Research Article

Diffusion-weighted MRI in patients with acute stroke

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Abstract

Background: Acute stroke is an abrupt non-traumatic brain insult, caused by either brain infarction (75%) or hemorrhage (25%).

Aim of the Study: To compare the sensitivity of Diffusion - weighted imaging (DWI) and apparent diffusion coefficient (ADC) map in detection of acute stroke with sensitivity of conventional MRI study.

Patients &methods: Thirty - eight patients (24 male and 14 female with age range between 43-90 years) with a clinically suggestive stroke and negative CT-scan, all patients referred for MRI study within 4-40 hours [mean of 17 hrs] of acute attack. brain MRI was performed for these patients. Starting with conventional MRI sequences done followed by diffusion weighted in the same study and follow up clinically afterwards. The study was conducted in a general hospital in Baghdad from January 2012 to January 2013 .Ratios were calculated between the apparent diffusion coefficient value of normal appearing brain in the right & left hemispheres & between apparent diffusion coefficient value of the ischemic area & the corresponding contralateral region .

Results: With diffusion - weighted images , 100% of the ischemic lesions were detected, and with fluid-attenuated inversion recovery, 73.7% were detected, whereas with early T2-weighted or T1-weighted, only 52.6 % and 21% of lesions were detected , respectively , using McNemar test we found statistically significant differences in sensitivity between Diffusion weighted images and T1W ($p<0.0001$), diffusion weighted images and T2W ($p<0.0001$) and between diffusion weighted images and fluid attenuated inversion recovery ($p< 0.002$) .The mean apparent diffusion coefficient of acute ischemic lesions was 30 % lower than the apparent diffusion coefficient of normal appearing parts of brain .($P <0.001$).

Conclusions: Diffusion -Weighted images + apparent diffusion coefficient map Imaging is more sensitive than conventional MRI sequences in MRI detection of acute stroke **.**

Keywords: Diffusion-weighted MRI ,acute stroke

INTRODUCTION

Stroke is a clinical term applied to any abrupt non-traumatic brain insult, strokes are caused by either brain infarction (75%) or hemorrhage (25%) and must be distinguished from other conditions that cause abrupt neurologic deficits[1] . Risk factors for stroke are family history, older age, male gender, hypertension, diabetes mellitus, smoking, hypercholesterolemia, many cardiac conditions, and inherited and acquired hyper-coagulable states.For several decades the incidence of stroke has steadily declined, mostly attributable to control of

hypertension. Stroke can be categorized according to time from symptom onset: Hyper acute stroke refers to the 1st to 6 hour time period, acute stroke refers to the 6 to 24 hour period, sub-acute stroke refers to the 24 hour to approximately 2 week time period and chronic stroke refers to strokes older than 2 weeks[2].

Magnetic Resonance (MR) imaging has a major advantage over CT in that it has better soft tissue contrast [3,4] .

In the hyperacute phase of ischemic stroke, CT are often normal or show subtle changes only. On the contrary, DWI scans can reveal the ischemic lesion in its full extent within minutes only. ([5]

Diffusion is a term used to describe the movements of molecules due to random Brownian motion , this means that there is no net direction of movement overall from the water molecules when diffusion freely , this motion however is restricted by boundaries such as membranes or large molecules [6] . In early stroke after metabolic failure, the cells absorb water and swell thus leading to restricted diffusion in these tissues, thus areas of unimpeded diffusion such as the extracellular space of the normal brain are dark on diffusion weighting image, whereas areas of cytotoxic edema with reduced diffusion such as stroke have high signal intensity [7].

A note of caution is related to the fact that diffusion weighted imaging carry a significant T2 weighted , this give rise to increased signal not caused by restricted diffusion (T2 shine through) as may occur with gliosis or edema , this potential source of diagnostic confusion is resolved by the calculation of the ADC where the T2 effects are cancelled.Areas of restricted diffusion have reduced signal on calculated maps of the ADC. ([6,7]

This changes on diffusion weighted image precedes changes on T2 & FLAIR , making DWI a key sequence in the early detection of stroke. [8]

MR Findings in acute stroke:

T1WI : Early cortical swelling &hypo- intense, loss of gray –white border.
T2WI : Early cortical swelling, hyper - intense in affected distribution, may normalize 2-3 weeks post-ictus .
FLAIR : May be positive (hyper -intense) when other sequences normal (as early as 6 hrs. post-ictus)
DWI : Hyper-intense signal (restriction) from cytotoxic edema [9-10].

The magnitude of diffusion weighting is connoted by the "b"value of the image .Typical "b"value (in seconds per square millimeter)for imaging stroke are on the order of 400 to 1000 sec/mm^2 .by comparing diffusion sensitizing gradients (the "b" zero image),one can compute the amount of diffusion that appear to have occurred .If this done on a pixel –by-pixel basis ,the result is a computed map of apparent diffusion known as an Apparent diffusion coefficient map [20-21]. By this way we can calculate the apparent diffusion coefficient (ADC) value.

ADC values vary with the age of ischemic stroke, usually decrease rapidly within first hours & begin to increase after one -two weeks [22].

Finally some conditions other than stroke can be associated with diffusion restriction, for example, cerebral abscess, cerebral trauma resulting in diffuse axonal injury can also result in foci of hyper-intensity on diffusion weighted scans. The aim of this study was to compare the sensitivity of DWI images and apparent diffusion coefficient map in detection of acute stroke with sensitivity of conventional MRI study.

PATIENTS AND METHODS

Prospective study was done at AL- Yarmouk Teaching Hospital over twelve month period from January 2012 to January 2013. The total number of patients was 38 after exclusion of eight of them, who are proved clinically to be non-stroke patients .We therefore analyzed the results of thirty eight adult patients who referred from emergency department for radiological evaluation of their condition .Of the 38patients, 14 were women and 24 men , mean patient age was 64 years , (range, 43-90years). Of the 38 patients, all had negative CT scan.

Imaging protocol: MR imaging was performed using 1.5 Tesla Philips (Germany), Model 2011 super-conductive system [achieva]. Each patient gave written informed consent before undergoing MRI. All the images were obtained in early phase (4-40 hours).

T1w	TR= 149 ms	,TE= 1.8 ms
T2W	TR= 3000 ms	,TE= 110 ms
FLAIR	TR= 6000 ms	,TE= 120 ms
DWI	TR= 4363 ms	,TE= 98 ms

Follow up of patients done after 24 hours afterwards, clinically. For patients handling and performing the entire imaging protocol=20 minutes needed,=or less than 6 minutes needed for diffusion weighted image .

In addition to diffusion weighted image (DWI) we use apparent diffusion coefficient (ADC) trace map to exclude artifact and to confirm that pathology is recent one with b value =1000sec /mm2 .

ADC measurements: Ratios were calculated between the ADC of normal appearing brain in the right & left hemispheres & between ADC of the ischemic area & the corresponding contralateral region.

Image analysis: Data were statistically analyzed using McNemar tests to compare different MR sequences .Differences with p-value of less than 0.05 were considered statistically significant.

RESULT

We analyzed the results of 38 patients with signs and symptoms of ischemia of acute onset (24 men(63%),14 women(36.8%)with male : female ratio =1.7:1 ; mean age, 64 years; range,(43-90)years. The demographic data are shown in table (1) . These 38 patients 30 suffered from hypertension [78.9%] , 6 suffered from diabetes mellitus and hypertension [15.7%] and 8 of them suffered from hyperlipidemia. Before the current ischemic event, 16 patients (26 %)had suffered from a minor ischemic stroke and 8 patients (21%) had suffered from a transient ischemic attack (TIA) , summarized in table (2).The results for the detection of lesions on early T1W, T2W, FLAIR, and DWI scans are summarized in table (3)

The mean time between the onset of symptoms and the early MR investigations was 17 hours (range, 4-40 hours). 6 patients were imaged in the hyper-acute stage (0-6 hours from onset) , 8 patients were imaged between 6 and 12 hours after onset, 14 patients were imaged between 12 and 24 hours, and 10 patients were imaged between 24 and 48 hours after onset of symptoms, time from onset summarized in table (4).

From those 38 patients ,16 patients [42%] show involvement of middle cerebral artery (MCA) as shown in figure (2) ,also 16 patients [42%] show involvement of posterior circulation system [posterior cerebral artery (PCA) ,vertebral and basilar artery branches] as shown in figure (3) and (5) , 4 patients show involvement of water shad area (border zone between anterior cerebral artery and middle cerebral artery , middle cerebral artery and Post cerebral artery [10.5%] as shown in figure (4). Anterior choroidal artery was involved in 2 patients [5%] , while anterior cerebral artery involved only in 1 patients [2.6%] (who also showed involvement of middle cerebral artery in same time) .

During the first 48 hours after stroke, more lesions were detected on the DWI scans (100%) {95% confidence interval 88.6%-100%} than on the T1-W images{21%;T1W vs DWI *P*<0.0001(95% confidence interval :10%-37.8%)} or T2W images {52.6%;T2W vs DWI*P*<0.0001(95% confidence interval :36%-68.8%)}. With FLAIR,73.7% of the lesions was detected (FLAIR vs DWI; p<0.002 (95% confidence interval :56.7%-86%)}.

No false-positive lesions were found with DWI: all hyper-intensities resembling an ischemic lesion on DWI evolved into infarcts on clinical follow-up scan.

Table (5)summarize the ADC values of patients in normal appearing areas in the cerebrum & ischemic regions , no significant difference in ADC was found between the various regions in the brain parenchyma of patients , the mean ADC of the ischemic lesions was 30 % lower than the mean ADC in corresponding areas of the contralateral hemispheres P < 0.001 .

Table 1. Distribution of cases in present study according to previous attacks

		No.	%
Previous attacks	**Stroke**	**10**	**26%**
	TIA	**8**	**21%**
	Negative	**20**	**52.6%**

Table 2. Distribution of study sample of acute stroke according to the time between onset of symptoms & the MRI study

	All lesions	**0-6 hrs**	**6-12 hrs**	**12-24 hrs**	**24-48 hrs**
T1-W	**8/38**	**1/6**	**1/8**	**4/14**	**2/10**
T2-W	**21/38**	**2/6**	**4/8**	**10/14**	**5/10**
FLAIR	**28/38**	**5/6**	**5/8**	**12/14**	**6/10**
DWI	**38/38**	**6/6**	**8/8**	**14/14**	**10/10**

Values are number (percentage) of ischemic lesions. *(p<0.0001) in T1W vs DWI, (p<0.0001) in T2W vs DWI and (p<0.002) in FLAIR vs DWI

Table 3. Distribution of cases in present study according to time from onset of symptoms.

		No.	%
Time from onset	**0-6**	**6**	**15.7%**
	6-12	**8**	**21%**
	12-24	**14**	**36.8%**
	24-48	**10**	**26.3%**
Mean±SD(Range)	**17±3.4 (4-40)**		

Table 4. Distribution of cases in present study according to site of lesion distribution.

		No.	%
Site of lesion	MCA	16	42%
	Post. System	16	42%
	WS	4	10.5%
	ACHA	2	5%
	ACA	1	2.5%

MCA:middle cerebral artery
post.System :posterior circulation system
WS:water shad areas
ACHA:anterior chorodial artery

Table 5. Distribution of cases in present study according to according to ADC map.

Brain region	ADC Patients	I/C Ratio
Frontal	1.09±0.19	0.99±0.15
Occipital	1.08±0.06	1.04±0.12
Periventricular	0.79 ±0.56	0.93±0.65
Parietal	0.97±0.10	0.98±0.11
Brain stem /Pons	1.23±0.04	
Lesion	0.71 ±0.12	0.70±0.92
Contralateral	1.01±0.13	

DISCUSSION

Stroke is the third leading cause of death in the United States and a major source of long-term disability among survivors. The approach to treatment of ischemic stroke has been largely preventative or supportive in the past, but approval of IV thrombolysis for acute stroke and neuroprotective drug development have made rapid imaging and intervention a critical part of stroke management at 4 to 6 hours and lasts for approximately 5 days.[3] Following breakdown of the blood-brain barrier, vasogenic edema develops, mainly from the shift of water from the intravascular to the extracellular space.[6] The flow of water into the extracellular space is mainly driven by osmotic forces linked to protein extravasation. Vasogenic edema is associated with a large increase in overall tissue water , this leads to marked brain swelling that peaks at 3 to 5 days. In 10% of large cerebral infarctions, space-occupying brain swelling leads to an increase in intracranial pressure, herniation and death[4] .

Our results confirm that DWI is essential imaging method to detect ischemic lesions in the early stage after stroke [first 24 hrs][1]**.** which agree with other study , also possibility of DWI to exclude stroke if examination is negative [8 patients with picture suggestive of stroke ,who are negative in DWI and other MR sequences proved to be non-stroke patients on clinical follow up , 3 of them had improper clinical examination , other 3 patients had transit ischemic attacks (TIA) and 2 had hysterical attack].Age range in our study between 43-90 [mean 64 yrs] , similar age range found in other study[14] .

In patients with previous attack in our study ,10 patient [26%] had suffered from minor stroke ,8 patients [21%] had suffered from TIA compared with other study where 9 patients (21%) had suffered from a minor ischemic stroke and 8 patients(19%) had suffered from (TIA).

All fresh lesions were depicted on DWI, whereas with T1W or T2W imaging, 79% and 47.4% of lesions, respectively, were not found in the early stage[8,15,16] .

Although less accurate than DWI, FLAIR imaging provided better results in detecting ischemic lesions than the T2W scans , only 26 % of lesions were not found in the early stage ,compare with study done by Van Everdingen et al[13] that show about 29% of lesions not found in the early stage in T2W ,while in FLAIR only 9% of lesions not found in acute stage .In our study, the sensitivity of DWI (100 %) for direct depiction of acute stroke was higher than that of FLAIR ,T2WI (73.7%, 52.6% respectively) these findings approximate sensitivity of DWI in other study [2] and slightly differ from other studies [13-19] where they report sensitivities about (98%) for DWI and (91% ,71%) for FLAIR ,T2WI respectively, this can be attributed to different MRI protocols , also the mean time of examination in our study was 17hrs [4-40 hrs] after the event , compared to time of examination in other study with mean of 27 hrs [6-48 hrs][10] .

MCA and Posterior circulation are involved in equal percentage about 42% while WS areas are involved in 10.5% , ACA involved in 2.6% and Anterior choroidal artery in 5% , compared with other study in which MCA involved in 60% , Posterior circulation in 15% ,WS areas in 12% ,ACA and ACHA both involved in 9%,the high involvement of posterior circulation can be attributed to low sensitivity of CT-scan to posterior fossa because bony artifact and small size lesions can tolerate the long time of MRI imaging compared with patients with MCA involvement who come with large lesions and can tolerate long examination time with altered level of consciousness causing motion artifact or technical problems that impaired imaging with MRI which can take about 15-20 minutes if diffusion added to examination ,lastly we think that the MRI machine technology is improved now a day

in comparison to that before 10 years or more ,so that DWI become more sensitive to subtle changes in posterior fossa , these results are in agreement with other studies [12,16].The ADC values vary with the age of ischemic stroke. In the first hours after the onset of ischemia, ADC values decrease rapidly, often 30% or more below normal[13,14,17,20]. After about 24 hours, ADC values begin to increase again, approaching normal values at about 5 to 7 days. This tendency for ADC values to increase and return to the normal range after the initial decrease that occurs in acute cerebral infarction is termed pseudonormalization .After about 2 weeks, ADC values are typically increased within the territory of infarction[2,18,20] .

The limitation in our study that some patients are uncooperative or suffered from claustrophobia from closed MRI machine . So in conclusion the DWI & ADC map are more sensitive than conventional sequences in MR detection of acute stroke.

REFERENCES

1. Modic M. Masarykt , Ross J, etal. cerebro-vascular disease. In: William E. Brant ,Clyde A. Helms ,editors .fundamentals of diagnostic radiology .3rd edition .Lippincott Williams &Wilkins;2007.
2. Pamela W. Schaefer, Luca Roccatagliata , R.Gilberto Gonzalez ,etal. stroke and cerebral ischemia .In :Robert R.Edelman , John Hesselink,and Michael Zlatkin ,editors ,Clinical Magnetic Resonance Imaging .3rd edition ;2010.
3. De lucas EM , Sanches E , Guterrez A , etal . CT Protocols for Acute Stroke : Tips and Tricks for General Radiologists . Radiographics.2008 oct ;28(6) : 1673-87 .
4. H.Ric Harnsberger . stroke anatomy and imaging issues. In: AnneG.Osborn ,Susan I. Blaser, Karen L. Salzman, editors. Diagnostic imaging-brain.1st edition .AMIRSYS; 2004.
5. Turgut Tatisumak . Is CT or MRI the method of choice for imaging patients with acute stroke ? .Stroke J. ; 33:2144-2145 .
6. Derek K. Jones . Diffusion MRI : Theory , Methods & Applications . Edition 1 ,copyright 2011 by Oxford university press , Inc.
7. N . Hoggard , I. D. Wilkinson & P.D.Griffiths . MR imaging in Acute Stroke . Imaging Decisions MRI J. .2001 April ; vol 5 , issue 1 ;2-10
8. Yuh WTC, Crain MR, Loes DJ, etal. MR imaging of cerebral ischemia: findings in the first 24 hours. AJNR Am JNeuroradiol. 1991;12:621– 629.
9. Shimosegawa E, Inugami A, Okudera T, etal. Embolic cerebral infarction: MR findings in the first 3 hours after onset. AJR Am J Roentgenol. 1993;160:1077–1082.
10. G.W.Alberts ,M.G.Lansberg , A.M.Norbash, etal .Yield of Diffuion -Weighted MRI for detection potentially relevant findings in stroke patients .Neurology 2000;vol.54 ,no.8 : 1562-1567 .
11. Agid R, Shelef I, Scott JN, etal ,In : John R. Haaga,Vikram S. Dogra, Michael Forsting,editors . CT and MRI of whole body ,fifth addition .MOSBY ELSEVIER ;2009.
12. P.J.Hand, J.M.Wardlaw ,C.S.Rivers , etal .MR Diffusion imaging & outcome prediction after ischemic stroke . Neuroradiology J .2006 ;vol . 66 ; no.8 ; 1159-1163 .
13. K.J. van Everdingen , J. van der Grond , L.J. Kappelle , etal. Diffusion -Weighted Magnetic Resonance Imaging in Acute Stroke . Stroke J .1998 ;29:1783 -1790.
14. R.Gilberto Gonzalez , Pamela W. Schaefer , Ferdinando S.Buonanno, etal .Diffusion-Weighted MR Imaging: Diagnostic Accuracy in Patients Imaged within 6 Hours of Stroke Symptom Onset .J.Radology 1999; 210:155-162.
15. Ebisu T, Tanaka C, Umeda M, etal . Hemorrhagic and non-hemorrhagic stroke: diagnosis with diffusion-weighted and T2-weightedecho-planar MR imaging. Radiology. 1997;203:823– 828.
16. Mark E. Mullins , Pamela W. Schaefer , A. Gregory Sorensen , etal .CT and Conventional & Diffusion -Weighted MR Imaging in acute stroke . Radiology J.2002 ; 224:353-360 .
17. Schaefer PW , Copen WA , Lev MH , etal. Diffusion-Weighted imaging in acute stroke .J Neuroimaging clinNAm.2005 ; Aug ; 15 (3) : 503-30 .
18. Pamela W. Schaefer , P. Ellen Grant , R. Gilberto Gonzalez . Diffusion weighted MR imaging of the brain .Radiology 2000 ; 217 : 331 - 345 .
19. Rosso C , Drier A. , Lacroix D. , etal . Diffusion -Weighted MRI in acute stroke within the firsr 6 hours . Neurology J. 2010; jun 15 ; 74 (24) .
20. Ajai K. Srivastava , Gopesh Mehrota , Satish K. Bhargava , etal .Studies on the time coaese of apprent diffusion coeffient and signal intensities on T2 and Diffusion-Weighted MR imaging in acute cerebral ischemic stroke . Med Phys J 2008 Oct-Dec ; 33(4):162-170.