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Assessing Brain Tumours through Diffusion-Weighted Imaging Techniques

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Abstract

Introduction: Cancer is the second leading cause of death globally, and early detection is crucial for improving outcomes. Brain tumors, characterized by abnormal cell growth in the brain, can be either benign or malignant. Although conventional MRI techniques are routinely used for diagnosis, they often lack the sensitivity needed for tumor grading and characterization. This study aims to evaluate the effectiveness of Diffusion-Weighted Imaging (DWI) and the Apparent Diffusion Coefficient (ADC) in providing additional diagnostic information for brain tumors. ***Methods:*** A retrospective analysis was conducted involving 100 patients who underwent MRI examinations, including conventional and DWI, at a diagnostic radiology department between January 2022 and December 2024. The study employed a 1.5-T magnetic resonance scanner, with DWI analyzed using calculated ADC values. Data on demographics, MRI characteristics, and MRI findings were collected and analyzed using SPSS Version 27. ***Results:*** The mean age of participants was 43.2 years, with a gender distribution of 53% male and 47% female. The analysis showed that most lesions had irregular borders (42%) and heterogeneous characteristics (56%). Statistically significant associations were found between tumor border irregularity, edema type, and ADC values, with significant differences in ADC values correlating with tumor types. DWI indicated that most hyper-intense tumors showed mass restrictions, whereas hypo-intense tumors demonstrated no restrictions. ***Conclusion:*** This study highlights the critical role of DWI and ADC in enhancing the diagnostic accuracy of brain tumors. Integrating these advanced imaging techniques into routine MRI practices can significantly improve the differentiation and characterization of brain tumors, aiding in better clinical decision-making

Keywords: Brain tumors, Diffusion-Weighted Imaging, Apparent Diffusion Coefficient, MRI, Diagnosis, Imaging Techniques.

INTRODUCTION

Cancer is the second leading cause of death globally, according to the World Health Organization (WHO). Early detection of cancer can prevent death, but this is not always possible [1].

Brain tumors can be defined as the development of abnormal cells within different parts of the brain. Brain tumors usually develop when the tumors cells escape from the normal physiological control and invade nearby healthy cells. There are various types of brain tumors, The two major types of brain tumors include benign tumors and malignant tumors [2]. However, biopsy is still generally considered the gold standard for determining the tumors type and degree of malignancy[5].

Diagnosis of brain tumors by conventional magnetic resonance imaging (MRI) is based on non-contrast T1-weighted images (T1WI) and T2-weighted images (T2WI) and post-contrast (T1WI). Conventional MRI techniques are considered not enough for grading, classifying, and detecting the aggressiveness of brain tumors. Although conventional MRI provides mainly structural information, such as tumor size, site, and morphological appearance, it does not give a concern about the tumor grade, its aggressiveness, or its histological criteria. For this purpose, studies that are more recent showed that there is a need for other imaging modalities like diffusion-weighted imaging (DWI) [3].

Diffusion-weighted imaging (DWI) is a non-contrast-enhanced type of magnetic resonance imaging (MRI) which is most simply performed with two b

values, such as 0 and 1000 s/mm2. The exponential decay of signals is proposed based on the assumption of the mono-exponential fit to arrive at a decay constant, referred to as the apparent diffusion coefficient (ADC) value. In DWI, signal attenuation in tissue with increasing b values reflects tissue diffusivity and reduces the effect of tissue microcapillary perfusion. The most common quantitative evaluation of DWI is by ADC [4].

The brain tumors diagnosis in MRI is characteristic subjectively according to the size and site and the shape and homogeneity of contrast enhancement which is variable on the radiologist dependency and his literature knowledge and the accurate diagnosis depend on the biopsy which is invasive and not suitable or available for all patient New techniques such as DWI and ADC may add new information to attempt to accurate diagnosis.

The aim of this study is to evaluate the efficacy of Diffusion-Weighted Imaging (DWI) and the calculation of Apparent Diffusion Coefficient (ADC) values in providing additional diagnostic information about brain tumors. Specifically, the study seeks to assess whether DWI and ADC can enhance tumor characterization, differentiate between benign and malignant lesions, and improve the overall accuracy of MRI in the diagnosis of brain tumors, thus potentially establishing these techniques as routine practices in clinical radiology.

PATIENTS AND METHODS

Retrospective study was conducted from January 2022 to December 2024, involving a total of 100 patients. Which was conducted at the diagnostic Radiology department. The study utilized a 1.5-T magnetic resonance scanner (Toshiba), manufactured in China in January 2009.

All patients included in the study underwent a comprehensive medical history review, neurological examination, histopathological assessment, and MRI examination (both conventional and DWI).

Conventional MRI was done in supine position using standard head coil with the head maintain in a neutral position. Sagittal and axial T1-weighted non-contrast images were done then axial T2-weighted fast spin echo image and axial fluid attenuated inversion recovery (FLAIR).

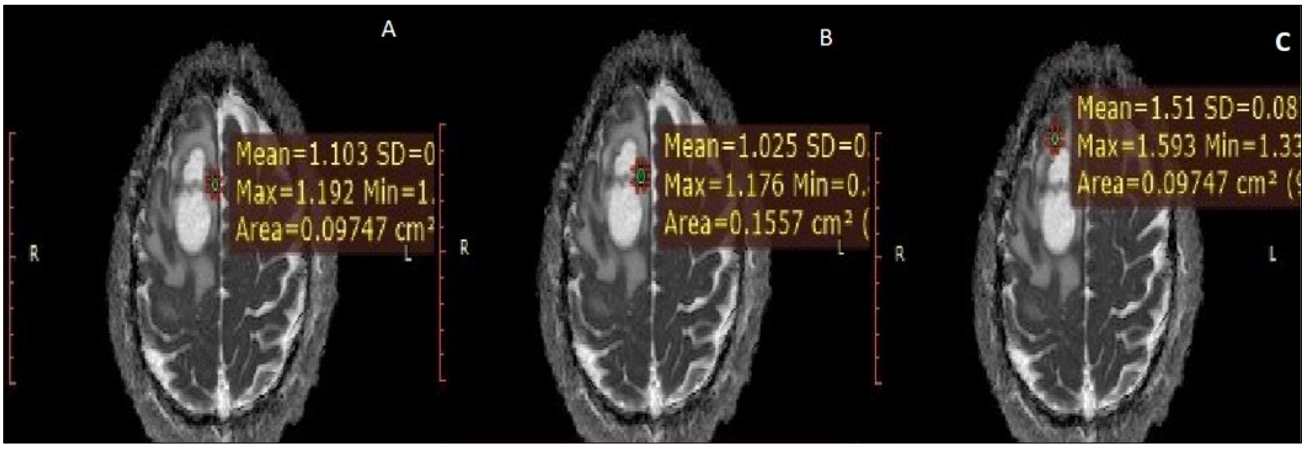
Post-contrast-enhanced axial, coronal, and sagittal T1-weighted images were obtained. Then, DWI was performing using multi-section single-shot spin echo planar imaging (EPI) sequence.

The diffusion gradients were applied sequentially in the three types of images obtained: orthogonal images, trace images, and ADC maps.

Calculation of ADC maps automatically was done by MRI software. Regions of interests (ROIs) was manually position, and all values were automatically calculated and express in $10^{-3}mm^2/s$. ADC measurements perform used a region of interest (ROI) method, with uniform ellipsoid ROI of 50–100mm^2 area. The ROI did not involve cystic and necrotic tumor areas. The ADC calculated using (RadiAnt DICOM Viewer) software.

Four ROIs placed in each corresponding tumor. The representative value used in the data and statistical analysis was mean ± S.D.

The first ROI was placed over a homogenous enhancing region in the central portion of the tumor. The second was placed on the edge of the tumor. The third was placed in the location of the edema if present. As for the fourth, it was placed in the area free of tumor to measure normal tissues. Four ROIs were measured (**fig 1,2**), and their average was calculated. The DWI + ADC value was interpreted by senior radiologist.



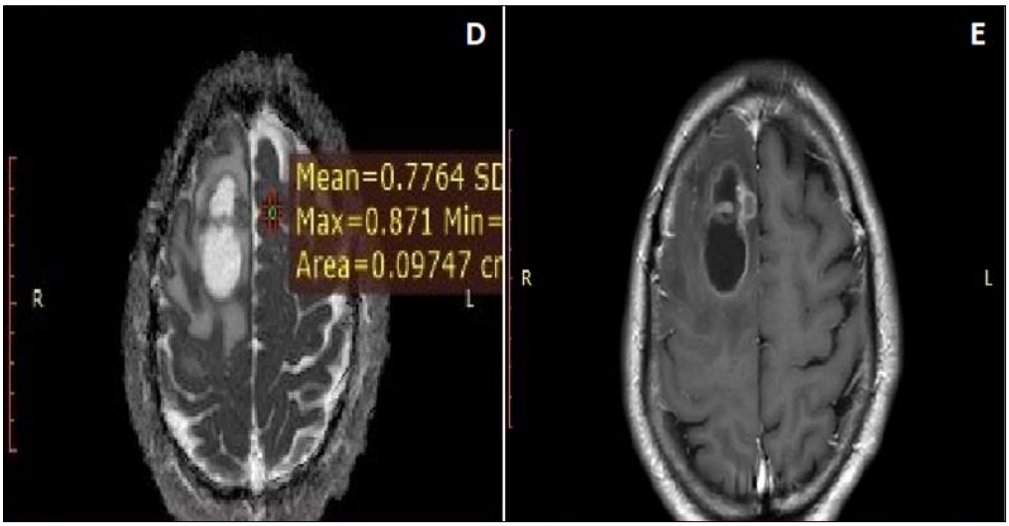


Figure 1: Astrocytoma in 45 years old male

Figure 1, show Astrocytoma in 45 years old male presented with headache and dysphasia MRI shows right frontal intra-axial cystic lesion with mural nodule measuring 4.5×2.7cm with nodule measuring 1.3×1cm. the lesion surrounded by perifocal edema with effacement of cortical sulci. **A:** ADC map shows ROI on border of mural nodule area p value is 1.103 × 10^{-3} mm^2/s. **B:** ADC map shows ROI on center of mural nodule p value is 1.025× 10^{-3} mm^2/s. **C:** ADC map in edema around the lesion p value is 1.51× 10^{-3} mm^2/s. **D:** ADC map shows ROI in same side normal area p value is .7764× 10^{-3} mm^2/s. **E:** Post-contrast T1WI axial image showed marginal enhancement with enhancement of the nodule.

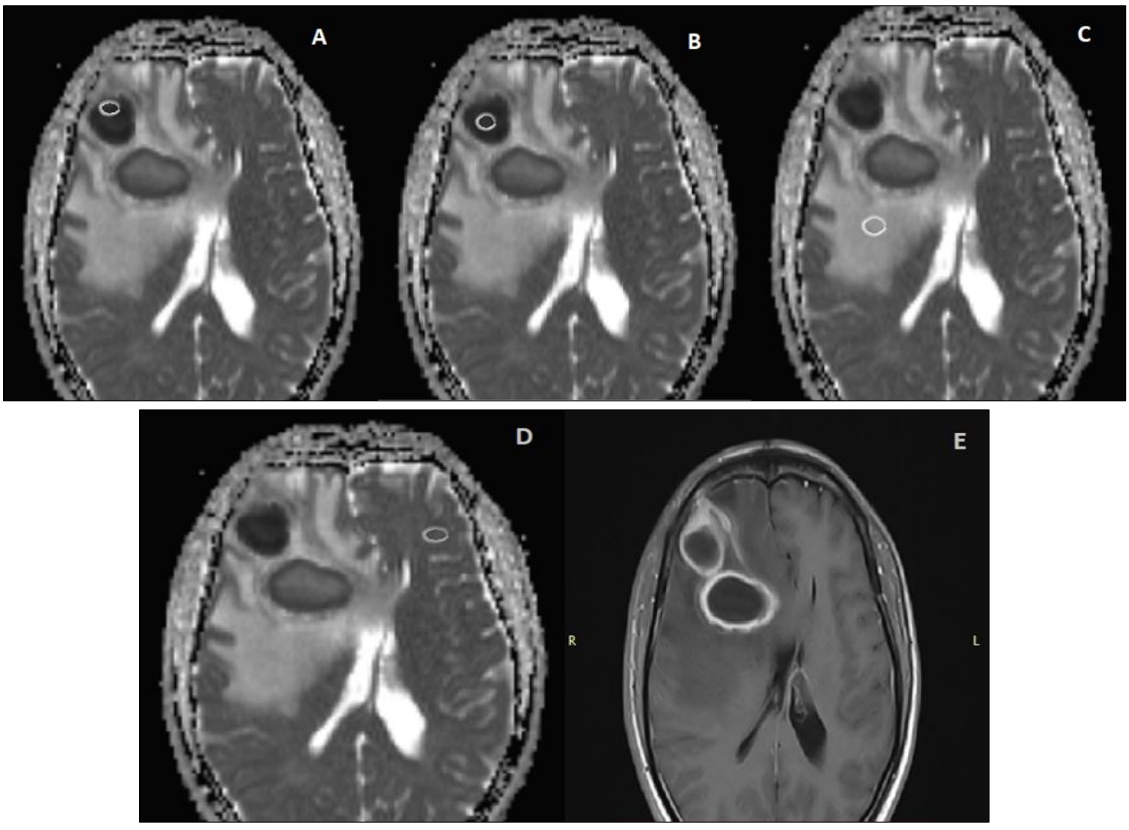


Figure 2: The two space abscesses in 34 years old female

Figure 2, show presented with repeated headache and vertigo MRI show right frontal subcortical and deep white matter rounded and oval space occupying lesions surrounded by marked vasogenic edema and causing mass effect A**:** ADC map ROI in border area of lesion P value is .425 × 10^{-3} mm^2/s. **B:** ADC map ROI in center area of lesion P value is .436 × 10^{-3} mm^2/s. **C:** ADC maps show ROI in edema P value is 1. 478 × 10^{-3}

mm^2/s. **D:** ADC map shows ROI in same side normal area p value is .746 $\times 10^{-3}$ mm^2/s **E:** Post-contrast T1WI axial image showing marginal/ring enhancement.

Method of Data Collection

The data was collected by used data collecting sheet including the following variable: The variables of the study were divided into four parts; the first part was related to demographic variable age, gender. The second part was related to MRI appearance (T1, T2. T1 with contrast, DWI and ADC). The third part was related to tumors characterization such as border, homogeneity, site and associated with tumors. The fourth part is final MRI diagnosis, type of restriction and ADC values.

Data Analysis

Data analysis was performed using SPSS (Statistical Package for the Social Sciences). The variables were expressed as mean values of ADC ± standard deviation (SD). Group differences were assessed using univariate ANOVA. A p value of ≤ 0.05 was considered statistically significant, and a p value of ≤ 0.001 was considered highly significant, while a p value of > 0.05 was considered non-significant.

Ethical Consideration

Identifying information was not made available to or accessed by anyone but the research team. All data sheets were protected by passwords and strictly shared with research team only. This study was approved by the ethical committee of Karary University and the need for informed consent was waived.

RESULTS

After retrospectively reviewed 100 cases with brain lesions. The mean age of the was 43.2±19.293 years, with a predominance of males (53 [53%]) over females (47 [47%]).

The border of lesions is regular in the majority of cases (58 [58%]), as for irregular border it was (42[42%]) from cases. As for homogeneity, it was homogeneous in 44(44%), vs heterogeneous in 56(56%).

Most of brain lesions come with vasogenic edema 52(52%) in cases and without edema in 47(47%). the vast majority of cases had mass restriction and partial restriction in 66 (66%) in both cases, no restriction in 23(23%), center restriction in 7(7%) and peripheral restriction in 4(4%) (table 1).

Table 1: Demographic and Mass Characteristics of Cases with Brain Tumor

Variables	**N (%)**
Age (mean ±SD)	43.2±19.293
Gender	
Male	53(53%)
Female	47(47%)
Mass characterization Border	
Irregular	42(42%)
Regular	58(58%)
Mass characterization Homogeneity	
Heterogeneous	56(56%)
Homogenous	44(44%)
Mass characterization Type of edema	
Cytotoxic	1(1%)
Vasogenic	52(52%)
Nil	47(47%)
Mass characterization Type of restriction	
Partial	33(33%)
All mass	33(33%)
No	23(23%)
Central	4(4%)
Peripheral	7(7%)

Compared with lesions signal intensity, the T2-weighted signal analysis showed high signal intensity in approximately 76% of cases and T1-weighted signal showed low signal intensity in 73%, most of lesions show enhancement on T1-weighted post-contrast 49% in cases. The diffusion-weighted signal analysis showed low signal in 52% and high signal in 48%, Reformatted ADC signal analysis showed low signal in 51% and high signal in 49% of cases.

Regarding the site of lesions, most tumors sit in the brain in the frontal lobe at 29% and are rarely found in brain stems at 3%.

There was a statistically significant difference between the border of tumor and homogeneity (p, value <.001), most of the regular tumor's borders are homogenous and also, between the border of tumor and types of edema (p, value 0.02), most regular and irregular border tumors come with vasogenic edema. There was

significance between border of tumor and T2 WI (p, value 0.03), most of the regular and irregular appearances are hyper-intense. There is no significant between border and Type of restriction (p, value 0.845), also between border and diffusion-weighted signal (p, value 0.20) show table 2.

Table 2: Association between Border and Other Mass Characterization and MRI Appearance Variables

Variables	Border		*P*. value
	Irregular N (%)	Regular N (%)	
Homogeneity			
Heterogeneous	39(92.9)	17(29.3)	<0.001*
Homogenous	3(6.1)	41(70.7)	
Type of edema			
Cytotoxic	0	1(1.7)	0.022*
Vasogenic	26(61.9)	49(74.3)	
Nil	16(38.1)	8(13.8)	
Type of restriction			
Partial	15(35.7)	18(31)	0.845
No	15(35.7)	18(31)	
All mass	9(21.4)	14(24.1)	
Central	1(2.4)	3(5.2)	
Peripheral	2(4.8)	5(8.6)	
MRI Appearance DWI			
Hyper	18(42.9)	31(53.4)	0.200
Hypo	24(57.1)	27(46.6)	
MRI Appearance T2			
Hyper	38(90.5)	38(65.5)	0.034*
Hypo	2(4.8)	11(19.0)	
ISO	2(4.8)	7(12.1)	
Mix	0	2(3.4)	

***Significant P-Value less than 0.05**

There are significant differences between DWI and type of restrictions (p, value 0.001), most hypo-intense tumors come with no restrictions and most hyper-intense tumors come with all mass restrictions. Also, there is no statistical relationship between the DWI image and other mass characteristics such as tumor border, type of edema, and tumor homogeneity show table 3.

Table 3: Chi-square Test for Association between MRI Appearance and other Mass Characterization Variables

Variables	MRI Appearance DWI		*P*. value
	Hyper N (%)	Hypo N (%)	
Homogeneity			
Heterogeneous	23(46.9)	33(64.7)	0.074
Homogenous	26(53.1)	18(35.3)	
Type of edema			
Cytotoxic	0	1(2)	0.069
Perifocal	19(38.8)	9(17.6)	
Vasogenic	12(23.5)	12(23.5)	
Nil	18(36.7)	29(56.9)	
Type of restriction			
Partial	17(34.7)	16(31.4)	<0.001*
no	4(8.2)	29(56.9)	
All mass	19(38.8)	4(7.8)	
Central	4(8.2)	0	
Peripheral	5(10.2)	2(3.9)	
Border			
Irregular	18(36.7	24(47.1)	0.200
Regular	31(63.3)	27(52.9)	

***Significant P-Value less than 0.05**

Table 4: Chi-square test for association between type of restriction and mass characterization variables

Variables	Type of restriction					*P.* value
	Partial n (%)	No n (%)	All mass n (%)	Central n (%)	Peripheral n (%)	
MRI Appearance DWI						
Hyper	17(51.5)	4(12.1)	19(82.6)	4(100)	5(71.4)	<0.001*
Hypo	16(48.5)	29(87.9)	4(17.4)	0	2(28.6)	
MRI Appearance ADC						
Hyper	14(42.4)	29(87.9)	4(17.4)	0	2(28.6)	<0.001*
Hypo	19(57.6)	4(12.1)	19(82.6)	4(100)	5(71.4)	
MRI Appearance T1						
Hyper	1(3)	5(15.2)	0	0	0	0.163
Hypo	26(78.8)	24(72.7)	16(69.6)	2(50)	5(71.4)	
ISO	6(18.2)	4(12.1)	7(30.4)	2(50)	2(28.6)	
MRI Appearance T2						
Hyper	27(81.8)	26(78.8)	17(73.9)	3(75)	3(42.9)	0.323
Hypo	4(12.1)	4(12.1)	2(8.7)	1(25)	2(28.6)	
ISO	1(3.0)	3(9.1)	4(17.4)	0	1(14.3)	
Mix	1(3.0)	0	0	0	1(14.3)	

***Significant P-Value less than 0.05**

There are significant differences between type of restrictions and DWI and ADC appearance (p, value < .001).

In DWI most partial restrictions appear as hyper, all mass restrictions appear as hyper, no restriction appear as hypo, central restrictions appear as hyper and peripheral restrictions appear as hyper.

In ADC most partial restrictions appear as hypo, all mass restrictions appear as hypo, no restriction appear as hyper, central restrictions appear as hypo and peripheral restrictions appear as hypo.

There are significant between final MRI report and center ADC (p, value < 0.001). Each type of tumor found in the analysis has a different ADC value in center of tumors and border of tumors (p, value 0.001), Whole-lesion ADC values ranged 1.195±0.371× 10^{-3} mm2/s for SOL in center and 1.073±0.440 × 10^{-3} for border, 1.417±0.474× 10^{-3} mm2/s for glioma center and 1.191±0.205× 10-3 for border, 1.042±0.231× 10-3 mm2/s for meningioma center and 0.987±0.213× 10-3 for border….etc. show table 5.

According to ANOVA test there are significant differences between groups in ADC center (p, value 0.000) and ADC (p, value 0.001) border group that means b value is different in each tumor in this groups show table 6.

Table 5: Association between Different ADC and MRI Final Report

ANOVA Test						
Mean ADC		**Sum of Squares**	**df**	**Mean Square**	**F**	**P-Value**
Center	Between Groups	8.066	10	0.807	7.660	0.000*
	Within Groups	9.372	89	0.105		
	Total	**17.438**	**99**			
Border	Between Groups	2.507	10	0.251	3.552	0.001*
	Within Groups	6.281	89	0.071		
	Total	**8.788**	**99**			

***Significant P-Value less than 0.05**

Table 6: Association between Final MRI Report and ADC in Center & Border

MRI Final Report	N	ADC			
		Center		Border	
		Mean ±SD	P. value	Mean ±SD	P. value
SOL	24	1.195±0.371	<0.001*	1.073±0.440	0.001*
schwannoma	3	1.346±0.042		1.318±0.170	
Metastasis	15	1.174±0102		0.862±0.102	
Meningioma	12	1.042±0.231		0.987±0.213	
Hemangioma	7	1.327±0.180		1.140±0.099	
Glioma	23	1.417±0.474		1.191±0.205	

glioblastoma	7	1.229±0.210		1.218±0.132	
epidermoid cyst	1	1.261±0.00		1.354±0.00	
cyst	2	2.615±0.007		1.637±0.007	
Abscess	5	0.541±0.117		1.113±0.072	
Macroadenoma	1	0.565±0.00		0.462±0.00	
Total	100	1.231±0419		1.09±0.298	

***Significant P-Value less than 0.05**

DISCUSSION

The main role of conventional MRI in brain tumors is to distinguish its location, extent, morphology, and relation to important structures, but alone it is deficient in diagnostic examination. Thus, there is a need for additional imaging modalities such as DWI which may aid in diagnosis and differentiation of brain tumors [6].

DWI can give important information about each tumor cellularity and water motion as well as the water content of their related matrix [7]. Also, DWI can assess diffusion of water particles within intra-, extra-, and transcellular spaces by the aid of ADC measurement. In addition to the role of DWI in differentiating most posterior fossa brain tumors, it also participates in preoperative management and in postoperative follow-up for detection of any tumor residual [8].

This study aimed to evaluate patient demographic data and correlate between restriction in diffusion weighted image DWI and final diagnosis and correlate the signal in diffusion weighted image (DWI) and final diagnosis, to evaluate the associated mass and homogeneity as well to evaluate the mass site and to measure the signal intensity of apparent diffusion coefficient (ADC).

According to our study results, there is significance between the border of tumor and homogeneity (p, value <.001), most of the regular tumor's borders are homogenous this suggests that it is benign. And most irregular tumors are heterogenous this suggests that it is malignant.

Also, the significance between the border of tumor and types of edemas (P- Value 0.02), most regular and irregular border tumors come with vasogenic edema. This agree with Mai-Lan Ho *et al*., that said: Both benign and malignant neoplasms are associated with vasogenic edema, which results from tumor angiogenesis with disruption of the blood-brain barrier [9].

The significance between border of tumor and T2 WI (p, value 0.03), most of the regular and irregular appearances are hyper-intense due to the lesion contain of water. This is agreed with the findings of Alison S. Smith *et al*., who reported on T2-weighted images that the increased signal of metastatic lesions and primary brain tumors is likely due to increased free water in these lesions, which is associated with varying degrees of blood-brain barrier breakdown [10].

According to DWI appearance there are significant differences between DWI and type of restrictions (p, value 0.001), most hypo-intense tumors come with no restrictions and most hyper-intense tumors come with all mass restrictions. This means that most tumors have high density because they contain lipids in tissue and this lipid hinders the movement of water molecules and thus appears with restriction. This is consistent with the view of Dow-Mu Koh and David J. Collins who said: The motion of water molecules is more restricted in tissues with a high cellular density associated with numerous intact cell membranes (e.g., tumor tissue) [11].

According to lesion restrictions there are significant differences between type of restrictions and DWI and ADC appearance (p, value < .001).

In DWI most partial restrictions appear as hyper, all mass restrictions appear as hyper, no restriction appear as hypo, central restrictions appear as hyper and peripheral restrictions appear as hyper.

In ADC most partial restrictions appear as hypo, all mass restrictions appear as hypo, no restriction appear as hyper, central restrictions appear as hypo and peripheral restrictions appear as hypo.

That mean brain tumors had different appearance in DWI and ADC because the different in type of tumors grading, this agrees with E. Karaarslan and A. Arslan b, that said: Brain neoplasms show variable signal on the DW image and the ADC map. Tumors with higher cellularity or higher grade show increased signal on the DW image and a marked reduction in ADC values. In addition to the hypercellularity which causes increased intracellular water, the low ADC values are also related to the decreased extracellular fluid [12].

As for the ADC value our study found that statistically significant and very important with final MRI diagnosis (p, value < 0.001) show (table 5) if we look we notice a clear difference between ADC values and type of brain lesion this will help in diagnosing and distinguishing between lesions, that agree with Abdulaziz Mohammad Al-Sharydah *et al.*, that found that ADC may be useful in the differential diagnosis of Pediatric brain tumor because it allowed the discrimination between five types of Pediatric brain tumor [13].

Abscess ADC center is (0.541±0.117) and Macroadenoma is (0.565±0.00) there are very close, but ADC border is different in abscess is (1.113±0.072) and macroadenoma is (0.462±0.00) that because abscess is surrounded by thick capsule had high signal ADC. So, the border values can help in discrimination.

According to ANOVA test there are significant differences between groups in ADC center (P-Value 0.000) and ADC (p, value 0.001) border group that means b value is different in each tumor in this groups, which can be used to help in diagnose brain tumors and other diseases; that is agree with the opinion of W. F. Mustafa *et al*., who conclude that DWI can give important information about each tumor cellularity and water motion as well as the water content of their related matrix. Also, it can classify brain tumors into low, moderate, and high cellularity, so it is helpful to differentiate, characterize, and distinguish between brain tumors [14].

Our study had some limitations such as the diagnosis must be confirmed by histopathological analysis and not depend on radiologist's opinions only to ensure the ADC value for each lesion.

CONCLUSION

DWI is perfect additional imaging technique which is a fast, simple, and non-invasive imaging modality, and no contrast injection is needed. Using both conventional MRI and add to DWI and ADC may lead to good diagnosis of brain lesions.

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