Original Article

Clinical Utility of Arterial Spin Labeling Magnetic Resonance Imaging in the Evaluation of the Brain

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Abstract

Introduction: Cerebral blood flow (CBF) is essential for studying the brain in both normal and diseased states. Arterial spin labeling (ASL) is a functional magnetic resonance imaging (MRI) technique that uses arterial water as an endogenous tracer to measure CBF, thus does not require an injection of exogenous tracers and is noninvasive and can therefore be used to track changes in CBF. **Materials and Methods:** This prospective, observational and descriptive study was done at the department of imaging, Maxcure Hospital, Hyderabad, for the duration of 18 months. All studies were performed on a 1.5T Philips Prodiva CX using a phased array coil. **Results:** A prospective observational and descriptive study was done among 100 patients to study the clinical utility of ASL. Out of 100 patients, 20 (20%) patients showed normal MRI findings. Rest 80 (80%) patients had abnormal MRI findings. **Conclusion:** ASL provides additional and complementary information to that available from structural MRI in all categories of abnormalities.

Keywords: Arterial spin labeling, brain, magnetic resonance imaging

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Introduction

Magnetic resonance imaging (MRI) has become an integral part of the clinical evaluation of the brain as it provides an excellent morphostructural overview with good spatial and temporal resolution. It allows quick and exact differentiation of ischemic, hypoxic, inflammatory, oncologic, traumatic and metabolic diseases. Continuous and sufficient cerebral blood flow (CBF) is vital to neural function. CBF delivers glucose and oxygen to the brain to maintain basal ATP production and replenish it during increased neuronal activity. Changes in CBF cause changes in metabolism that often indicate the presence of disease.[1] CBF is essential for studying the brain in both normal and diseased states.

All the current methods in clinical use for measuring CBF are based on the principles of tracer kinetics followed through compartmental modeling which describe the dynamics of a tracer as it crosses the arterial tree into the brain's microvasculature (nondiffusible tracers) and into the tissue (diffusible tracers) prior to venous washout.

Arterial spin labeling (ASL) is a functional MRI technique that uses arterial water as an endogenous tracer to measure CBF, thus does not require an injection of exogenous tracers and is noninvasive and can therefore be used to track changes in CBF such as those due to disease progression or drug therapy. ASL yields CBF images with higher spatial and temporal resolution than any other current technique. It has been extensively performed in the research arena and sporadically validated in disease, but, because of obstacles related to licensing as well as postprocessing, has seen little in the way of routine application in large clinical populations.[1-4]

In the present study, we aim to study the preliminary assessment of the utility of ASL in routine clinical MRI imaging of brain with spectrum of abnormalities encountered in our experience which includes but not limited to cerebrovascular disease, space-occupying lesions, seizures.

Materials and Methods

This prospective, observational, and descriptive study was done at the Department of Imaging, Maxcure Hospital, Hyderabad,

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for the duration of 18 months. Total number of patients included in the study was 100 individuals. Written informed consent was obtained from all adults before enrollment. Patients of all age groups who were referred for evaluation of the brain were included in this study. Patients having extreme claustrophobia and head trauma were excluded from the study. Furthermore, those who were uncooperative and were showing contraindications to MRI study were excluded.

All studies were performed on a 1.5T Philips Prodiva CX using a phased array coil in the supine position.

Routine MRI brain was performed using a standard protocol with additional sequences depending on the clinical indication.

Data analysis

All the magnetic resonance images were analyzed on conventional sequences for morphostructural features, signal intensity, and diffusion weighted imaging features. Postcontrast images were used for the recognition of enhancement of the solid component, the tumor wall, septations, and vegetations. Perfusion data were saved as raw echo signals for interpretation of ASL and transferred to a workstation for processing. Qualitative analysis of these ASL studies was analyzed for patterns of perfusion on final gray-scale DICOM images and color Joint Photographic Experts Group CBF maps.

Statistical analysis

For the description of data, mean values, percentages, and standard deviations were used.

Data were expressed as mean ± standard deviation. One-way ANOVA test was applied for determining the mean differences in the CBF in different age groups in all lobes gray and white matter (WM), basal ganglia, and cerebellum. *P* value showed significance when it was <0.05.

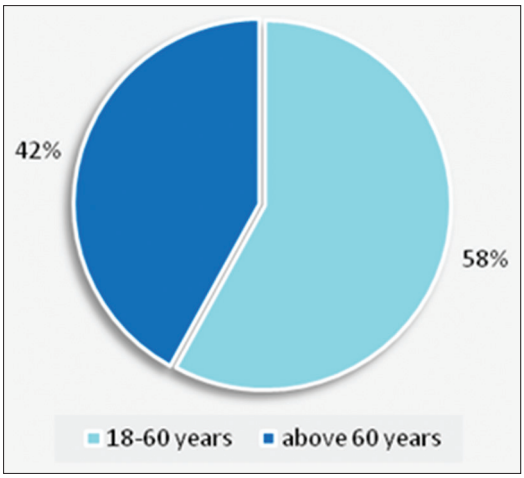
Results

A prospective observational and descriptive study was done among 100 patients to study the clinical utility of ASL in diverse MRI brain indications in addition to routine MRI brain protocol.

The majority of the patients (58%) were in the age group of 18–60 years. The rest (42%) of patients were from the age group of >60 years [Graph 1].

Out of 100 patients, 20 (20%) patients showed normal MRI findings. Rest 80 (80%) patients had abnormal MRI findings [Graph 2].

Out of 100 patients, 20 (20%) were normal. Under acute cerebrovascular disease category, 11 (11%) patients were of middle cerebral artery (MCA) territory infarct, 6 (6%) patients were of basal ganglia infarct, and 4 (4%) patients were of anterior cerebral artery (ACA) territory infarct and posterior cerebral artery (PCA) territory infarct. 5 (5%) patients were of lacunar infarct. Among the patients suffering from neoplasm, 5 (5%) patients, 3 (3%) patients, and 2 (2%) patients had



Graph 1: Distribution of patients according to age

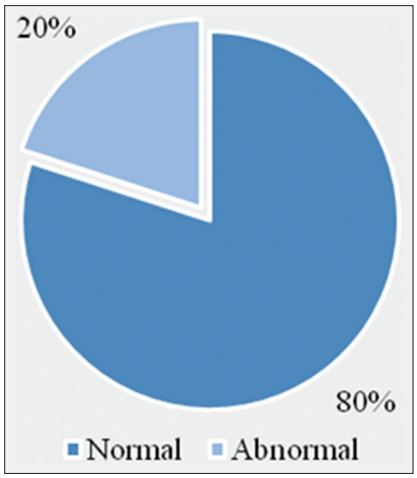
meningioma, glioma, and acoustic schwannoma, respectively. One (1%) patient each was of cerebellopontine (CP) angle tumor, craniopharyngioma, and pituitary macroadenoma.

Seven (7%) patients were suffering from cerebral atrophy. Six (6%) patients were having aging and chronic infarct. Seizure disorder was observed in 4 (4%) patients. Hemorrhage was seen in 5 (5%) patients. Six (6%) patients exhibited infective conditions. Arteriovenous malformations were seen in 2 (2%) patients. Gliosis was observed in 4 (4%) patients. 1 (1%) patient showed brain death and altered mental status [Table 1].

Patients having age between 18 and 60 years had whole gray matter of mean 58.12 ± 4 and WM of mean 19.49 ± 0.57. Patients having age above 60 years showed gray matter of mean 48.47 ± 2.54 and WM of mean 18.53 ± 0.72. *P* values for both gray matter CBF and WM CBF were statistically significant [Table 2].

The mean frontal gray matter CBF was 68.88 ± 4.83 (ml/100 g/min) in patients of age group 18–60 years and patients having age above 60 years had a mean of 52.5 ± 2.5 (ml/100 g/min). In case of parietal gray matter, the mean of 64.85 ± 4.96 and 48.14 ± 1.74 was observed in age group 18–60 and above 60 years, respectively. The mean temporal gray matter CBF was 64.17 ± 4.59 (ml/100 g/min) in patients of age group 18–60 years and patients having age above 60 years had a mean of 51.4 ± 4.20 (ml/100 g/min). In the occipital region, patients between 18 and 60 years old exhibited a mean gray matter measurement of 56.37 ± 5.19 (ml/100 g/min), whereas those above 60 years old showed a mean of 48.95 ± 2.82 (ml/100 g/min) [Table 3].

As shown in Table 4, the mean frontal WM CBF was 19.74 ± 1.89 (ml/100 g/min) in patients of age group 18–60 years and patients having age above 60 years had a mean of 18.79 ± 1.29 (ml/100 g/min). In case of parietal WM, the mean of 19.19 ± 2.01 and 17.55 ± 1.68 was observed in the age group 18–60 and above 60 years, respectively. The mean temporal WM CBF was 19.62 ± 1.77 (ml/100 g/min)



Graph 2: Distribution of patients according to magnetic resonance imaging findings. MRI: Magnetic resonance imaging

in patients of age group 18–60 years and patients having age above 60 years had a mean of 18.78 ± 2.01 (ml/100 g/min). 19.44 ± 2.33 (ml/100 g/min) WM was seen in occipital region of patients having age between 18 and 60, while patients of age above 60 years showed 19.36 ± 1.32 (ml/100 g/min) WM [Table 4].

The mean regional blood flow in basal ganglia in the age group of 18–60 years was 48.27 ± 3.15 and in the age group above 60 years was 46.93 ± 4.01. In cerebellum, the mean regional blood flow in the age group 18–60 years was 44.13 ± 2.99. Patients having age above 60 years showed the mean of 41.83 ± 3.56 [Table 5].

Arterial spin labeling in spectrum of central nervous system abnormalities

In our study, total 30 patients having acute ischemic stroke were studied and analyzed. Out of these 30 patients, the most common was MCA territory infarcts (11 patients), followed by basal ganglia infarct (6 patients), ACA territory infarct (4 patients), PCA territory infarct (4 patients), and multiple acute lacunar infarcts (5 patients). In our study Arteriovenous malformations were seen in 2 (2%) patients.

Discussion

Continuous uninterrupted and sufficient CBF is essential for neural function and an important measure in the understanding of brain pathophysiology. Kety and Schmidt were the first to measure mean CBF, using nitrous oxide (Fick's formula) and reported a global mean CBF level of 54 ± 12 ml/100 g/min, in healthy young men, which is still considered a reasonable value.[5] CBF is an important tool in the monitoring of treatment of many brain diseases and also in functional brain imaging.[6,7] There are various methods for the quantitative measurement of CBF such as single photon emission computerized tomography, positron emission tomography (PET), computed tomography, and MRI. These techniques are expensive, require radiation exposure, and are not suitable for a certain group of patients having different limitations.

Our study is a prospective observational and descriptive one done among 100 patients to study the clinical utility of ASL in diverse MRI brain indications as an addition to routine MRI

Table 1: Distribution of patients according to diseased conditions

Conditions	Number of patients
Normal	20
Acute cerebrovascular disease	
MCA territory infarct	11
Basal ganglia infarct	6
ACA territory infarct	4
PCA territory infarct	4
Lacunar infarct	5
Neoplasm	
Meningioma	5
Glioma	3
CP angle tumor	1
Acoustic schwannoma	2
Craniopharyngioma	1
Pituitary macroadenoma	1
Cerebral atrophy	7
Aging and chronic infarct	6
Seizure disorder	4
Hemorrhage	5
Infective conditions	6
Arterio-venous malformations	2
Gliosis	4
Miscellaneous	
Brain death	1
Postcontrast study	1
Altered mental status	1

MCA: Middle cerebral artery, ACA: Anterior cerebral artery, PCA: Posterior cerebral artery, CP: Cerebellopontine

Table 2: Comparison of whole gray matter cerebral blood flow and white matter cerebral blood flow (mL/100 g/min) value in each age group

Age (years)	Mean CBF (g)	Mean CBF (WM)	*P*
18–60	58.12±4	19.49±0.57	<0.00001
Above 60	48.47±2.54	18.53±0.72	<0.00001

CBF: Cerebral blood flow, WM: White matter

Table 3: Regional gray matter cerebral blood flow (mL/100 g/min) value in each age group

Brain area	18–60 years	Above 60 years	*P*
FGM CBF	68.88±4.83	52.5±2.5	<0.00001
PGM CBF	64.85±4.96	48.14±1.74	<0.00001
TGM CBF	64.17±4.59	51.4±4.20	<0.00001
OGM CBF	56.37±5.19	48.95±2.82	<0.00001

CBF: Cerebral blood flow, FGM: Frontal gray matter, OGM: Occipital gray matter, TGM: Temporal gray matter, PGM: Parietal gray matter

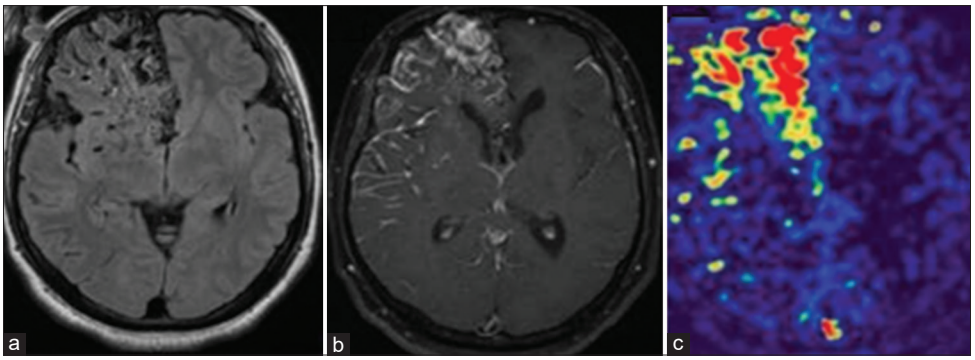


Figure 1: A 27-year-old male presented with severe headache for the past few months and episodes of seizures. Magnetic resonance imaging with magnetic resonance angiography was performed. FLAIR (a), T2 weighted (not shown) and T1 post contrast images (b) shows area with tortuous vessels in right frontal region suggesting arteriovenous malformation. Arterial spin labeling images (c) shows increased perfusion in the corresponding area suggesting increased flow

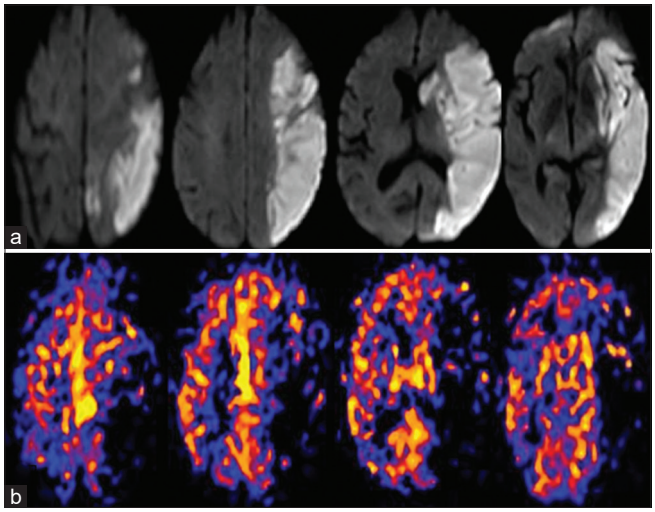


Figure 2: 75-year-old male with left hemiparesis. Diffusion-weighted sequence images (a) shows restriction involving left capsule-ganglionic region and peri-sylvian temporo-parietal lobe s/o acute large left middle cerebral artery (MCA) territory infarct. Arterial spin labeling perfusion (b) magnetic resonance imaging shows left MCA territory hypoperfusion, without arterial transit abnormality, suggesting poor collateral flow

brain protocol. Out of 100 patients, 20 patients have normal MRI brain findings. These patients with normal MRI findings were divided into 2 age groups, i.e., >18–60 (10 patients) years and >60 years (10 patients). In our study, we employed the fast three-dimensional pseudo-continuous ASL (PCASL) technique to assess age-related changes in both whole-brain and regional cerebral blood flow (CBF). The CBF values for gray matter (GM), white matter (WM), and cerebellum obtained in our study [Tables 1 and 4] align with those reported in previous studies that utilized PCASL, continuous ASL (CASL), and pulsed ASL (PASL) in studies involving adults.[8-11]

In adults (>18–60 years), our whole GM CBF and WM CBF values [Table 1] are consistent with the values obtained with PASL by Chen *et al*.[11] with CASL by Biagi *et al*.[9]

Table 4: Regional white matter cerebral blood flow (mL/100 g/min) value in each age group

Brain area	>18–60 years	>60 years	*P*
FWM CBF	19.74±1.89	18.79±1.29	<0.00001
PWM CBF	19.19±2.01	17.55±1.68	<0.00001
TWM CBF	19.62±1.77	18.78±2.01	<0.00001
OWM CBF	19.44±2.33	19.36±1.32	<0.00001

CBF: Cerebral blood flow, FGM: Frontal white matter, OGM: Occipital white matter, TGM: Temporal white matter, PGM: Parietal white matter

Table 5: Regional blood flow in the basal ganglia and cerebellum

Brain area	18–60 years	Above 60 years	*P*
Basal ganglia	48.27±3.15	46.93±4.01	<0.00001
Cerebellum	44.13±2.99	41.83±3.56	<0.00001

The current study on Neoplasm includes various tumor types, such as meningioma (5 cases), glioma (3 cases), CP angle tumor (1 case), acoustic schwannoma (2 cases), craniopharyngioma (1 case), and pituitary macroadenoma (1 case). Among these, there were four patients with 'Seizure disorder,' while the 'Miscellaneous' category, encompassing conditions like brain death, post-contrast study findings, and altered mental status, each accounted for one patient [Figure 1]. All these conditions are detailed in Table 1. Notably, similar findings were not observed in any previous studies conducted.

Effect of age on whole gray matter and white matter cerebral blood flow

Significant difference (P = 0.00001) was found in the GM and WM CBF among different age groups [Table 1]. These findings were similar to that reported in previous studies conducted using ASL, PET, and Xenon 133 [Figures 2 and 3].[8,9,11-13] On comparing the regional CBF values in adults and the elderly group, the values for frontal gray matter, temporal gray matter, occipital gray matter, and basal ganglia found in our study were consistent with the values obtained with PASL by Chen *et al* [Figures 2 and 4].[11]

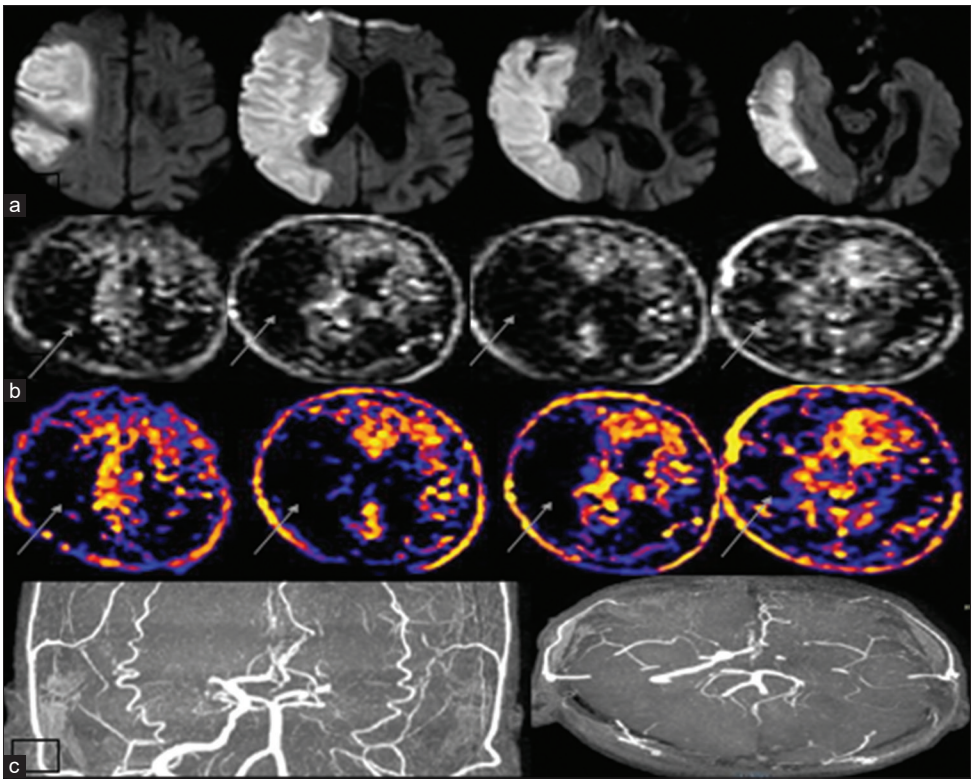


Figure 3: A 55-year-old female presented with slurring of speech and upper and lower limb weakness with focal neurological deficits. Diffusion-weighted sequence images (a) shows restriction involving right fronto-temporo-parietal region s/o acute right anterior cerebral artery (ACA) and middle cerebral artery (MCA) territory infarct. Arterial spin labeling (ASL) perfusion (b) magnetic resonance imaging shows right ACA and MCA territory hypoperfusion (arrows). Absent flow of left intracranial internal carotid artery (c). No obvious diffusion weighted imaging and ASL mismatch is seen

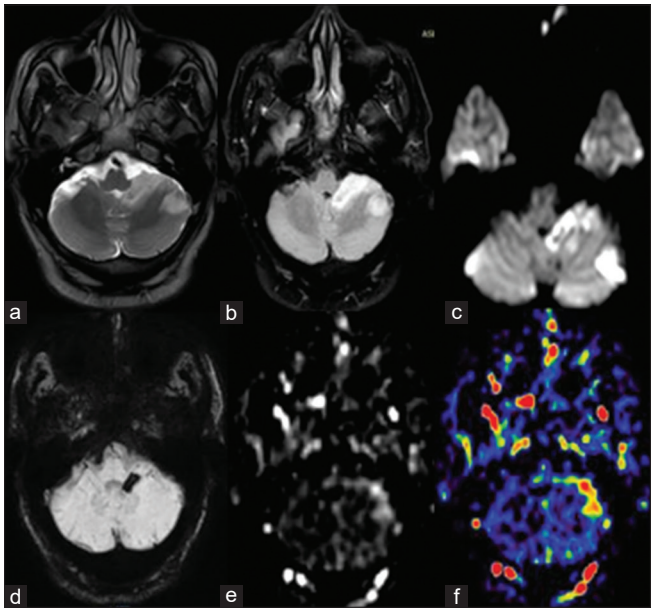


Figure 4: 49-year-old male patient presented with weakness and ataxia. Magnetic resonance imaging brain shows acute infarct in the left posterior inferior cerebellum, with focal hemorrhage inferiorly. Arterial spin labeling perfusion maps shows increased perfusion in the periphery of the infarcted region whereas the rest of the area shows decreased perfusion - likely due to luxury perfusion. (a) T2 Weighted image. (b and c) Showing areas of diffusion restriction. (d) Swi showing blooming. (e) Arterial spin labelling. (f) Perfusion images showing increased perfusion suggests luxury perfusion

Effect of age on regional cerebral blood flow

In our study, it is found that there is a substantial nonuniformity in the various regional GM and WM CBF values independent of age. Higher CBF values being found in the frontal lobe compared to other regions [Tables 2 and 3]. The results correspond to the previous values found in the 15-O PET and CASL studies that included the frontal and frontal-temporal regions [Figures 5 and 6].[3-9]

Our measurements of the GM and WM CBF-age relationship in >18–60 year age group are in excellent agreement with the observations made by Biagi *et al.*,[9] while those in the deep gray matter nuclei are in agreement with the longitudinal findings by Beason-Held *et al*.[7,9,14]

Conclusion

A prospective single-center study aimed to preliminarily assess the usefulness of ASL in routine clinical brain MRI imaging, covering a spectrum of abnormalities commonly encountered based on our clinical experience. ASL provides additional and complementary information to that available from structural MR imaging in all categories of abnormalities.

Acknowledgments

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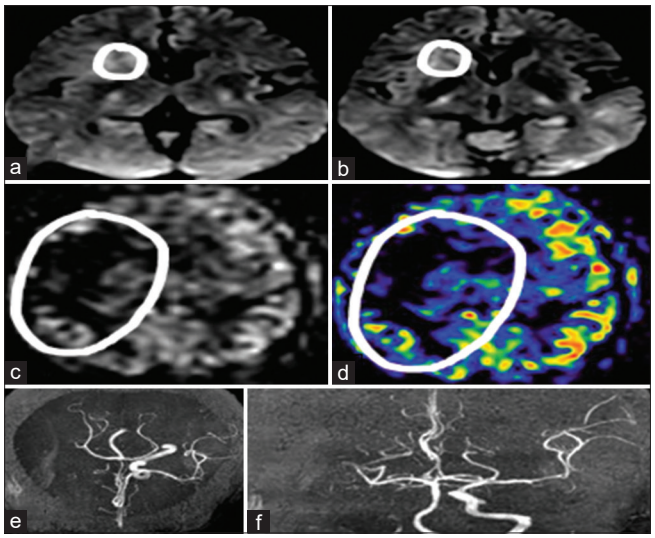

Figure 5: Ischemic stroke – diffusion weighted imaging (DWI) and arterial spin labeling (ASL) mismatch positive. 45-year-old female presented with sudden onset of UL weakness. Acute infarcts noted in right insular cortex, basal ganglia (a and b). Absent flow in right internal carotid artery and middle cerebral artery (e and f). DWI shows (a and b) an area of reduced diffusion in the right insular cortex and basal ganglia (small circles) and distinct asymmetrical hypoperfusion in the ASL images (c and d) beyond the area of diffusion abnormality (big circle) corresponding to the penumbra s/o DWI - ASL perfusion mismatch. It is useful for guiding thrombolytic treatment decisions especially in delayed time window presentations

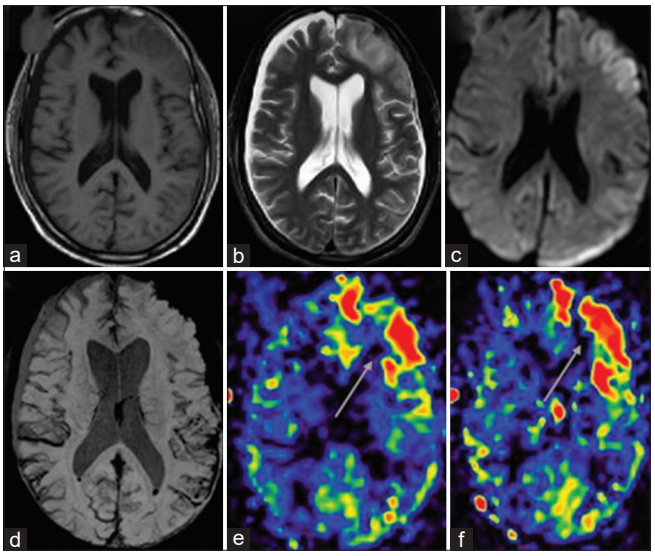

Figure 6: 54-year-old patient presented with history of fall at home. Magnetic resonance imaging brain shows hemorrhagic contusions with perilesional oedema in the left frontal region (a and b). Diffusion weighted imaging shows gyral pattern of hyperintensity (c) in the above mentioned area. Thin chronic subdural hematoma seen along the eight cerebral convexity (d). Area of loss of signal intensity on the arterial spin labeling (ASL) cerebral blood flow map (e and f) (white arrow) corresponds to the area of hemorrhagic contusions. Surrounding it the perilesional oedema shows hyper perfusion. The SDH shows loss of signal intensity in ASL maps

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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