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Research paper

Predictive value of early MRI findings on neurocognitive and psychiatric outcomes in patients with severe traumatic brain injury

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ABSTRACT

Background: Traumatic brain injury (TBI) is the major public health problem worldwide, particularly in the Middle East. Diffuse axonal injury (DAI) is commonly found in TBI. Although DAI can lead to physical and psychosocial disabilities, its prognostic value is still a matter of debate. Magnetic Resonance (MR) is more sensitive for detecting DAI lesions.

Objective: To identify the radiological and clinical factors associated with the functional capacity one year after the traumatic brain injury.

Methods: The study included 251 patients with severe head trauma for whom Brain MRI was done within one month after injury. Demographic, clinical, and radiological data were collected during hospitalization. Neurocognitive and psychiatric evaluation were done one year thereafter.

Results: DAI was more frequent in our patients. Psychiatric disorders, cognitive impairment, and poor functional outcome were more common in patients with DAI especially those with cerebral hemisphere and brain stem lesion, and mixed lesions. Duration of post traumatic amnesia (DPTA), lost consciousness and hospital stay (DHS) as well as the volume of diffuse axonal injury (DAI) were associated with poor neurocognitive outcome. DPTA, and DAIV may be considered independent factors that could predict the neurocognitive outcome.

Conclusion: MRI following traumatic brain injury yields important prognostic information, with several lesion patterns significantly associated with poor long-term neurocognitive and psychiatric outcomes.

1. Introduction

Traumatic brain injury (TBI) is a major public health problem because of its high mortality and long-term disability worldwide. TBI results in severe disabilities in 150–200 per million people annually (Kraus and McArthur, 1996).

To overcome this growing public health problem, it is mandatory to develop intervention strategies to decrease the post injury consequences. The first step in such strategy would begin with identifying risk factors of poor outcome. According to the severity of head trauma and the level of consciousness, patients can be grouped into mild, moderate and severe TBI (Kraus and McArthur, 1996; von Wild, 2008; Coordinators MCTN 2003; Jiang et al., 2002). Diffuse axonal injury (DAI) is commonly found in TBI (Ozsarlak et al., 1998). There are some disagreements about the prognostic value of DAI (Bhatoe, 1999; van der Naalt et al., 1999; Hoelper et al., 2000; Paterakis et al., 2000; Aguas et al., 2005). Skandsen et al. (2010) did not show any difference in good outcome between patients with or without DAI. Cicuendez et al. (2017) emphasized on the site of the lesion, with worse outcome associated with corpus callosum lesion whether hemorrhagic or nonhemorrhagic, on the other hand, bilateral (Skandsen et al., 2011) hemorrhagic brain stem lesion was found to carry the worst functional outcome (Hilario et al., 2012). Other study reported that, callosal, and brain stem injuries were not necessarily associated with poor outcome (Paterakis et al., 2000). DAI can lead to physical and psychosocial disabilities. Physical impairments are easily detectable and frequently lead to mild disabilities after TBI, while the more common disabling problems of cognitive and behavioral impairments are often neglected or misdiagnosed by medical professionals. Regardless of the age, social level and educational status of the patients, it is the changes in cognition and behavior that represent the greatest burden to the patients and their families after a TBI (Fleminger and Ponsford, 2005; Ponsford

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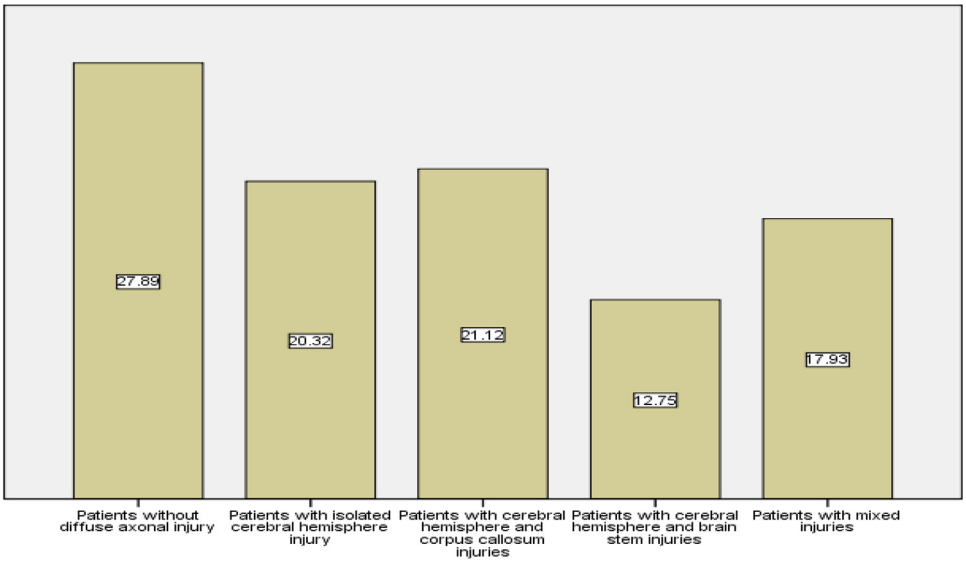

Fig. 1. Distribution of MRI findings in the studied groups (number = 251).

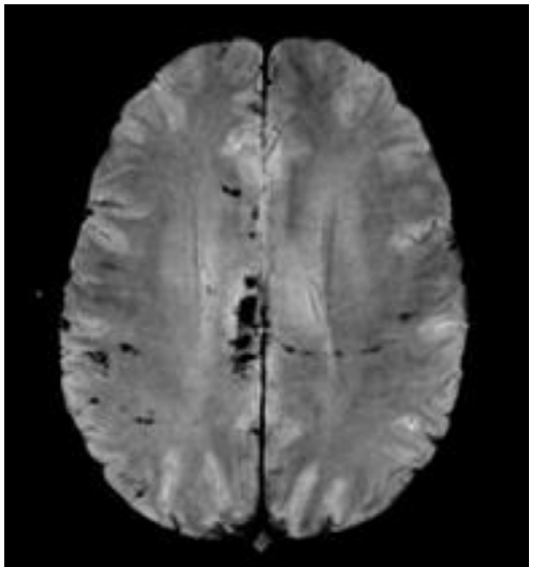

Fig. 2. Axial susceptibility-weighted image shows multiple focal areas of susceptibility artifact in the corpus callosum and at the corticomedullary junction which is characteristic of diffuse hemorrhagic axonal injury.

et al., 2003). According to the International Mission for Prognosis and Clinical Trial Study, accurate neuroradiologic diagnostic assessment represents a potential prognostic value in TBI (Hilario et al., 2012; Murray et al., 2007). Although Computerized Tomography (CT) is the imaging technique of choice in TBI (Marshall et al., 1992), MRI is more sensitive for detecting DAI lesions (Hilario et al., 2012; Lagares et al., 2006). Few studies on TBI patients have focused on the radiological and clinical factors associated with the neurocognitive and psychiatric outcome. Thus, the aim of this study was to describe the neurocognitive and psychiatric outcomes of patients with TBI and to identify the radiological and clinical factors associated with the functional capacity 12 months after the injury.

2. Subjects and methods

The present study is a prospective cross-sectional research. It was conducted in accordance with the local medical ethical guidelines. The study included 251 patients with severe head trauma for whom conventional MRI was done within the first month of the head trauma. Data were collected from the registered cohort of patients with head trauma admitted to three regional hospital in Saudi Arabia during the period from 1 January 2014 to 1 January 2018. Severe head trauma was defined as a patient with Glasgow Coma Scale (GCS) of 8 or less after non-surgical resuscitation at admission (Fleminger, 2008),or GCS deterioration to 8 or less within 48 h from admission (Cicuendez et al., 2017). The inclusion criteria were: (1) patients aged $\geq$18 year but $\leq$60 year; (2) patients with severe head trauma; (3) performance of an MRI in the first month after head injury. Exclusion criteria included: (1) patients with history of psychiatric disorders, drugs or substances abuse, neurocognitive deficits, or prior head trauma; (2) signs of brain death at admission; (3) CT or MRI evidences of gross intracranial lesion; (4) neurosurgical intervention.

One thousand eighty-eight patients were admitted to the Accident department of the selected hospitals with traumatic brain injury. Of them, 376 patients were diagnosed as severe traumatic brain injury. During the study, 125 patients, were dropped out (death, not fulfilling the inclusion criteria, or patients refused to participate in the research). The remaining 251 patients completed the study.

Data were collected by the medical personnel. The collected data included demographic characteristics, GCS, duration of unconsciousness, duration of post traumatic amnesia, results of neuroimaging (CT brain at onset and MRI brain within one month), mechanism of injury, presence of severe extracranial injury, pupil examination, and length of hospitalization.

Patients were contacted one year after the head trauma. Psychiatric status was evaluated by Schedules for Clinical Assessments of Neuropsychiatry (SCAN), cognitive functions was assessed by Mini Mental State Examination (MMSE). Neurological assessment was done according to Extended Glasgow Outcome Score (GOSE).

MRI was performed on a 1.5-T scanner (GE Optima 450w). The imaging protocol consisted of a 3-plane localizer sequence, sagittal T1 weighted, Inversion Recovery technique (sagittal, axial and coronal CUBE Flair), axial T2 FSE weighted, axial Diffusion Weighted Image (DWI), axial Susceptibility Weighted Image (SWI), coronal T2 FSE with fat saturation (FS).

The authors identified Diffuse axonal injuries based on visual inspection according to their location: subcortical white matter, basal ganglia, corpus callosum, and brain stem. Brain lesions other than DAI were excluded from the study. The site, number and volume of the lesions were calculated.

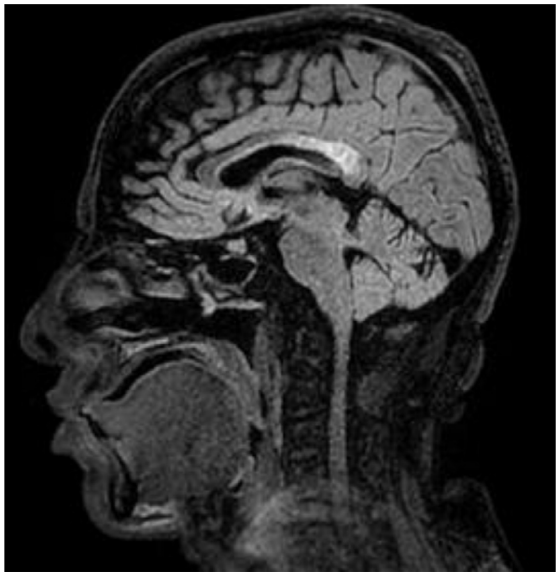

Fig. 3. Sagittal FLAIR weighted image demonstrates hyperintense signal in the posterior body and splenium of the corpus callosum.

3. Statistical analysis

The data were analyzed using the Statistical Package for the Social Sciences (SPSS) 13.0. Descriptive statistics were calculated. We used independent samples *t*-test to compare age, loss of consciousness, post traumatic amnesia, hospital stay, mini mental state examination, and Glasgow outcome scale extended in patients with and without diffuse axonal injury. The statistical analysis was performed with nonparametric Chi-Square between gender, mechanism of head trauma, pupillary abnormality, Glasgow coma score and psychiatric manifestations in patients with and without diffuse axonal injury. Analysis of variance (ANOVA) was used to test the differences in clinical variables among subgroups. Pearson's correlation coefficient (r) was used to analyze the association between the different variables. Values of $p < 0.05$ were considered to be statistically significant. Multiple logistic regression was performed to identify predictive factors of different outcomes after TBI.

4. Results

The present study included 251 patients with severe traumatic brain injury (TBI) who fulfilled the inclusion criteria. According to MRI findings, 70 (27.9%) patients had no evidence of diffuse axonal injury (DAI) while 181 (72.1%) patients had MRI evidence of (DAI) Figs. 1–5. No significant differences were detected between the patient's groups regarding, gender, mechanism of head injury, pupillary abnormality, mean of age and duration of loss of consciousness (DLOC). The mean (± SD) DAIV was 10.9 (± 4.2) Tables 1 and 2. Patients with mixed lesions had significantly larger diffuse axonal injury volume than other subgroups of patients Table 4. Patients with DAI had significantly deeper impairment of conscious level than patients without DAI $p < 0.001$. The worst conscious level was observed in patients with isolated cerebral hemisphere, and cerebral hemisphere and corpus callosum lesions. Personality changes, aggression and major depressive disorder were significantly common among patients with (DAI). Personality changes was commonest among patients with isolated cerebral hemisphere lesions while, aggression was more frequent among patients with cerebral hemisphere and corpus callosum lesions. Major depressive disorder frequently reported in patients with cerebral hemisphere and corpus callosum lesions as well as patients with cerebral hemisphere and brain stem lesions Tables 1 and 3. The duration of hospital stay and the period of post traumatic amnesia were significantly longer in patients with (DAI) compared to patient without (DAI). In subgroup analysis, both patients with mixed lesion and cerebral hemisphere and brain stem lesions, had significantly longer duration of hospital stay and post traumatic amnesia compared to other subgroups. Patients with cerebral hemisphere and corpus callosum lesions had significantly shorter duration of lost consciousness than other subgroups. The worthiest cognitive and functional outcomes were noticed in patients with (DAI). Cognitive outcome was better in patients with isolated cerebral hemisphere lesion than patients with both cerebral hemisphere and corpus callosum lesions ($p < 0.001$), both groups had better cognitive outcome than other groups. Patients with mixed lesions had the worst functional outcome Tables 2 and 4. In Table 5, it is evident that diffuse axonal injury volume, long duration of post traumatic amnesia, lost consciousness and hospital stay were associated

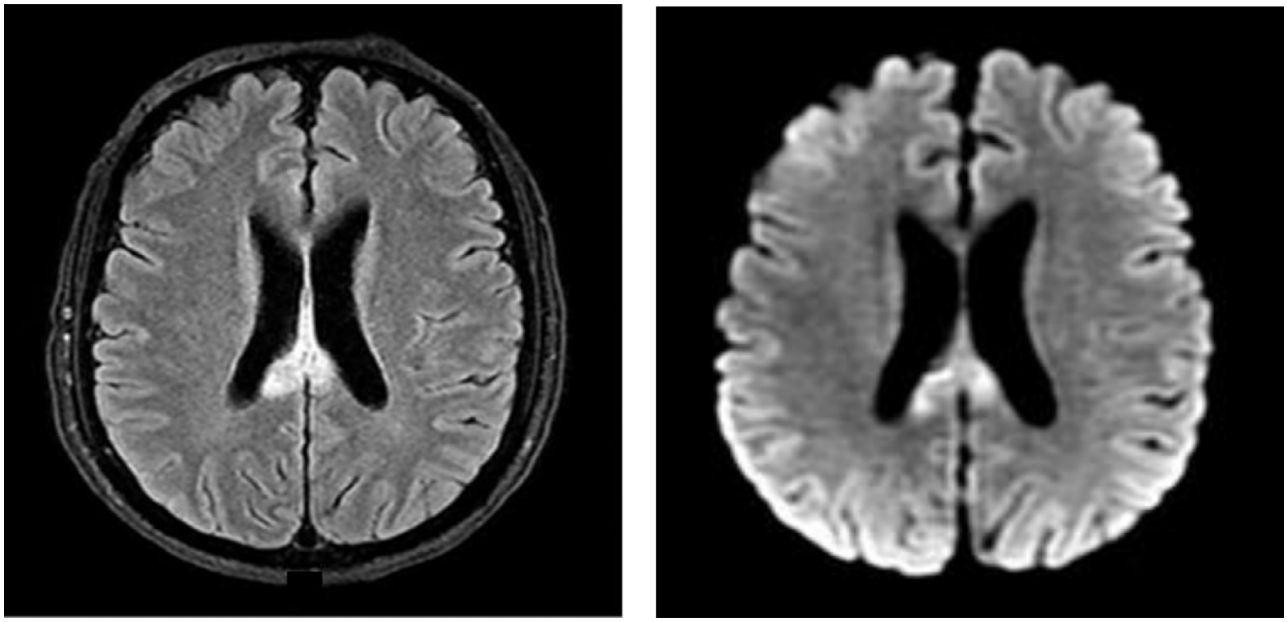

Fig. 4. Axial FLAIR image shows abnormal high signal intensity in the splenium of the corpus callosum (***left***) which exhibits restricted water diffusion on the DWI (***right***).

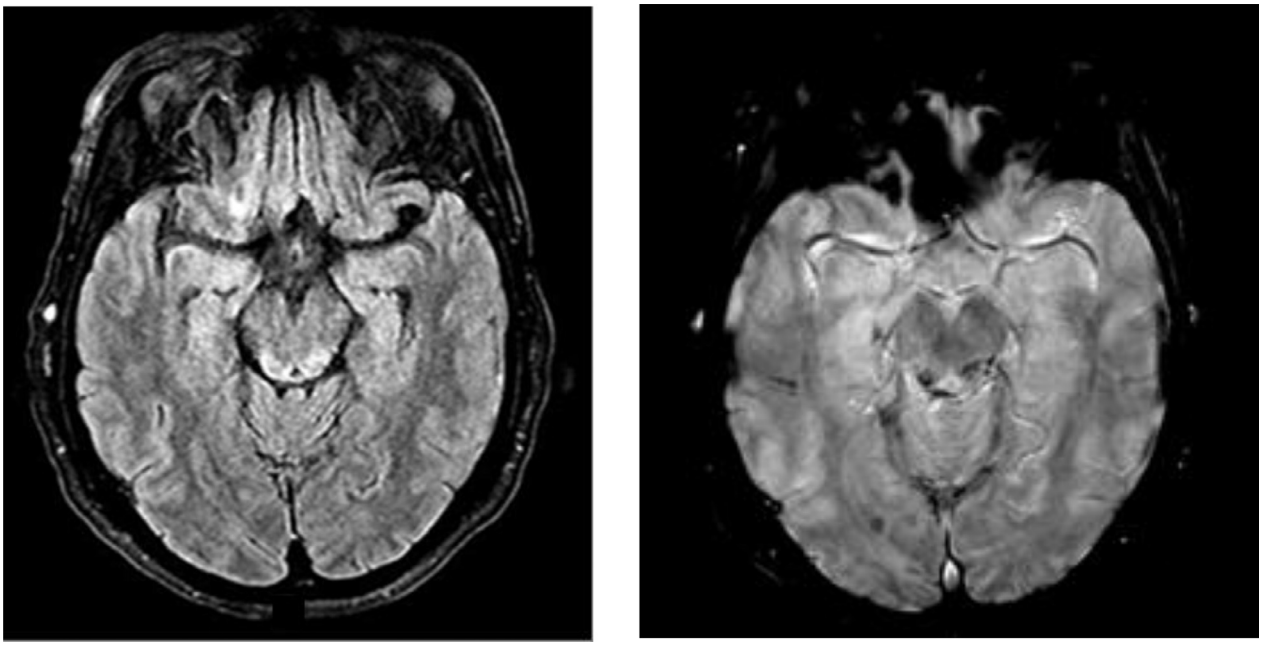

Fig. 5. Axial FLAIR image reveals hyperintense signal in the dorsal aspect of the midbrain (***left***) with corresponding hemorrhagic component on the SWI (***right***).

Table 1
Comparison between gender, mechanism of head trauma, pupillary abnormality, Glasgow coma score and psychiatric manifestations in patients with and without diffuse axonal injury.

Variable	Patients without diffuse axonal injury $N = 70$		Patients with diffuse axonal injury $N = 181$		Significance	
	N	%	*N*	%	X^2	*p*
Gender					NS	
Male	52	74.3	141	77.9		
Female	18	25.7	40	21.1		
Mechanism of head injury					NS	
Traffic	52	74.3	134	74.1		
Fall	10	14.3	33	18.2		
Other	8	11.4	14	7.7		
Pupillary abnormality	8	11.4	23	12.7	NS	
GCS						
8	35	50	15	8.3	8.00	<0.005
7	23	32.9	15	8.3	NS	
6	5	7.1	13	7.2	NS	
5	3	4.2	16	8.8	8.89	<0.003
4	2	2.9	29	16.1	23.51	<0.001
3	2	2.9	93	51.3	87.17	<0.001
Psychiatric manifestations						
Personality changes	6	8.6	50	27.6	34.57	<0.001
Aggression	4	5.7	36	19.8	25.60	<0.001
MDD	5	7.1	40	22.1	27.22	<0.001
Psychotic disorders	2	2.9	6	3.3	NS	
Anxiety disorders	9	12.8	9	4.9	NS	
Total	26	37.1	141	77.9	37.66	<0.001

GCS = Glasgow coma score, MDD = major depressive disorder, $p < 0.05$, NS = none significant.

with worthiest neurocognitive outcome. The linear regression analysis proved that duration of post traumatic amnesia, was the most important predicator for cognitive outcome while diffuse axonal injury volume, duration of post traumatic amnesia, and hospital stay were the independent factors that predict the neurological outcome Tables 6 and 7.

Table 2
The difference of mean age, loss of consciousness, post traumatic amnesia, hospital stay, mini mental state examination, and Glasgow outcome scale extended in patients with and without diffuse axonal injury.

Variable	Patients without diffuse axonal injury Mean ± SD	Patients with diffuse axonal injury Mean ± SD	Significance	
			t	*p*
Age	39.4 ± 9.2	40.3 ± 8.4	NS	
DLOC in hours	44.03 ± 14.6	47.71 ± 21.7	NS	
DPTA in weeks	2.69 ± 0.9	6.23 ± 2.6	16.07	<0.001
DHS in days	15.65 ± 1.9	16.50 ± 4.3	2.13	0.034
MMSE	21.81 ± 1.9	10.62 ± 6.1	21.88	<0.001
GOSE	6.80 ± 0.7	4.80 ± 1.4	14.41	< 0.001
DAIV cm^3		10.9 ± 4.2		

DLOC = duration of loss of consciousness, DPTA = duration of post traumatic amnesia, DHS = duration of hospital stays, MMSE = mini mental state examination, GOSE = Glasgow outcome scale extended, DAIV = diffuse axonal injury volume, $p < 0.05$, NS = none significant.

5. Discussion

Impairment of consciousness is a serious acute manifestation of severe TBI while physical, neurocognitive and psychiatric disabilities are considered subacute and chronic complications. The vast majority of recovery after TBI occur in the two years after brain injury; after this the brain injured patient faces an uncertain future. MRI imaging in the early subacute stage can accurately detect the presence of DAI and precisely localize its location. A neurocognitive and psychiatric assessment during recovery will facilitate awareness of the cognitive and behavioral consequences of injury. Early detection of them will help professionals to start strategic therapeutic plans to avoid or at least ameliorate the effects of these potentially serious complications.

Most of our patients (181 patients, 72.1%) had DAI. In accordance with our results, previous studies reported that, the DAI is one of the most common types of primary lesion in patients with severe TBI (Ozsarlak et al., 1998; Gentry, 1994; Giugni et al., 2005). In the present study, patents with DAI, especially those with isolated cerebral hemisphere lesion, and cerebral hemisphere and corpus callosum lesions,

Table 3
shows comparison between Glasgow coma score and psychiatric manifestations in subgroup of patients with diffuse axonal injury according to the site of the lesion.

Variables	Isolated cerebral hemisphere lesion		Cerebral hemisphere and corpus callosum lesions		Cerebral hemisphere and brain stem lesions		Mixed lesions		Significance	
	N = 51		*N* = 53		*N* = 32		*N* = 45			
	N	%	*N*	%	*N*	%	*N*	%	X^2	*p*
GCS										
8	0	0	0	0	0	0	15	33.3		
7	0	0	0	0	0	0	15	33.3		
6	0	0	0	0	0	0	13	28.9		
5	0	0	0	0	14	43.8	2	4.4		
4	0	0	11	20.8	18	56.2	0	0	NS*	
3	51	100	42	79.2	0	0	0	0	NS**	
Psychiatric manifestations										
Personality changes	50	98	0	0	0	0	0	0		
Aggression	1	1.9	35	66	0	0	0	0		
MDD	0	0	18	34	22	68.7	0	0	NS#	
Psychotic disorders	0	0	0	0	6	18.8	0	0		
Anxiety disorders	0	0	0	0	4	12.5	5	11.1	NS##	

GCS = Glasgow coma score, MDD = major depressive disorder, $p < 0.05$, NS = none significant.
* Between cerebral hemisphere and corpus callosum lesions, and cerebral hemisphere and brain stem lesions.
** Between isolated cerebral hemisphere lesion, and cerebral hemisphere and corpus callosum lesions.
# Between cerebral hemisphere and corpus callosum lesions, and cerebral hemisphere and brain stem lesions.
Between cerebral hemisphere and brain stem lesions, and mixed lesions.

Table 4
The difference of loss of consciousness, post traumatic amnesia, hospital stay, mini mental state examination, and Glasgow outcome scale extended in subgroup of patients with diffuse axonal injury according to the site of the lesion.

Variables	Isolated cerebral hemisphere lesion Mean ± SD	Cerebral hemisphere and corpus callosum lesions Mean ± SD	Cerebral hemisphere and brain stem lesions Mean ± SD	Mixed lesions Mean ± SD
DLOC in hours	50.3 ± 26.1	33.6 ± 12.8*	57.3 ± 19.2	54.5 ± 18.5
DPTA in weeks	3.4 ± 1.2**	6.3 ± 2*	7.9 ± 2.1	8.2 ± 1.7
DHS in days	13.9 ± 3***	15.6 ± 4.3#	17.9 ± 3.8	19.4 ± 3.9
MMSE	19.8 ± 1.6**	8.2 ± 1.8*	5.9 ± 2.4	6.4 ± 2.2
GOSE	6.3 ± 0.5**	5.1 ± 0.7*	4.3 ± 0.7##	3.1 ± 0.8
DAIV cm^3	8.9 ± 2.8	9.1 ± 3.1	8.9 ± 2.2	16.7 ± 2^

DLOC = duration of loss of consciousness, DPTA = duration of post traumatic amnesia, DHS = duration of hospital stays, MMSE = mini mental state examination, GOSE = Glasgow outcome scale extended, DAIV = diffuse axonal injury volume, $p < 0.05$,
* Significant difference between cerebral hemisphere and corpus callosum lesions, and other subgroups.
** Significant difference between isolated cerebral hemisphere lesion, and other subgroups.
*** Significant difference between isolated cerebral hemisphere lesion, and cerebral hemisphere and brain stem lesions, and mixed lesions.
# Significant difference between cerebral hemisphere and corpus callosum lesions, and cerebral hemisphere and brain stem lesions, and mixed lesions.
Significant difference between cerebral hemisphere and brain stem lesions, and mixed lesions.
^ Significant difference between mixed lesion and other subgroups.

Table 5.
Correlations between duration of loss of consciousness, duration of post traumatic amnesia, duration of hospital stays, and mini mental state examination, Glasgow outcome scale extended.

Variable	MMSE		GOSE	
	r	*p*	*r*	*p*
DLOC	−0.484	< 0.001	−0.465	< 0.001
DPTA	−0.789	< 0.001	−0.723	< 0.001
DHS	−0.472	< 0.001	−0.509	< 0.001
DAIV in patients with DAI	−0.294	< 0.001	−0.656	< 0.001

DLOC = duration of loss of consciousness, DPTA = duration of post traumatic amnesia, DHS = duration of hospital stays, MMSE = mini mental state examination, GOSE = Glasgow outcome scale extended, DAI = diffuse axonal injury, DAIV = diffuse axonal injury volume, $p < 0.05$.

Table 6
The regression analysis for the GOSE score.

Dependent variable	Independent variable	*B*	Lower 95% C.I. for *B*	Higher 95% C.I. for *B*	*p*
GOSE	DLOC	−0.003	−0.010	0.003	0.356
	DPTA	−0.369	−0.420	−0.318	< 0.001
	DHS	−0.063	−0.100	−0.026	0.001
	DAIV cm^3	−0.550	−0.219	−0.144	< 0.001

GOSE = Glasgow outcome scale extended. DLOC = duration of loss of consciousness, DPTA = duration of post traumatic amnesia, DHS = duration of hospital stays, DAIV = diffuse axonal injury volume, $p < 0.05$.

had the worst conscious level at onset. This was in partial accordance with the result of Cicuendez et al. (2017) who reported a significant correlation between GCS and corpus callosum lesion and that patients with corpus callosum lesion had more conscious impairment than patients with other sites of lesion (Cicuendez et al., 2017). A significant number of our patients with DAI developed psychiatric disorders. It had been observed that, DAI usually occurs in the frontal and anterior temporal lobes (Dilley and Avent, 2011) that might disrupt neural circuits through alteration of the neurotransmitter system such as norepinephrine, serotonin, dopamine and acetylcholine (Tang et al., 1997; Busto et al., 1997; Reeves et al., 1997).This could be an

Table 7
The regression analysis for the MMSE score.

Dependent variable	Independent variable	*B*	Lower 95% C.I. for *B*	Higher 95% C.I. for *B*	*p*
MMSE	DLOC	−0.003	−0.031	0.025	0.831
	DPTA	−2.072	−2.294	−1.850	<0.001
	DHS	−0.044	−0.204	0.116	0.590
	DAIV cm^3	−0.043	−0.217	0.132	0.630

MMSE = mini mental state examination, DLOC = duration of loss of consciousness, DPTA = duration of post traumatic amnesia, DHS = duration of hospital stays, DAIV = diffuse axonal injury volume, $p < 0.05$.

explanation for the higher rate of psychiatric disorders among this group. The usually reported psychiatric disorder was personality changes (in the group of patients with DAI), and it was the commonest psychiatric manifestation in patient with isolated cerebral hemisphere lesion. Our finding was in agreement with the finding of Pelegrin-Valero and colleagues in 2001 when they evaluated 55 patients one year after severe traumatic brain injury, and they reported that, the criteria for personality changes due to head injury were fulfilled in 60% of the patients (Pelegrin-Valero et al., 2001). Personality changes, usually associated with frontal lobe lesion, and may occur due to disturbances of neural circuits, or due to indirect effects of the brain injury such as the individual's reactions and responses to impairments (Chaudhury et al., 2005). 40 patients (22.1%) among DAI group had major depressive disorder, and it was more frequent among patients with cerebral hemisphere and corpus callosum lesions, and patients with cerebral hemisphere and brain stem lesions. It is reported that, depression occurs more frequently with left dorsolateral frontal and left basal ganglia lesions, and is probably due to disruption of biogenic amine-containing neurons along its pathway, consequently, the deep seated lesion might have a role in the development of post-traumatic depressive disorders (Rapoport et al., 2003). Previous studies (Kim et al., 2007; Jorge et al., 2004) reported a variable prevalence rate for major depressive disorder from 15% to 60%. Fleminger (2010) reported aggression as a common behavior consequence of TBI (Fleminger, 2010). Less than quarter of our patients with DAI developed aggressive behavior, however, aggression was reported in more than 50% of patients with cerebral hemisphere and corpus callosum lesions and it was very infrequently reported in other subgroups. This partial discrepancy could be due to the poorly defined post traumatic aggression (Schwarzbold et al., 2008). As such, it is difficult to make comparisons between studies and therefore to determine its true epidemiology. At the same time, it could clarify the importance of corpus callosum involvement in the occurrence of aggressive behavior.

Cognitive impairment, at one year follow up, was more severe in patients with DAI. In subgroup analysis we noticed that, patients with cerebral hemisphere and brain stem lesion, and patients with mixed lesions had the worst cognitive impairment, while patients with isolated cerebral hemisphere lesion had the best outcome. In disagreement with our results, Wallesch et al. (2001), concluded that DAI mainly causes mild and transient neurocognitive deficit. This study included patients with mild traumatic brain injury; however, our study included patients with severe and very severe TBI. On the other hand, our finding was supported by the study of Scheid et al. (2006), who suggested that DAI led to chronic cognitive dysfunction in the majority of patients. Cognitive impairment may be a manifestation of underlying disruptions of important white matter pathways connecting the cortex and deep gray matter structures (Warner et al., 2010).

It is reported that, the location of white matter abnormality predicted cognitive function to some extent. Lesion of the fornices could affect associative learning and memory, whilst lesion of the frontal lobe connections could affect executive function. A complex relationships between white matter structure and cognition could be concluded (Kinnunen et al., 2010). Warner et al., 2010 demonstrated a spatial relationship between diffuse axonal injury and post-traumatic brain volumes. In addition, post-traumatic brain volumes were predictive of performance in neuropsychological domains conventionally associated with those subcortical and cortical regions (Warner et al., 2010).

Our results showed significant poor functional outcome according to GOSE in patients with DAI. Patients with cerebral hemisphere and brain stem lesion, and patients with mixed lesions had the worst functional outcome, and patients with isolated cerebral hemisphere lesion had the best one. There has been disagreement about the relationship between DAI and outcome; previous studies, concluded that the outcome is not related to the presence or the site of DAI (Bhatoe, 1999; Skandsen et al., 2010; Giugni et al., 2005; Weiss et al., 2007; Humble et al., 2018). Other studies suggested the frontal lobe, temporal lobe, basal ganglia, and corpus callosum as areas where lesions can predict patient's outcome (Cicuendez et al., 2017; Van Der Naalt et al., 1999; Hoelper et al., 2000). Some others emphasized on the relation between outcome and the site as well as the type of the lesion with poor outcome associated with bilateral and hemorrhagic lesions ((Paterakis et al., 2000; Cicuendez et al., 2017; Hilario et al., 2012; Firsching et al., 2001, 2002; Wedekind et al., 2002a; Mannion et al., 2007a). Moreover, patients with corpus callosum lesion had been observed to have poor outcome than patients with isolated cerebral hemisphere lesions (Cicuendez et al., 2017). Brain stem lesion had been reported to be a poor prognostic factor either directly due to its location ((Hilario et al., 2012; Wedekind et al., 2002)b; (Mannion et al., 2007)b), or indirectly by indicating the force needed for injury of the brainstem and the possibility of associated lesion in other brain areas (Hashimoto et al., 1993).

In the present study, neurocognitive outcome was significantly related to DLOC, DPTA, DHS, and DAIV. However, linear regression analysis indicated that, DPTA was the only independent factor for predicting the cognitive outcome, and DPTA, DHS, and DAIV were independent factors for functional outcome. In agreement with our results, previous studies concluded that DPTA is considered a strong predictor of long term functional outcome, return to employment, and cognitive impairment (Brown et al., 2005; Sherer et al., 2008; Walker et al., 2010). It was reported that, cognitive outcome depends on a number of factors, such as degree of diffuse axonal injury, duration of LOC and PTA, clinical evidence of brain stem dysfunction at the time of injury, and presence and size of focal hemispheric injury (Chaudhury et al., 2005). In addition, the total DAI volume (regardless of the site of the lesion) (Moen et al., 2012), and the volume of corpus callosum lesion (Cicuendez et al., 2017) were found to be significantly related to functional outcome. Our results were also consistent with the result of Ardelean et al. (2007) in that study they reported that, the greater the proportion of brain volume affected by DAI, the poorer their functioning at 6 months post-injury as measured by the GOSE (Ardelean et al., 2007).

6. Conclusion

Diffuse axonal injury is more common among patients with severe brain injury. Psychiatric manifestations are associated with the presence of DAI. Site of the lesion has an impact on the neurocognitive outcome. Duration of post traumatic amnesia, and DAIV are considered as independent predictors of neurocognitive impairments and poor functional outcomes.

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