Diffusion Weighted Magnetic Resonance Imaging Features of Intracranial Lesions

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***Abstract*: Diffusion weighted imaging (DWI) is a specialized magnetic resonance imaging technique that depends on the random movement of water molecules within and between the intracellular and extracellular spaces. Regions with restricted mobility of water molecules yield a greater DW-MRI signal and appear bright. In apparent diffusion coefficient (ADC) maps, regions that contain high water mobility appear bright. Purpose: The objectives of the study were to describethe imaging characteristics of intra cranial lesions on DWI and to compare these features with ADCand T2W images. Results: In this study all cases (100%) of acute infarcts showed true diffusion restriction. 13% of acute infarcts showed no signal change on T2W images. The rest werehyperintense on T2WI. 50% of subacute infarcts and none of the chronic infarcts showed diffusionrestriction. All cases of subacute and chronic infarcts were hyperintense on T2WI. All cases of abscesses showed diffusion restriction. The cystic or necrotic component of none of the tumors seen in this study showed true diffusion restriction. Extradural empyema showed restricted diffusion. 40% of cases of glioblastoma multiforme showed true restricted diffusion while none of**
the low-grade gliomas or anaplastic astrocytomas showed diffusion restriction.

***Keywords*: Diffusion weighed imaging (DW1), Infarcts, Intra cranial Lesions**

Introduction:
Diffusion weighted imaging is a technique that assesses local environment at the cellular level to determine changes in the random movement of water protons. Restricted diffusionappears as an area of increased signal on DWI and reduced signal on ADC maps which are calculated from a matrix of tensor vectors obtained in three planes without and with application of diffusion gradients. The amount of diffusion weighting of a DW image depends on the magnitude of the applied gradients, how long they are switched on, and thetime between the two lobes.

Acute cerebral infarct results in anoxic injury to the cell membrane. This results in reducedmovement of water molecules between extra and intracellular compartments. Thus the earliest imaging feature of stroke is hyperintensity on DWI. ADC values vary with the ageof the ischemic stroke, a fact that can affect the analysis of clinical cases. In the first few hours after onset of ischemia, water diffusion decreases rapidly. After about 24 hours it begins to rise and reaches normal values by 5 to 7 days. After about two weeks diffusion typically increases within the territory of the infarct. (1)

Whereas DWI is most often used to identify acute arterial ischemia, other processes that interfere with or restrict the movement of water can cause notable changes on DWI, including neoplastic lesions, encephalitis, pyogenic abscesses and occasionally demyelinating disease.
Water diffusivity in the extracellular space is inversely related to the constituents of intracellular space; cells with a high nucleus to cytoplasm ratio and tissues with high cellularity cause increased volume of intracellular space, resulting in diminished mobilityof water protons with restriction of diffusion. Thus reduced diffusion can be seen in highlycellular tumors such as lymphoma, meningioma and glioblastoma. Several reports have reported an inverse correlation between ADC value and glioma grade for grade II throughIV astrocytomas. (2)

The signal intensity of gliomas on DW images is variable (hyper, iso, or hypointense), anda subtle hyperintensity is a common nonspecific finding. Tumor cellularity is probably a major determinant of ADC values of brain tumors, although probably not the only one. ADC values cannot be used in individual cases to differentiate glioma types reliably (the ADCs of patients with grade II astrocytoma and glioblastoma overlap). However, in the study of Kono et al, the combination of routine image interpretation and ADC values had a higher predictive value. (3) A study done by Tadeusz et al however showed no significantadvantage of DWI in the grading of gliomas. The ADC values of solid gliomas, metastases,and meningioma were in the same range. In cases of lymphomas, however there was a goodcontrast with white matter, with strongly reduced ADC values. (4) Therefore further studiesare needed to define clearly the ability of DWI to help differentiate various brain tumors and to help grade gliomas. (5)
Enhancing lesions of the brain include abscesses and tumors. The center of abscesses showrestricted diffusion and thus high signal intensity on DWI as compared to necrotic tumorswhich show low signal intensity. Thus DWI is useful in providing a greater degree of confidence in distinguishing brain abscesses from cystic or necrotic brain tumors than conventional MRI. (6)

Conventional MR imaging and clinical findings might be non-specific in cases of herpes encephalitis. DW image shows high signal

in the lesions with usually decreased ADC values representing cytotoxic edema and rarely higher ADC values representing vasogenic edema. Thus it may increase the diagnostic accuracy when combined with other sequences.Likewise in Creutzfeld-Jacob disease, DWI imaging helps differentiate from infarct by showing persistent restricted diffusion. (7)
Thus DWI has a wide range of applications in the evaluation of intracranial pathological conditions. It provides a specific diagnosis in few situations, and adds to the informationprovided by conventional sequences in many others. It is in this backdrop, that the objectives set out in this research programme will enable us to understand the appearancesof various intracranial lesions on diffusion weighted images. The signal characteristics of these lesions on ADC images and T2 FLAIR images will also be described.

Methodology:

Patients

Patients diagnosed with brain metastases were identified from a single institution histopathology archive. Records were searched and cases selected with a diffusion-weighted MRI scan of the brain before the first neurosurgical intervention. The class of recursive partitioning analysis (RPA) [18] and Graded Prognostic Assessment (GPA) [19] were determined; These are validated predictive measures in patients with brain metastases based on information such as primary cancer control, extracranial metastases, number of metastases, and the patient's overall health or performance status. The postoperative clinical course and oncologic care, including administration of whole-brain radiation therapy (WBRT) or use of adjuvant systemic chemotherapy, were recorded using the tumor board and patient notes as these represented potential confounders. This study was conducted in accordance with the principles of the Declaration of Helsinki and ethical approval was obtained as an internal project within the facility's research tissue bank (National Research Ethics Service # 11/WNo03/2)

MRI acquisition and analysis

All patients underwent preoperative MRI brain scans of various whole-body systems at 1.5 T with a single-channel head coil at local facilities before being referred to the Regional Neuroscience Center (of the 76 cases: 11 with GE Signa HD, 6 with a GE Discovery, 43 witha Philips Achieva, and 16 with a Siemens Avanto). All patients had received treatment with dexamethasone (at least 4 mg orally twice daily) for at least 24 to 48 hours prior to MRI imaging. Imaging in all cases included DWI with acquisition over 90 seconds by single frame echo planar imaging with two b-values of 0 and 1000 seconds/mm2. MR parameters were similar between scanners and ranged as follows: slice thickness 6 mm for all, TR 2515-3513 ms, TE 71-94 ms. Trace-weighted imaging and ADC trace maps were calculated using the GEFuncTool version 4.5.5 post-processing software package (General Electric Co., Maryland, USA) and subsequent measurements were performed. All patients had also undergone a fast spoiled gradient echo (FSPGR) or equivalent sequence with gadolinium contrast, again varyingbetween institutions, but most commonly TR 25 ms, TE 6.1 ms, flip angle 20 degrees. Conventional MRI measurements were taken on this post-contrast T1-weighted sequence, including number of lesions, maximum diameter on axial slices, and volume (using three orthogonal diameter measurements). The largest operated metastasis was evaluated only in patients with multiple lesions (note that there are generally cases with more than one metastasis).

Results:

Table 1: Age distribution and type of intracranial lesions

Intra cranial lesion	Age range								Total
	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	
Abscess		1	1	1					3
ADEM	1								1
Acute infarct					4	11	14	1	30
Adrenoleucodystrophy	1								1
Anaplastic Astrocytoma				1	1				2
Arachnoid Cyst		2	2	1					5
Chronic infarct					1	5	7	5	18
Demyelination toxic				1					1
Epidermoid cyst				1					1
Extradural empyema			1	1					2
GBM						2	3		5
Hemangioblastoma					1				1
HSV encephalitis			1						1
Low grade glioma		1		3					4
Lymphoma						1	1		2
Medulloblastoma		4							4
Meningioma			1	2	5	1			9
Multiple sclerosis				1	1				2

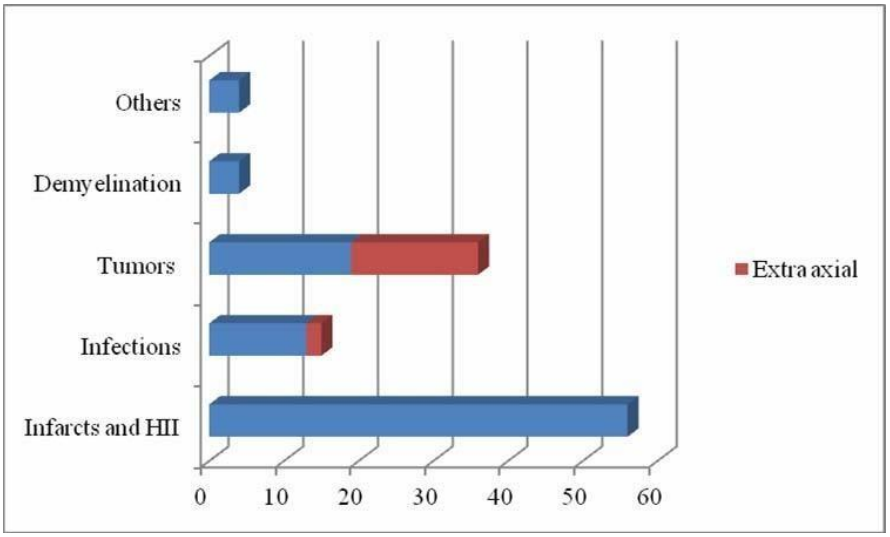
NCC granuloma			1	2					3
PVL	1								1
Pilocytic astrocytoma	1								1
PRES		1	1						2
Preterm HII	3								3
Profound term HII	1								1
Schwannoma				1		1			2
Subacute infarct					2	2			4
TB granuloma	1	1	2	1	1				6
TOTAL	9	10	10	16	16	23	25	6	115

Intra cranial lesions were found in patients of all age groups. However the peak (21.7%)was noted in 61-70 year age group (table 1).

Spectrum of intracranial lesions.

Of the total cases included in this study, infarcts were the majority which constituted 52 cases (45.2%). 4 cases of hypoxic ischemic encephalopathy (3.4%) were also included. Theother cases were 36 cases of tumors (31.3%) of which 19 (52.8%) were intra axial and 17(47.2%) were extra axial tumors, 15 infective conditions (13%), 4 cases of demyelination (3.4%) and 4 other miscellaneous conditions (3.4%). These included 1 case of adrenoleucodystrophy, 1 periventricular leucomalacia, and 2 posterior reversible encephalopathy syndrome cases.

Chart 3 Types of intracranial lesions



Imaging characteristics of intracranial lesions

Of the 115 patients included in this study, 82 cases (71.2%) showed hyperintensity on DWIof which true restriction (hyperintense on DWI and hypointense on ADC) was noted in 52patients (45.2%). This constituted 63.4% of the cases showing diffusion restriction. T2 shine through was noted in 30 patients (26%). This constituted 36.6% of the cases showingdiffusion restriction.

52 cases (45.2%) showed hypointensity on ADC images. All of these were hyperintense onDW images. 13 patients (11.3%) showed T2 washout (hyperintense on T2WI and isointense on DWI). 5 patients (0.43%) showed no signal change on DWI or ADC images. 51 patients (44.3%) had lesions that showed increased diffusivity (hyperintense signal on ADC image). Of these 15 (13%) were hypointense on DWI. This constituted 29.4% of thecases showing increased diffusivity. 13 of these showed T2 washout, and 23 showed T2 shine through.

All 30 cases (100%) of acute infarcts showed true diffusion restriction with hyperintensity on DWI and hypointensity on ADC images. Of these, 26 cases (86.66%) showed hyperintensity on T2W images. The remaining 4 cases (13%) showed no signal change on T2W images.

Of the 18 cases of chronic infarcts, ADC signal was increased in all, suggesting increasedwater diffusivity. In 8 cases (44.44%), there was hypointensity on DWI and T2 FLAIR images with hyperintensity on ADC images indicating encephalomalacic changes. T2 shinethrough was noted in 10 cases (55.55%). None of the cases showed T2 washout.

Out of 4 cases of subacute infarcts, 2 (50%) showed true restriction and 2 (50%) showedT2 shine through.

Hypoxic Ischemic Injury

Four cases of hypoxic ischemic injury were included in this study, age range of 3 days to 15 days. Three cases were preterm neonates and one was a term neonate.

All four cases showed true diffusion restriction. 3 of four cases (75%) showed hyperintensity on T2 FLAIR images, and 1 (25%) did not show any change on T2 FLAIRimages.

The extent of abnormality was noted to be more on DW and ADC images than on T2 FLAIR images.

Infections

The study included 15 infective conditions of which 6 (40%) were tubercular granulomas,3 (20%) were NCC granulomas, 3 (20%) were abscesses, 2 (13.3%) were extradural empyemas and 1 case (6.7%) was HSV encephalitis.

True restriction of diffusion was noted in 7 (46.66%) cases. This included 2 tubercular granulomas 3 abscesses and 2 extradural empyemas. Thus 33.33 % of tubercular

granulomas, 100% of abscesses and 100% of extradural empyemas showed true diffusionrestriction.

T2 washout was seen in all 3 cases (100%) of NCC granulomas and 3 cases (50%) of tubercular granulomas.

T2 shine through was seen in 1 case of tubercular granuloma and one case of HSV encephalitis.

Extra axial Tumors

17 cases of extra axial tumors were included in this study with an age range of 14 to 52 years, mean 36 years. Of these 6 were females and 11 were males. These were 5 cases of arachnoid cysts, 1 epidermoid cyst, 9 cases of meningiomas and 2 cases of schwannomas.True restricted diffusion was noted in 4 cases (23.52%). This included the single case of epidermoid cyst and 3 cases (33.3%) of meningiomas. In one case of meningioma, T2 shinethrough was noted. In 6 (66.6%) cases of meningiomas, T2 FLAIR showed iso to hypointense signal probably due to high cellularity and presence of calcification.

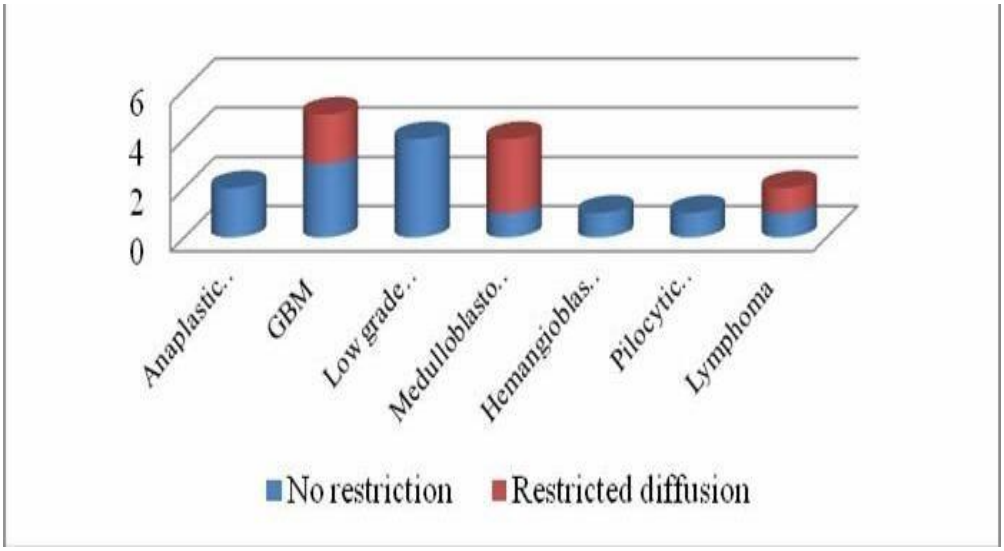
1 case (50%) of schwannoma showed T2 washout.

Tumors Intra axialtumors

There were 19 cases of intra axial tumors in this study. The age of the patients ranged from

10 to 68 years with 5 females and 14 males. This included 2 cases of anaplastic astrocytoma, 5 cases of glioblastoma multiforme, 1 hemangioblastoma, 4 low gradegliomas, 4 medulloblastomas, 1 pilocytic astrocytoma, and two cases of lymphomas. 6 cases(31.6%) showed true diffusion restriction. Of these were 2 were GBM, 3 were medulloblastomas, and one was lymphoma. Thus 40% of GBM, 75% of medulloblastomas,and 50% of lymphomas showed true restriction of diffusion.

Chart 4: Intra Axial Tumor



T2 shine through was noted in 8 cases (42.1%). This included all 2 cases of anaplastic astrocytomas, 3 cases (60%) of GBM, 2 cases (50%) of low grade gliomas and 1(50%) case of lymphoma.

T2 washout was seen in one case of hemangioblastoma and 2 cases (50%) of low grade gliomas.

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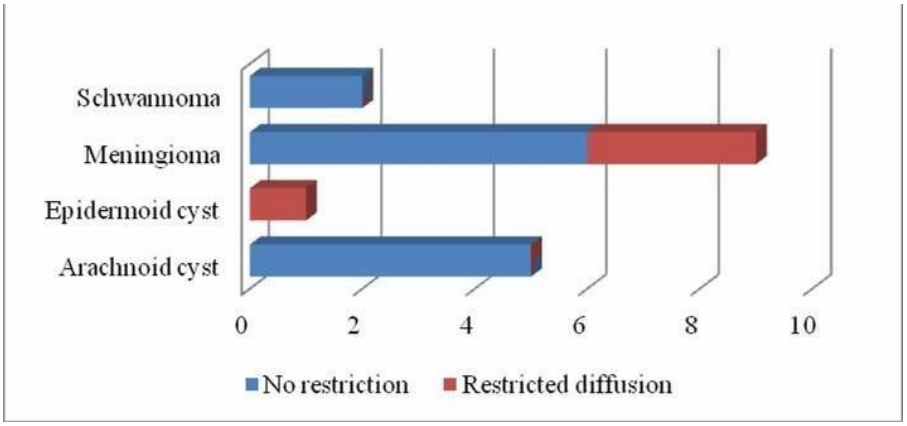
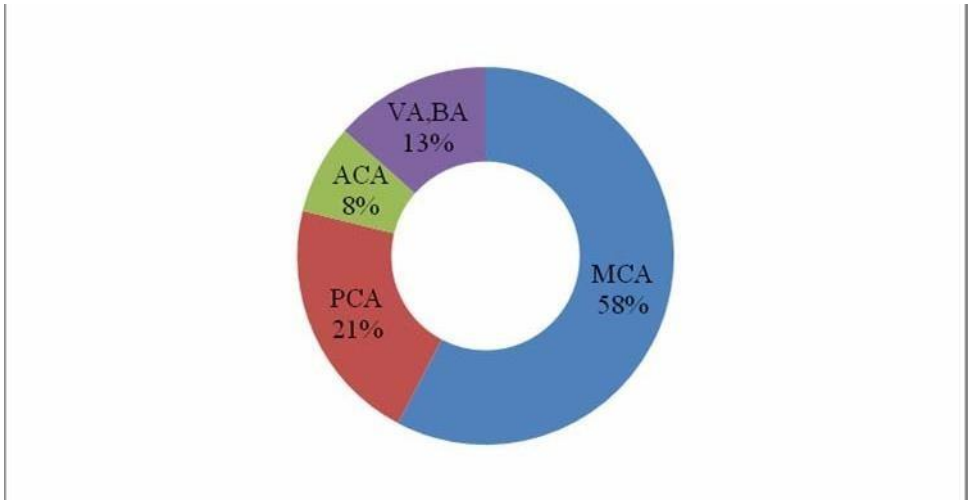
Extra Axial Tumors



Infarcts and HII



The sensitivity and specificity of DWI in the detection of acute ischemia is 100%. The difference in sensitivity of DWI and conventional MRI sequences is more in the initial time period and decreases as time progresses. Results of this study are correlated with a study done by Gonzalez et al (52) who concluded that DWI is superior to conventional MRI in the diagnosis and characterization of acute infarct.

In this study restricted diffusion was noted in 100% of acute infarcts. In 13% of acute infarcts, no change was noted on T2WI. Thus DWI was noted to be superior to T2WI indetection of acute infarcts.

In subacute infarcts and chronic infarcts, abnormal signal was noted on T2WI and on DWI in all patients. Thus there was no difference in their sensitivity for later stages of infarcts.

Rima K et al (80) and) showed that restricted diffusion is present in all patients on DW MR studies obtained within 24 hours of the onset of symptoms, and in 94% of patients scanned after 2 weeks after ictus. In this study subacute infarcts were defined as patients in whom imaging was performed between 2 and 14 days after symptom onset. (62) Truediffusion restriction was noted in 50 % of patients with subacute infarcts. The other 50 %showed T2 shine through.

In this study 58% of infarcts were noted to be in MCA territory, 21% in PCA territory, 8% in ACA territory and 13% in vertebral artery and basilar artery territory. This is comparable to a study done by Van Der Zwan et al (81) which showed that MCA territoryis the most common site for infarcts and ACA territory is the least common among majorarterial territories.

In chronic infarcts the signal on DWI and ADC images is variable and depends on a ombination of T2 signal and increased ADC values. The T2 signal is also affected by theonset of cystic encephalomalacia. (40)

In this study T2 shine through was noted in 55.5% of chronic infarcts and cystic encephalomalacia was noted in 44.4%.

Discussion

Diffusion weighted MRI provides image contrast that is different from that provided by conventional MRI sequences. It provides a technique for mapping proton contrast that reflects the microvascular environment. This imaging technique is sensitive to early ischemic insult. DWI is performed with a pulse sequence capable of measuring water translation over short distances. This water diffusion is much slower in certain pathological conditions as compared with normal brain. (80)

In this study 115 patients with intracranial lesions detected on DW MRI of the brain wereincluded. It was found that DW MRI provides adjunctive information for intracranial lesions including stroke, neoplasms, infections, hypoxic ischemic encephalopathy and extra axial lesions in conjunction with conventional MRI.

Hypoxic ischemic injury

Diffusion-weighted imaging has proved to be more sensitive than conventional MR imaging sequences for early detection of hypoxic ischemic brain injury. Fu JH et al (63)compared conventional MRI sequences to DWI in the evaluation of HII and found that

DWI showed abnormal high signal intensity in the brain in patients in whom theconventional MR sequences were initially normal. Schaefer et al (40) concluded that HIIlesions not seen on routine MR images are identified on DW MR images. When lesions are identified on conventional images, lesion conspicuity is increased and lesion extent is seen to be larger on DW MR images.

All cases of neonatal HII included in this study showed true diffusion restriction. In 25%of cases there was no abnormality on T2 FLAIR images. The extent of abnormal signal was much more in the remaining 75% of cases on DWI, than that showed by T2W images.

This was also demonstrated in a study by Cruz et al (10), in which epidermoid cysts hadADC values similar to brain parenchyma while arachnoid cysts had ADC values similarto CSF.

In this study all 5 cases of arachnoid cysts had signal similar to CSF on DWI and ADCimages. The single case of epidermoid cyst noted in this study had restricted diffusion. Tadeusz et al (3) and Cruz et al (10) concluded that most meningiomas are isointense onDWI. Only few may show restricted diffusion depending on their cellularity. In theirstudy 23% of meningiomas showed restricted diffusion. This study had similar resultswith 33% of meningiomas showing true diffusion restriction.

Schwannomas show high signal on ADC images with no restricted diffusion reflectinglack of high cellularity.

Conclusion

In this study all cases (100%) of acute infarcts showed true diffusion restriction. 13% of acute infarcts showed no signal change on T2W images. The rest were hyperintense on T2WI. 50% of subacute infarcts and none of the chronic infarcts showed diffusion restriction. All cases of subacute and chronic infarcts were hyperintense on T2WI.

100% of cases of HII showed restricted diffusion while only 75% of them showed abnormal signal on T2WI. The extent of abnormality was more on DWI than on T2WI in all these cases.

All cases of abscesses showed diffusion restriction. The cystic or necrotic component of none of the tumors seen in this study showed true diffusion restriction. Extradural empyema showed restricted diffusion.

40% of cases of glioblastoma multiforme showed true restricted diffusion while none of the low grade gliomas or anaplastic astrocytomas showed diffusion restriction. Diffusion restriction was also noted in 75% of medulloblastomas and 50% of lymphomas. Among extra axial tumors, 33% of meningiomas showed diffusion restriction. All cases of arachnoid cysts showed low signal on DWI while epidermoid cysts showed restricted diffusion.

Demyelination and PRES did not show restricted diffusion. By using a combination of various MR sequences coupled with DWI and ADC images avaluable diagnosis may be provided to the clinicians. In this study the signal characteristics of various lesions on DWI, ADC, T2FLAIR and T1W images were studied.

Diffusion weighted MRI has been proven to be of excellent use in the characterization ofinfarcts and in the detection of acute infarcts. It is especially useful in the initial few hoursof the ischemic insult when conventional MR sequences may be inconclusive and may not detect the infarct.

Financial or Other Competing Interests

None.

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