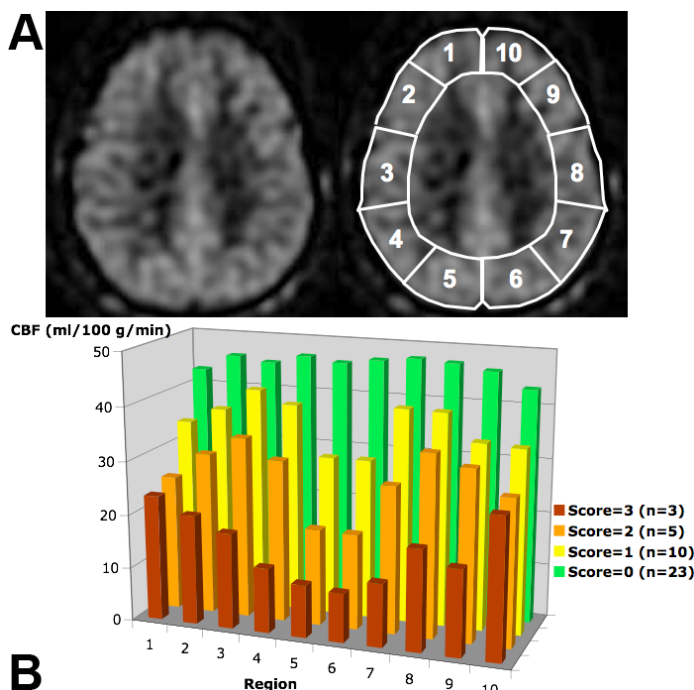
**Results:** 41/139 patients (29%) had normal bolus PWI studies. There was good concordance between the reviewers, with a Kendall's tau-b score of 0.62 (p<0.0001). The reviewers differed in their scores by 2 scale points in only 2/41 patients (5%). 23 patients (56%) had normal ASL imaging, with homogeneous, symmetric parenchymal CBF signal. The remaining 18 patients (44%) had a watershed sign (10 mild, 5 moderate, and 3 severe). Fig 2, demonstrates decreasing cortical CBF with increasing ASL score, particularly posteriorly. Mean cortical CBF decreased monotonically from 45±12 ml/100 g/min in grade 0 patients to 18±10 ml/100g/min in grade 3 patients (p<0.0001). 12% of patients had additional focal abnormalities on ASL as follows: linear high signal near small DWI lesions; high signal due to slow or stagnant flow in a vascular structure, or low signal in resection cavities.

**Discussion:** 3D FSE background-suppressed pcASL [5] has reasonable SNR, reduced motion sensitivity, and improved performance in high susceptibility regions compared with EPI read-out methods, making it a promising ASL method at 1.5 T. This study shows that additional information relating to perfusion can be identified using ASL in patients with normal bolus PWI. We believe that the watershed sign is a reflection of either (a) longer than normal arrival times, (b) lower CBF, or (c) a combination of both. In theory, bolus PWI parameters such as Tmax should be sensitive to arterial arrival delays, though only those greater than or equal to the repetition time of the EPI sequence, which in our study ranged between 1.225 and 2 s; by definition, this was not observed in our patients who had normal PWI. Based on our findings, we recommend the supplemental use of ASL imaging in all cases of suspected or known cerebrovascular disease.

**References:** 1. Sorensen et al., Radiology 1996; 2. Cha et al., Radiology 2002; 3. Detre et al., MRM 1992; 4. Newbould et al., MRM 2007; 5. Wu et al., MRM 2003; 6. Dai et al., MRM 2008.



**Fig 1:** ASL patterns used as a grading template for the watershed sign. Despite normal bolus PWI, many ASL studies had signal dropout in the bilateral MCA-ACA and MCA-PCA borderzones with serpiginous high signal in the surrounding cortex.



**Fig 2:** Regional cortical CBF at the level of the centrum semi-ovale, segregated by ASL score. CBF decreased significantly with increasing ASL score (p<0.0001, J-T test for ordered alternatives).