Published in final edited form as:

Cerebrovasc Dis. 2012 ; 34(3): 221–228. doi:10.1159/000339682.

Arterial Spin Labeling Imaging Findings in Transient Ischemic Attack Patients: Comparison with Diffusion- and Bolus Perfusion-Weighted Imaging

Greg Zaharchuk^a, Jean-Marc Olivot^b, Nancy J. Fischbein^a, Roland Bammer^a, Matus Straka^a, Jonathan T. Kleinman^b, Gregory W. Albers^b

^aDepartment of Radiology, Stanford University, Stanford, Calif., USA

^bDepartment of Neurology and Neurological Sciences, Stanford University, Stanford, Calif., USA

Abstract

Background: Since transient ischemic attacks (TIAs) can predict future stroke, it is important to distinguish true vascular events from non-vascular etiologies. Arterial spin labeling (ASL) is a non-contrast magnetic resonance (MR) method that is sensitive to cerebral perfusion and arterial arrival delays. Due to its high sensitivity to minor perfusion alterations, we hypothesized that ASL abnormalities would be identified frequently in TIA patients, and could therefore help increase clinicians' confidence in the diagnosis.

Methods: We acquired diffusion-weighted imaging (DWI), intracranial MR angiography (MRA), and ASL in a prospective cohort of TIA patients. A subset of these patients also received bolus contrast perfusion-weighted imaging (PWI). Two neuroradiologists evaluated the images in a blinded fashion to determine the frequency of abnormalities on each imaging sequence. Kappa (κ) statistics were used to assess agreement, and the χ^2 test was used to detect differences in the proportions of abnormal studies.

Results: 76 patients met the inclusion criteria, 48 (63%) of whom received PWI. ASL was abnormal in 62%, a much higher frequency compared with DWI (24%) and intracranial MRA (13%). ASL significantly increased the MR imaging yield above the combined DWI and MRA yield (62 vs. 32%, $p < 0.05$). Arterial transit artifact in vascular borderzones was the most common ASL abnormality (present in 51%); other abnormalities included focal high or low ASL signal (11%). PWI was abnormal in 31% of patients, and in these, ASL was abnormal in 14 out of 15 cases (93%). In hemispheric TIA patients, both PWI and ASL findings were more common in the symptomatic hemisphere. Agreement between neuroradiologists regarding abnormal studies was good for ASL and PWI [$\kappa = 0.69$ (95% CI 0.53–0.86) and $\kappa = 0.66$ (95% CI 0.43–0.89), respectively].

Conclusion: In TIA patients, perfusion-related alterations on ASL were more frequently detected compared with PWI or intracranial MRA and were most frequently associated with the symptomatic hemisphere. Almost all cases with a PWI lesion also had an ASL lesion. These

results suggest that ASL may aid in the workup and triage of TIA patients, particularly those who cannot undergo a contrast study.

Keywords

Perfusion; Arterial spin labeling; Perfusion-weighted imaging; Magnetic resonance imaging; Magnetic resonance angiography; Transient ischemic attack; Cerebrovascular disease

Introduction

Transient ischemic attacks (TIAs) are common, with 18% of adults over 45 years of age experiencing at least one symptom suggestive of a TIA. Prior large-scale studies report that 10% of TIA patients suffer a completed ischemic stroke and 25% experience other serious adverse events (including death, myocardial infarction, and silent cerebral infarcts) within 90 days, with half occurring in the first week [1, 2]. Triage of these patients is challenging, given the large numbers and the variability of clinical presentation. TIA patients are, by definition, asymptomatic following the event; therefore, separating patients with ‘true TIA’ secondary to a vascular etiology from those with ‘TIA mimics,’ such as migraine, seizure, or metabolic disease, is critical [3, 4]. Clinical characteristics and imaging play a significant role in objectively identifying true TIA patients. Purely clinical scales, such as the ABCD² score [2], can identify patients at high risk of subsequent stroke. Diffusion-weighted imaging (DWI) is positive in approximately a third of TIA patients, and significantly improves the ability to predict subsequent events [5–8]. More recently, several groups have shown that many early TIA patients also have perfusion abnormalities, based on magnetic resonance imaging (MRI) or CT bolus perfusion studies [9–13]. It has been hypothesized that TIA patients with perfusion abnormalities, even in the absence of DWI changes, may be at higher risk of subsequent events [14].

Arterial spin labeling (ASL) is a non-invasive method of interrogating cerebral hemodynamics without contrast agents [15]. In ASL acquired without vascular suppression techniques, delayed flow appears as serpiginous high signal within cortical vessels, termed arterial transit artifact (ATA) [16]. ATA detects subtle perfusion alterations, in which cerebral blood flow (CBF) might be normal but in which arterial arrival times are prolonged. One manifestation of this is the ability to visualize perfusion alterations in vascular watershed regions, a finding termed the borderzone (BZ) sign [17]. ASL is an attractive modality to study the minor perfusion abnormalities seen in TIA given its ability to detect both decreased CBF and subtle blood arrival time delays [17, 18]. The goal of this study was to examine how often perfusion abnormalities were present on ASL images in TIA patients, to record their characteristics, and to compare with DWI, magnetic resonance angiography (MRA), and perfusion-weighted imaging (PWI).

Methods

Patient Population

The study was approved by our institution’s institutional review board and was HIPAA compliant. Patients were prospectively enrolled with informed consent between September

2007 and April 2010. Enrollment criteria included transient neurologic symptoms thought by the clinical neurologist at the end of the evaluation to have a possible vascular etiology and patients who underwent an MRI study that included ASL (in addition to standard sequences such as DWI and MRA). Clinical parameters were collected from the electronic medical record.

Imaging Parameters

MRI studies were performed at 1.5 T (GE Signa, Waukesha, Wisc., USA). All patients received standard sequences, including DWI and MRA. DWI was performed with a b value of 1,000 s/mm²; TR/TE 6,000/70 ms; FOV 24 cm; matrix 128 × 128; slice thickness 5 mm; skip 1.5 mm, and gradients in three tetrahedrally-encoded directions to create isotropic DWI and apparent diffusion coefficient maps. 3D time-of-flight intracranial MRA was performed using the following parameters: TR/TE 34/3.1 ms; FOV 24 cm; matrix 512 × 128; slice thickness 1 mm, and overlap 0.5 mm. Extracranial vascular imaging was acquired in a subset of patients using 2D TOF MRA of the neck and 3D contrast-enhanced MRA of the neck, but it will not be discussed in this paper, as it was not performed in all patients.

Pseudocontinuous background-suppressed 3D fast-spin-echo ASL [19] was acquired with the following parameters: TR/TE: 5,500/2.5 ms; labeling duration 1,500 ms; post-label delay (PLD) 2,000 ms; in-plane resolution 3 mm; slice thickness 6 mm, and skip 0 mm. In a subset of patients, bolus PWI was performed using gradient-echo echo-planar imaging (EPI) during passage of 0.1 mmol/kg of either gadopentetate dimeglumine (Magnevist; Berlex, Wayne, N.J., USA) or gadodiamide (Omniscan; GE Healthcare, Waukesha, Wisc., USA). Image readout was performed using either standard single-shot EPI (TR/TE 2,000/60 ms) or a multishot, multiecho EPI sequence with an acceleration factor of 3 and TR/TE of 1,225/(17,30,52) ms [20]. Between 14 and 18 axial slices of 5 mm thickness, skip 1.5 mm covered the supra-tentorial brain. Hemodynamic maps were created using automated AIF detection and delay-invariant deconvolution software (RAPID) [21], and included maps of relative CBF, cerebral blood volume (CBV), mean transit time (MTT), and the AIF-normalized time to the peak of the residue function (Tmax), a measure of delay.

Image Evaluation

Two neuroradiologists reviewed the images following removal of identifying and clinical information. Each methodology (DWI, ASL, and PWI) was reviewed separately from the other modalities to minimize bias. The PWI maps (CBF, CBV, MTT, and Tmax) were reviewed as a group. For each modality, the readers were asked to determine whether it was normal or abnormal. If abnormal, the readers were asked to either determine a ‘worst side’ or rate each side as equal. Furthermore, for ASL, if the study was deemed abnormal, the readers were asked whether a BZ sign was present and, if so, to rate its severity using a three-point scale (mild, moderate, and severe) [17]. For PWI, additional questions included which hemodynamics maps were abnormal and, if there were multiple abnormal maps, which one showed the abnormality the most clearly. Disagreements were resolved by consensus. Large artery atherosclerosis (LAA) on intracranial MRA was assessed as 150% stenosis based on NASCET criteria.

Statistical Analysis

Interobserver agreement was assessed using kappa (κ) statistics. $\kappa > 0.6$ is considered good agreement, while $\kappa > 0.8$ is considered excellent [22]. In cases of patients with hemispheric TIA, focal imaging findings using all three modalities (ASL, DWI, and PWI) were assessed to see if they corresponded to the hemispheric localization of the symptoms. Differences among proportions in patient characteristics were assessed for statistical significance using the χ^2 test.

Results

Seventy-six patients met the inclusion criteria and were enrolled in the study. Mean age was 71 years (range 29–94 years) and 59% were male. Most patients (61/76, 80%) had symptoms thought to represent hemispheric TIA (i.e. a TIA referable to a lesion within the cerebral hemispheres, as opposed to non-localizable or posterior fossa symptomatology). The median time between symptom onset and imaging was 25 h (IQR 14–44 h; range 2 h to 38 days). The median ABCD² score was 4 (IQR 3–5; range 1–7). The most common presenting indications were focal weakness, speech disturbance, and dizziness/vertigo. Forty-eight patients (63%) also received bolus PWI. The most common reason for not obtaining bolus PWI was renal insufficiency.

Agreement between readers for DWI was highest [$\kappa = 0.93$ (95% CI 0.83–1.00)]. For the perfusion studies, the agreement on ASL [$\kappa = 0.69$ (95% CI 0.53–0.86)] and PWI [$\kappa = 0.66$ (95% CI 0.43–0.89)] was similar. Eighteen patients (24%) had DWI lesions. Eight patients (11%) had a focal abnormality on ASL imaging. An additional 40 patients had an ASL BZ sign (11 were asymmetric, 29 were symmetric, and 1 case had both a focal abnormality and a mild BZ sign); if these were included as ‘abnormal’, the yield of an abnormal ASL examination increased to 62% (47/76 patients, table 1). If DWI was positive, ASL was almost always abnormal (16/18 patients, 89%). In the subgroup of DWI-negative patients, ASL was frequently abnormal (31/58 patients, 53%). ASL-positive studies were more common in patients above 60 years of age, with a higher ABCD² score, or with speech disturbance or focal weakness (table 2). Examples in selected patients are shown in figures 1–3.

In patients who received PWI imaging (n = 48; n = 38 single-echo, n = 10 multiecho), there was overlap between DWI, PWI, and ASL findings (fig. 4). Fifteen patients had PWI lesions (31%). ASL abnormalities were more common than PWI abnormalities (56 vs. 31%, $p < 0.05$). The frequency of ASL findings was not different between patients with or without PWI studies. Seven patients were PWI-positive but DWI-negative (15%), similar to a previous study [12]. Of the different PWI maps, Tmax was deemed the best for visualizing the hemodynamic abnormality in 13 out of 15 cases (81%). Most PWI studies showed a focal lesion; however, in 3 cases (19%), bilateral mild Tmax prolongation was noted in the vascular watershed regions. The same cases were scored as moderate BZ signs on ASL (see fig. 3). PWI CBF maps were much less sensitive than Tmax, present in only 4 cases (see table 3). This was largely due to the difficulty in identifying small abnormalities in the presence of many large vascular structures. ASL was always positive if either DWI or PWI was positive, except in 1 case. In this case, ASL was of poor quality and, based on

retrospective evaluation, did demonstrate a small perfusion deficit in the same region (fig. 5). In the group of patients who received PWI, either ASL or PWI was positive in 17 out of 37 patients (46%) who did not have a DWI lesion.

In hemispheric TIA patients, DWI abnormalities were present in 16 out of 61 patients (26%), and the lesion was in the expected hemisphere in all patients. ASL was abnormal in 37 out of 61 hemispheric TIA patients (61%). In patients with either a focal lesion or an asymmetric BZ (in whom sidedness could be assessed), the hemisphere with the most severe ASL abnormality was on the symptomatic side in 14 out of 21 patients (67%). However, excluding patients with asymmetric BZ signs, which were often difficult to assess, such that only focal ASL lesions were included, symptoms and ASL findings co-localized to the same hemisphere in 5 out of 7 patients (71%). In the hemispheric symptom group, PWI was performed in 39 out of 61 patients, and was abnormal in 12 out of 39 patients (31%). In 2 cases, the abnormality was bilateral and sidedness could not be assessed. In the remaining cases, the PWI lesion in 8 out of 10 patients (80%) was in the symptomatic hemisphere. These data are summarized in table 4.

Discussion

Imaging may help objectively identify true TIA patients as one cannot, by definition, rely on persistent symptoms to make the diagnosis. DWI has been shown to increase the yield of patients who have a higher rate of subsequent stroke [5, 6, 8]. In this study, we evaluated the role of perfusion imaging, using both ASL and bolus PWI. We found that there were many patients who had a perfusion abnormality who did not have either a DWI lesion or evidence of steno-occlusive lesion on MRA. Such approaches both help individual patients, who can be admitted and undergo expedited workup, but can also serve as entry criteria for clinical trials. Enriching the yield of such trials with patients with vascular events and who are therefore likely to benefit from treatment is essential to evaluate potential therapies.

This study shows that ASL imaging findings are commonly seen in patients who receive MRI for suspected TIA. ASL does not require contrast and for this reason can be used in a wider population of TIA patients, including those with renal dysfunction. In patients who received both ASL and PWI, significantly more perfusion alterations were observed with ASL compared with PWI, and in these cases, it was usually a BZ sign. In patients with DWI lesions, ASL was abnormal in 89%, suggesting a relationship between altered DWI and the observed perfusion alterations. In only 1 case was an ASL lesion not present in a patient deemed positive on the PWI study. These findings suggest that ASL may visualize more subtle abnormalities in perfusion and/or transit time. This is likely due to the fact that ASL sensitivity to arrival time is set by the T1 of arterial blood (about 1.1 s at 1.5 T), while Tmax sensitivity is largely set by the repetition time of the bolus PWI raw images (1.8 s in this study). This increased sensitivity is important in TIA patients, where perfusion abnormalities may be less severe than in ischemic stroke patients, and whose abnormalities may subside over time [12]. The rate of DWI- and MRA-positive cases is similar to that reported by previous TIA imaging series [5, 12, 23]. If patients with either a PWI or ASL abnormality were included, the frequency of abnormal MRI studies almost doubled compared with that based on DWI and/or MRA-based LAA abnormalities (62 vs. 32%, $p < 0.05$). Finally, in

patients with hemispheric symptoms, both PWI and ASL abnormalities (when they could be lateralized) overwhelmingly corresponded to the symptomatic hemisphere.

The most common ASL abnormality was either a symmetric or asymmetric BZ sign [17], seen in 40 out of 76 patients (53%). We found that the BZ sign was not good at distinguishing the presumed hemisphere responsible for symptoms in patients with hemispheric TIA. Most BZ signs were bilaterally symmetric (73%), and when asymmetric, was no better than chance at predicting the symptomatic hemisphere. It may be that patients with a BZ sign are at higher risk for stroke or TIA, but the BZ sign itself may be unrelated to the acute event. If that is the case, then BZ-positive cases do not have the same implication for ‘confirming’ a true TIA as would a focal lesion in the symptomatic hemisphere. In line with this, non-BZ focal ASL abnormalities were more commonly associated with the symptomatic hemisphere (71%), similar to findings on bolus PWI (80%). These findings are also consistent with a prior small study of ASL in TIA and minor stroke, which showed arrival time asymmetries in the symptomatic hemisphere [18]. The precise origin and implications of the ASL BZ sign are not yet clear, and further studies evaluating its correlation with cardiac function and small vessel ischemic markers, including FLAIR hyperintensities, would be valuable.

Reduction of perfusion is presumably the etiology of symptoms in TIA patients, but this reduction is either not severe enough or does not last long enough to cause permanent symptoms. Adding perfusion imaging to clinical- and imaging-based predictive models has yet to be undertaken, likely due to the fact that perfusion imaging is not a standard technique compared with DWI and MRA. While there have been many reports of the presence of DWI-positive TIA patients, there have been fewer MR studies of vascular or perfusion markers [6, 9–12, 14, 24], and many have examined a mixed population including TIA and minor stroke. Only one study, focused on phase-contrast velocity measurements of large cerebral artery blood flow, failed to show an abnormality [24]. The remainder found hemodynamic alterations, which were seen in approximately 33% of patients, with 3–16% demonstrating PWI abnormality only [10–12]. Coutts et al. [6] found that patients with a mismatch between DWI and MTT were almost four times more likely to have a poor outcome at 90 days. However, in multivariate analysis, they found no increase in sensitivity and specificity over that of vascular occlusion, and concluded that MTT yielded no additional information. In contrast, we found that a significant fraction of patients with a normal MRA had a perfusion abnormality. This difference is probably due to the precise definition (perfusion abnormality in the current study vs. mismatch), the examination of multiple different maps, and the use of different software post-processing [25]. In particular, no prior studies have examined multiple potential hemodynamic markers, including Tmax, which shows promise in stroke [26], and which we found to be the best map for visualizing PWI abnormalities.

The main limitation of this study is the small sample size. Also, imaging was performed at 1.5 T; many centers have already implemented 3 T scanning, and it is possible that the findings at 3 T may differ. We did not measure absolute CBF values, though this is straightforward using a combined ASL and PWI method [27]. The ASL sequence used was optimized for routine clinical use, and used only a single PLD; other ASL implementations

exist, including those that acquire images at multiple PLDs and those that can map regional perfusion territories of selected arteries. Finally, we do not have follow-up in these patients to assess whether a perfusion abnormality is associated with a higher risk of adverse events, as has been shown previously for DWI. For this purpose, the current study is underpowered, and a much larger, prospective study is required.

References

1. Johnston SC, Gress DR, Browner WS, Sidney S: Short-term prognosis after emergency department diagnosis of TIA. *JAMA* 2000;284: 2901–2906. [PubMed: 11147987]
2. Johnston SC, Rothwell PM, Nguyen-Huynh MN, Giles MF, Elkins JS, Bernstein AL, Sidney S: Validation and refinement of scores to predict very early stroke risk after transient ischaemic attack. *Lancet* 2007;369:283–292. [PubMed: 17258668]
3. Castle J, Mlynash M, Lee K, Caulfield AF, Wolford C, Kemp S, Hamilton S, Albers GW, Olivot JM: Agreement regarding diagnosis of transient ischemic attack fairly low among stroke-trained neurologists. *Stroke* 2010;41: 1367–1370. [PubMed: 20508192]
4. Amort M, Fluri F, Schafer J, Weisskopf F, Katan M, Burow A, Bucher HC, Bonati LH, Lyrer PA, Engelter ST: Transient ischemic attack versus transient ischemic attack mimics: frequency, clinical characteristics and outcome. *Cerebrovasc Dis* 2011;32:57–64. [PubMed: 21613786]
5. Ay H, Arsava EM, Johnston SC, Vangel M, Schwamm LH, Furie KL, Koroshetz WJ, Sorensen AG: Clinical- and imaging-based prediction of stroke risk after transient ischemic attack: the CIP model. *Stroke* 2009;40:181–186. [PubMed: 18948609]
6. Coutts SB, Eliasziw M, Hill MD, Scott JN, Subramaniam S, Buchan AM, Demchuk AM: An improved scoring system for identifying patients at high early risk of stroke and functional impairment after an acute transient ischemic attack or minor stroke. *Int J Stroke* 2008;3:3–10. [PubMed: 18705908]
7. Calvet D, Touze E, Oppenheim C, Turc G, Meder JF, Mas JL: DWI lesions and TIA etiology improve the prediction of stroke after TIA. *Stroke* 2009;40:187–192. [PubMed: 18988917]
8. Giles MF, Albers GW, Amarenco P, Arsava MM, Asimos A, Ay H, Calvet D, Coutts S, Cucchiara BL, Demchuk AM, Johnston SC, Kelly PJ, Kim AS, Labreuche J, Lavalley PC, Mas JL, Merwick A, Olivot JM, Purroy F, Rosamond WD, Sciolla R, Rothwell PM: Addition of brain infarction to the ABCD2 Score (ABCD2I): a collaborative analysis of unpublished data on 4,574 patients. *Stroke* 2010;41:1907–1913. [PubMed: 20634480]
9. Perez A, Restrepo L, Kleinman JT, Barker P, Beauchamp N, Wityk RJ: Patients with diffusion-perfusion mismatch on magnetic resonance imaging 48 h or more after stroke symptom onset: clinical and imaging features. *J Neuroimaging* 2006;16:329–333. [PubMed: 17032382]
10. Restrepo L, Jacobs MA, Barker PB, Wityk RJ: Assessment of transient ischemic attack with diffusion- and perfusion-weighted imaging. *AJNR Am J Neuroradiol* 2004; 25: 1645–1652. [PubMed: 15569725]
11. Krol AL, Coutts SB, Simon JE, Hill MD, Sohn CH, Demchuk AM: Perfusion MRI abnormalities in speech or motor transient ischemic attack patients. *Stroke* 2005;36:2487–2489. [PubMed: 16224075]
12. Mlynash M, Olivot JM, Tong DC, Lansberg MG, Eyngorn I, Kemp S, Moseley ME, Albers GW: Yield of combined perfusion and diffusion MR imaging in hemispheric TIA. *Neurology* 2009;72:1127–1133. [PubMed: 19092109]
13. Prabhakaran S, Patel SK, Samuels J, Mc-Clenathan B, Mohammad Y, Lee VH: Perfusion computed tomography in transient ischemic attack. *Arch Neurol* 2011;68:85–89. [PubMed: 21220677]
14. Tong T, Yao Z, Feng X: Combined diffusion- and perfusion-weighted imaging: a new way for the assessment of hemispheric transient ischemic attack patients. *Int J Dev Neurosci* 2011;29:63–69. [PubMed: 20868735]

15. Roberts DA, Detre JA, Bolinger L, Insko EK, Leigh JS: Quantitative magnetic resonance imaging of human brain perfusion at 1.5 T using steady-state inversion of arterial water. *Proc Natl Acad Sci* 1994;91:33–37. [PubMed: 8278387]
16. Detre JA, Samuels OB, Alsop DC, Gonzalez-At JB, Kasner SE, Raps EC: Noninvasive magnetic resonance imaging evaluation of cerebral blood flow with acetazolamide challenge in patients with cerebrovascular stenosis. *J Magn Reson Imaging* 1999;10: 870–875. [PubMed: 10548801]
17. Zaharchuk G, Bammer R, Straka M, Shankaranarayan A, Alsop DC, Fischbein NJ, Atlas SW, Moseley ME: Arterial spin-label imaging in patients with normal bolus perfusion-weighted MR imaging findings: pilot identification of the borderzone sign. *Radiology* 2009;252:797–807. [PubMed: 19703858]
18. Macintosh BJ, Lindsay AC, Kylintireas I, Kuker W, Guthrie M, Robson MD, Kennedy J, Choudhury RP, Jeppard P: Multiple inflow pulsed arterial spin-labeling reveals delays in the arterial arrival time in minor stroke and transient ischemic attack. *AJNR Am J Neuroradiol* 2010;31:1892–1894. [PubMed: 20110375]
19. Dai W, Garcia D, de Bazelaire C, Alsop DC: Continuous flow driven inversion for arterial spin labeling using pulsed radiofrequency and gradient fields. *Magn Reson Med* 2008;60:1488–1497. [PubMed: 19025913]
20. Newbould RD, Skare ST, Jochimsen TH, Alley MT, Moseley ME, Albers GW, Bammer R: Perfusion mapping with multiecho multishot parallel imaging EPI. *Magn Reson Med* 2007;58:70–81. [PubMed: 17659630]
21. Straka M, Albers GW, Bammer R: Real-time diffusion-perfusion mismatch analysis in acute stroke. *J Magn Reson Imaging* 2010;32: 1024–1037. [PubMed: 21031505]
22. Landis JR, Koch GG: The measurement of observer agreement for categorical data. *Biometrics* 1977;33:159–174. [PubMed: 843571]
23. Coutts SB, Simon JE, Eliasziw M, Sohn CH, Hill MD, Barber PA, Palumbo V, Kennedy J, Roy J, Gagnon A, Scott JN, Buchan AM, Demchuk AM: Triaging transient ischemic attack and minor stroke patients using acute magnetic resonance imaging. *Ann Neurol* 2005;57:848–854. [PubMed: 15929051]
24. Bisschops RH, Kappelle LJ, Mali WP, van der Grond J: Hemodynamic and metabolic changes in transient ischemic attack patients: a magnetic resonance angiography and (1)H-magnetic resonance spectroscopy study performed within 3 days of onset of a transient ischemic attack. *Stroke* 2002;33: 110–115. [PubMed: 11779898]
25. Heiss WD, Zaro Weber O: Uncertainties in the assessment of cortical flow by perfusion-weighted MRI in acute stroke. *Cerebrovasc Dis* 2011;32:194–195; author reply 196. [PubMed: 21849779]
26. Albers GW, Thijs VN, Wechsler L, Kemp S, Schlaug G, Skalabrin E, Bammer R, Kakuda W, Lansberg MG, Shuaib A, Coplin W, Hamilton S, Moseley M, Marks MP: Magnetic resonance imaging profiles predict clinical response to early reperfusion: the diffusion and perfusion imaging evaluation for understanding stroke evolution (DEFUSE) study. *Ann Neurol* 2006;60:508–517. [PubMed: 17066483]
27. Zaharchuk G, Straka M, Marks MP, Albers GW, Moseley ME, Bammer R: Combined arterial spin label and dynamic susceptibility contrast measurement of cerebral blood flow. *Magn Reson Med* 2010;63:1548–1556. [PubMed: 20512858]

Fig. 1. Imaging of a 59-year-old man with transient left arm weakness with an ABCD² score of 5. The patient had a normal intracranial MRA (not shown). **a** DWI demonstrates several small lesions in the right frontal and parietal lobes. **b** ASL demonstrates focal ATA consistent with delayed flow in the same region. **c** The PWI Tmax map shows a similar abnormality.

Fig. 2. Subtle ASL findings in an otherwise negative patient by imaging. Imaging of a 72-year-old woman with essential thrombocytopenia and transient left upper extremity weakness with an ABCD² score of 3. **a** DWI was negative, as was the MRA (not shown). **b** However, both readers identified subtle focal high signal in the left BZ region on ASL (arrows). **c–f** All hemodynamic maps from PWI were deemed negative.

Fig. 3. Imaging of a 79-year-old man with transient expressive aphasia with an ABCD² score of 3. **a** Normal MRA. **b** DWI shows a small lesion in the left frontal lobe (arrow). **c** ASL demonstrates a moderate bilateral symmetric BZ sign (arrows). **d** PWI Tmax maps show mild bilateral BZ abnormality.

Fig. 4. Venn diagram of patients with abnormal ASL, PWI, or DWI who underwent all three examinations (n = 48).

Fig. 5.

Imaging of a 74-year-old woman with left arm and leg weakness with an ABCD² score of 5. **a** DWI shows a small right-sided infarct. **b** ASL is of poor quality due to artifact anteriorly; both readers when blinded to the other sequences called the ASL normal, despite the fact that a small CBF reduction is present (arrow), best appreciated by comparing with the contralateral hemisphere. A perfusion abnormality is identified on PWI (**c–f**). The lesion was deemed present on the relative CBF, MTT, and Tmax maps, but was thought to be most clearly visualized on the Tmax map. This was the only patient in the cohort in whom PWI was judged to be abnormal and ASL was judged to be normal.

Table 1.

Summary of ASL and DWI findings in TIA patients

	DWI+	DWI-	Total
ASL+	16 (21.1)	31 (40.8)	47 (61.8)
Focal/BZ	3 (3.9)/13 (17.1)	5 (6.6)/26 (34.2)	8 (10.6)/39 (51.3)
ASL-	2 (2.6)	27 (35.6)	29 (38.2)
Total	18 (23.7)	58 (76.3)	76 (100.0)

Values are n (%).

Table 2.

Comparison of characteristics of TIA patients with and without abnormal ASL study

	Overall (n = 76)	ASL+ (n = 47)	ASL- (n = 29)	P
Mean age $\pm$ SD, years	71 $\pm$ 15	76 $\pm$ 11	62 $\pm$ 17	<0.01
Male, n (%)	45 (59)	28 (60)	17 (59)	NS
Median ABCD ² score (IQR)	4 (3–5)	4 (3–5)	3 (2–4)	<0.01
Age >60 years, n (%)	57 (75)	42 (89)	15 (51)	<0.01
Elevated BP (>140/90 mm Hg), n (%)	40 (53)	28 (60)	12 (41)	NS
Unilateral weakness or speech disturbance, n (%)	51 (67)	36 (77)	15 (51)	<0.01
Symptom duration >10 min, n (%)	65 (86)	39 (83)	26 (90)	NS
Presence of DM, n (%)	8 (11)	2 (4)	6 (21)	NS
Hemispheric symptoms, n (%)	61 (80)	37 (79)	24 (83)	NS
Abnormal MRA, n (%)	14 (18)	13 (28)	1 (3)	<0.01
PWI performed, n (%)	48 (63)	27 (56)	21 (72)	NS

Table 3.

Hemodynamic maps on which PWI lesions were identified in TIA patients

	Lesion identified	% of ASL-positive cases	Best map to identify lesion	% of ASL-positive cases
Tmax	16	15/16 (94%)	13	12/13 (92%)
MTT	7	7/7 (100%)	1	1/1 (100%)
CBF	4	4/4 (100%)	1	1/1 (100%)
CBV	4	4/4 (100%)	1	1/1 (100%)
Total	31	N/A	15	N/A

Author Manuscript

Author Manuscript

Author Manuscript

Author Manuscript

Table 4.

Correlation between the side of the most severe imaging abnormalities and the symptomatic hemisphere in patients with hemispheric TIA

	Corresponding to a clinically symptomatic hemisphere	
		%
DWI	16/16	100
PWI	8/10	80
ASL (including an asymmetric BZ sign)	14/21	67
ASL focal lesion (excluding an asymmetric BZ sign)	5/7	71