Int J Clin Exp Med 2023;16(4):95-104
www.ijcem.com /ISSN:1940-5901/IJCEM0144276

Original Article

Outcome of traumatic diffuse axonal injury in correlation to Marshal, Rotterdam and Adams grading systems

Ali Al Bshabshe[1], Wesam F Mousa[2], Ghazi Alshumrani[3], Ghaida Alharthi[4], Khloud Alahmari[4], Hala Alghamdi[4], Raghad Mohammed[4], Lamees Binmohammed[4], Lama Binmohammed[4], Mohammed W Mousa[5], Hosam Haider Omar[6], Yahia I Assiri[3], Mubarak Ali Algahtany[7]

[1]Department of Medicine/Critical Care, College of Medicine, King Khalid University, P.O. Box 641, Abha 61421, Saudi Arabia; [2]Department of Anesthesia and Intensive Care, College of Medicine, Tanta University, Egypt; [3]Department of Radiology, College of Medicine, King Khalid University, P.O. Box 641, Abha 61421, Saudi Arabia; [4]Department of Medicine, College of Medicine, King Khalid University, Abha, Aseer Region, Saudi Arabia; [5]College of Medicine, Tanta University, Egypt; [6]Department of Adult Critical Care Asser, Central Hospital, Abha, Saudi Arabia; [7]Department of Neurosurgery, College of Medicine, King Khalid University, P.O. Box 641, Abha 61421, Saudi Arabia

Received May 20, 2022; Accepted August 24, 2022; Epub April 15, 2023; Published April 30, 2023

Abstract: Background: Traumatic brain injury is one of the leading causes of diffuse axonal injury (DAI) that is associated with significant morbidity and mortality. This study was designed to determine the characteristics and outcome of traumatic DAI in correlation to Marshal, Rotterdam and Adams grading scores. Method: Data for this retrospective and cross-sectional study were collected from 33 DAI patients whose ages ranged from 15 to 60 years from 2017-2020. Data regarding gender, age, cause of trauma, associated brain findings, Marshal CT score, Rotterdam CT score, Adams MRI Grade, and outcome were collected and analyzed. Results: Out of 33 DAI patients, 21 (64%) were discharged to their home, 6 (18%) transferred to a peripheral hospital, and 6 (18%) passed away. CT findings showed brain contusion in 27 (82%) cases, subarachnoid hemorrhage (SAH) in 22 (67%) cases, intracerebral hemorrhage in 14 (42%) cases, subdural hemorrhage (SDH) in 10 (30%) cases, brain herniation in 9 (27%) cases, extradural hemorrhage (EDH) in 6 (18%) cases, brainstem injury in 6 (18%) cases, pneumocephalus in 5 (15%) cases, hydrocephalus in 2 (6%) cases and cerebellar injury in 1 (3%) case. There was no detected significance for the patient's mortality outcome concerning CT scan Marshal score, CT scan Rotterdam score, and MRI Adams grade. Conclusion: Road traffic accidents account for a high percentage of DAI among young males (15-25 years), and a high percentage of our studied population improved. We detected no significance in patient's mortality outcome in relation to Marshal, Rotterdam and Adams grading scores.

Keywords: Diffuse axonal injury, outcome, CT, MRI, Rotterdam score, Marshal score, Adams grading

Introduction

Traumatic brain injury (TBI) can result in axonal damage. Diffuse axonal injury (DAI) is microscopic damage linked to shear and tensile forces to the axons in the brain neural tracts, corpus callosum, and brainstem [1]. DAI that is biomechanically caused by rotational acceleration-deceleration forces at impact is characterized by widespread axonal injury in the superficial and deep white substance [2]. Pathophysiological changes in DAI are comprised of mechanical axonal violation, transport interruption, edema, and proteolysis with secondary physiological changes [3]. Clinically, it is defined by coma lasting 6 hours or more after TBI, excluding cases of swelling or ischemic brain lesions [4]. Survivors often display debilitating motor, sensory and cognitive symptoms, leading to reduced quality of life and a profound economic burden to society [5, 6]. If the brain is impaired functionally and not totally damaged, the brain may slowly resume its function as the neural connections are remodeled with an improvement of the patient's clinical condition [7].

In Saudi Arabia (KSA), road traffic accidents and injury are estimated at a rate of 28.8 per 100,000. Yet, there have been no data on the clinical characteristics and outcome of DAI in KSA. Thus, this study was designed to determine the characteristics and outcome of traumatic DAI in correlation to Marshal, Rotterdam and Adams grading scores.

CT scan Marshal score [8]

The Marshall score of TBI is a CT scan-derived metric using only a few features and has been shown to predict outcomes in patients with TBI.

It places patients into one of six grades (I to VI) of increasing severity based on findings on non-contrast CT scans of the brain. Higher grades have a worse prognosis and survival. It is primarily concerned with two features:

1. Degree of swelling, as determined by midline shift and/or compression of basal cisterns.

2. Presence and size of contusions/hemorrhages referred to as "high or mixed density lesions".

- Diffuse injury I
  - no visible intracranial pathology
- Diffuse injury II
  - midline shift of 0 to 5 mm
  - basal cisterns remain visible
  - no high or mixed density lesions >25 cm^3
- Diffuse injury III (swelling)
  - midline shift of 0 to 5 mm
  - basal cisterns compressed or completely effaced
  - no high or mixed density lesions >25 cm^3
- Diffuse injury IV (shift)
  - midline shift >5 mm
  - no high or mixed density lesions >25 cm^3
- Evacuated mass lesion V
  - any lesion evacuated surgically
- Non-evacuated mass lesion VI
  - high or mixed density lesions >25 cm^3
  - not surgically evacuated

CT scan Rotterdam grade [9]

A more recent system attempts to address some of the recognized limitations of the Marshall system, such as struggling to classify patients who have injuries of multiple types.

It includes four independently graded elements. Like the Marshall system, it includes:

1. Degree of basal cistern compression.

2. Degree of midline shift.

However, it does not include contusions but rather restricts mass lesions to epidural, intraventricular, and subarachnoid hematomas.

Each of these is given a grade, and these grades are tallied, with the addition of 1 to the total. In other words, a completely normal-appearing scan has a Rotterdam grade of 1, and the worse possible Grade is 6, which makes it comparable to the Marshall system:

- basal cisterns
  - 0: normal
  - 1: compressed
  - 2: absent
- midline shift
  - 0: no shift or ≤5 mm
  - 1: shift >5 mm
- epidural mass lesion
  - 0: present
  - 1: absent
- intraventricular blood or traumatic SAH
  - 0: absent
  - 1: present

MRI Adams grade [10, 11]

A classification based on MRI findings proposed in 1989.

• Grade 1 (lobar): diffuse axonal injury lesions confined to the lobar white matter, especially grey-white matter junction

○ most common sites: parasagittal regions of frontal lobes, periventricular temporal lobes

○ less common sites: parietal and occipital lobes, internal and external capsules, cerebellum

• Grade 2 (callosal): diffuse axonal injury lesions in the corpus callosum, almost invariably in addition to the lobar white matter

○ most common sites: posterior body and splenium of the corpus callosum

○ less common sites: anterior body and rostrum of corpus callosum (usually in conjunction with posterior involvement)

○ usually unilateral and eccentric but may be bilateral and symmetric

• Grade 3 (brainstem): diffuse axonal injury lesions in the brainstem, almost invariably in addition to the lobar white matter and corpus callosum

○ most common sites: dorsolateral midbrain, upper pons, and superior cerebellar peduncles

Methods

This was a retrospective cross-sectional study, with data collected from the medical records of patients with traumatic head injury who were admitted between 2017 and 2020 at a tertiary care hospital, in the southern region of Saudi Arabia. This study was approved by Ethics and Internal Review Board at Aseer Central Hospital with approval number: 20200410 On April 15, 2022.

Patients eligible for inclusion in the study had to have a history of TBI with Glasgow Coma Scale (GCS) grades of ≤14 at admission, aged more than 14 years, and had a computed tomography (CT) scan or MRI of DAI. The study criteria excluded patients who had Traumatic head Injury with mass lesions in the brain, who had psychiatric disorders, and patients who were younger than 14 years.

Data regarding age, gender, cause of trauma, associated brain findings, and outcome according to gender, year of admission, Rotterdam CT score, Marshal CT score, and MRI Adams grade were collected and analyzed. To exclude inter-observer variations, all CT and MRI scans were reported by one radiologist with 15 years of post-board experience.

Statistical analysis

After data were extracted, it was revised, coded, and fed to statistical software IBM SPSS version 22 (SPSS, Inc. Chicago, IL). All statistical analysis was done using two-tailed tests. A *P*-value of less than 0.05 was considered to be statistically significant.

Results

The study included 33 DAI patients whose ages ranged from 15 to 60 years (15-25 years: [17 cases = 52%], 26-36 years: [11 cases = 33%], above 36 years: [5 cases = 15%]) with majority of patients being males (30 case = 91%) with 3 females (9%). Number of admission cases per year was 15, 10, 7 and 1, in 2017, 2018, 2019, and 2020, respectively. Causes of trauma were road traffic accidents (RTA) (31 cases = 94%) and fall from height (2 cases = 6%). Regarding outcome, twenty-one patients (64%) improved (discharged home) [19 males, 2 females], 6 (18%) patients transferred to a peripheral hospital for long term nursing care [6 males, 0 females] while 6 (18%) patients expired [5 males, 1 female]. **Table 1**.

Description of CT findings associated with DAI is shown from higher incidence to the lower in **Table 2**. They include: brain contusion [27 cases = 81.81%], subarachnoid hemorrhage (SAH) [22 cases = 66.66%], intracerebral hemorrhage [14 cases = 42.42%], subdural hemorrhage (SDH) [10 cases = 30.30%], brain herniation [9 cases = 27.27%], extradural hemorrhage (EDH) [6 cases = 18.18%], brainstem injury [6 cases = 18.18%], pneumoencephalus [5 cases = 15.15%], hydrocephalus [2 cases = 6.06%] and cerebellar injury [1 case = 3.03%].

CT scan Marshal Grade showed the highest distribution in grade III [15 cases = 45.45%] followed by [9 cases = 27.27%], [4 cases = 12.12%], [3 cases = 9.1%], [1 case = 3%] and [1

Table 1. Descriptive statistics

Variables	Number	%
Age (in years)		
15-25	17	52%
26-36	11	33%
Above 36	5	15%
Gender		
Male	30	91%
Female	3	9%
Year of admission		
2017	15	45.45%
2018	10	30.30%
2019	7	21.21%
2020	1	3.03%
Cause of trauma		
RTA	31	94%
Fall from height	2	6%
Outcome		
Improved	21	64%
Male	19	
Female	2	
Transferred	6	18%
Male	6	
Female	0	
Expired	6	18%
Male	5	
Female	1	

Table 2. Description of CT findings associated with DAI

Variable	Number	%
Brain contusion	27	81.81%
Subarachnoid hemorrhage	22	66.66%
Intracerebral hemorrhage	14	42.42%
Subdural hemorrhage	10	30.30%
Brain herniation	9	27.27%
Extradural hemorrhage	6	18.18%
Brainstem injury	6	18.18%
Pneumocephalus	5	15.15%
Hydrocephalus	2	6.06%
Cerebellar injury	1	3.03%

case = 3%] in grades II, VI, I, IV and V respectively. Similarly, CT scan Rotterdam grade showed the highest distribution in grade IV: [15 cases = 45.45%] followed by Grade VII [8 cases = 24.24%], grade III [6 = 18.18%], grade V [2 cases = 6.06%] then grades 1 and VI [1 case for each = 3.03%]. MRI was done only in 26 cases (78, 78%), and MRI Adams grade showed the highest distribution in Grade II [14 cases, 42.42%] followed by Grade III [9 cases, 27.27%] and then Grade I [3 cases, 9.09%], shown in **Table 3**. No significance was detected for the patient's outcome in relation to CT scan Marshal Grade (P = 0.337), CT scan Rotterdam Grade (P = 0.148), and MRI Adam grade (P = 0.167). **Table 4**.

Table 3. CT scan Marshal and Rotterdam and MRI Adams grading: No. and %

Variable	Number	%
CT scan Marshal Grade		
Grade I	3	9%
Grade II	9	27%
Grade III	15	46%
Grade IV	1	3%
Grade V	1	3%
Grade VI	4	12%
CT scan Rotterdam Grade		
Grade I	1	3%
Grade II	8	24%
Grade III	6	18%
Grade IV	15	46%
Grade V	2	6%
Grade VI	1	3%
MRI Adam grading		
No MRI done	7	21%
Grade I	3	9%
Grade II	14	43%
Grade III	9	27%

A one-way ANOVA was performed to compare the effect of the independent variables on the dependent variable; for Marshal grade. It revealed that there was a statistically significant difference in Marshal grade and brain contusion (F = 6.089, P = 0.001), pneumcephalus (F = 8.209, P = 0.000), Rotterdam grade (F = 21.982, P = 0.000) and MRI Adam grade (F = 3.796, P = 0.010). On the other hand, no statistical significant difference was detected in Marshal grade and age (F = 0.21, P = 0.959), SAH (F = 2.591, P = 0.49), intracerebral hemorrhage (F = 2.53, P = 0.53), SDH (F = 1.457, P = 0.237), brain herniation (F = 2.33, P = 0.70), EDH (F = 0.781, P = 0.572), brainstem injury (F = 1.797, P = 0.147), Hydrocephalus (F = 0.627, P = 0.681), cerebellar injury (F = 0.21, P = 0.959). **Table 5**.

Table 4. Patient's outcome in relation to CT scan Marshal, Rotterdam, and MRI Adam grading

Variable	Outcome		
	Improved: No. & % within the Grade, % of total patients	Transferred: No., % within the Grade, % of total patients	Expired: No., % within the Grade, % of total patients
CT scan Marshal Grade			
Grade I	1, 33.3%, 3%	0, 0%, 0%	2, 66.6%, 6%
Grade II	7, 77.77%, 21%	1, 11.11%, 3%	1, 11.11%, 3%
Grade III	10, 66.66%, 30%	3, 20%, 9%	2, 13.33%, 6%
Grade IV	1, 100%, 1%	0, 0%, 0%	0, 0%, 0%
Grade V	0, 0%, 0%	1, 100%, 3%	0, 0%, 0%
Grade VI	2, 50%, 6%	1, 25%, 3%	1, 25%, 3%
CT scan Rotterdam Grade			
Grade I	0, 0%, 0%	0, 0%, 0%	1, 100%, 3%
Grade II	6, 75%, 18%	0, 0%, 0%	2, 25%, 6%
Grade III	4, 66,7%, 12%	2, 33.3%, 6%	0, 0%, 0%
Grade IV	9, 60%, 27%	4, 26.7%, 12%	2, 13.3%, 6%
Grade V	2, 100%, 6%	0, 0%, 0%	0, 0%, 0%
Grade VI	0, 0%, 0%	0, 0%, 0%	1, 100%, 0%
MRI Adam grading			
No MRI done	4, 57.14%, 12%	0, 0%, 0%	3, 42.86%, 9%
Grade I	3, 100%, 9%	0, 0%, 0%	0, 0%, 0%
Grade II	8, 57.14%, 24%	5, 35.71%, 15%	1, 7.15%, 3%
Grade III	6, 66.66%, 18%	1, 11.11%, 3%	2, 22.22%, 6%

Similarly, one-way ANOVA revealed that there was a statistically significant difference in Rotterdam grade and age (F = 2.918, P = 0.031), brain contusion (F = 3.637, P = 0.012), SAH (F = 3.881, P = 0.009), SDH (F = 3.089, P = 0.025), brain herniation (F = 2.10, P = 0.028), EDH (F = 0.899, P = 0.496), pneumocephalus (F = 2.410, P = 0.063), Hydrocephalus (F = 5.470, P = 0.001) and MRI Adam grade (F = 2.678, P = 0.043). On the other hand, no statistical significant difference was detected in Rotterdam grade and intracerebral hemorrhage (F = 1.926, P = 0.123), brainstem injury (F = 2.321, P = 0.071), cerebellar injury (F = 0.884, P = 0.505). **Table 5**.

Last of all, one-way ANOVA revealed that there was a statistically significant difference in MRI Adam grade and cerebellar injury (F = 4.39, P = 0.11), SAH (F = 4.72, P = 0.008) and SDH (F = 5.46, P = 0.004). However, no statistical significant difference was detected in Rotterdam grade and age (F = 1.392, P = 0.265), brain contusion (F = 1.921, P = 0.148), intracerebral hemorrhage (F = 0.393, P = 0.759), brain herniation (F = 0.139, P = 0.936), EDH (F = 0.433, P = 0.731), brainstem injury (F = 0.714, P = 0.552), pneumocephalus (F = 0.505, P = 0.682), Hydrocephalus (F = 0.504, P = 0.683). **Table 5**.

Discussion

The objective of our study was to focus on DAI, appraise the outcome and describe associated brain CT findings, categorize CT scan Marshal and Rotterdam scores and MRI Adams grading and find out any possible association between brain CT findings and different grading systems in DAI patients from a tertiary hospital in KSA.

The majority of our patients (30 patients, 91%) were males, similar to previous studies that found (70 patients, 89.7% [7]), (101 patients = 94.4% [12]), (97 patients, 72.9%) [13] that most of their patients were males. The younger population was more affected in our study, with 52% being between 15 and 25 years of age. Similar statistics for age were seen in other studies, with 43.6% [7], 48.59% [12], and 45.1% [13] being between the ages of 18 and 30 years.

Table 5. One-way ANOVA: DAI grades versus other variables

Variable	ANOVA (CT Marshal grade versus other variables)		ANOVA (CT Rotterdam Grade versus other variables)		ANOVA (MRI Adam grade versus other variables)	
	F	P	F	P	F	P
Age	0.21	0.959	2.918	0.031*	1.392	0.265
Brain contusion	6.089	0.001*	3.637	0.012*	1.921	0.148
Subarachnoid hemorrhage	2.591	0.49	3.881	0.009*	4.72	0.008*
Intracerebral hemorrhage	2.53	0.53	1.926	0.123*	0.393	0.759
Subdural hemorrhage	1.457	0.237	3.089	0.025*	5.46	0.004*
Brain herniation	2.33	0.70	2.10	0.028*	0.139	0.936
Extradural hemorrhage	0.781	0.572	0.899	0.496*	0.433	0.731
Brainstem injury	1.797	0.147	2.321	0.071	0.714	0.552
Pneumocephalus	8.209	0.000*	2.410	0.063	0.505	0.682
Hydrocephalus	0.627	0.681	5.470	0.001*	0.504	0.683
Cerebellar injury	0.21	0.959	0.884	0.505	4.39	0.11*

*diffuse axonal injury grades versus age and other radiological finding.

In our study, the most prevailing cause of DAI was RTA (94%), while fall from height accounted only for 6%. Similarly, previous studies [5, 7, 13] found RTA to account for a high percentage of DAI (83.8%, 60%, and 51.9% respectively). This may be due to the high incidence of the shearing forces associated with RTA as brain movement lags behind skull movement with subsequent tearing of the nerve axons and disruption of nerve communication [14].

The greater percentage of our studied patients improved (64%) with no association seen between gender distribution and outcome of DAI, similar to previous studies [7, 13]. There was a significant decrease in the number of TBI and hence DAI cases in the year 2020 compared to the previous three years investigated in our study. This may be attributed to the international lockdown due to the SARS COV2 pandemic (COVID-19) with a decline of RTA [15].

DAI describes multifocal brain damage, hemorrhagic and/or non-hemorrhagic, predominantly affecting gray-white matter junction resulting from axonal stretch and/or shear strain due to rotation and/or acceleration-deceleration forces in the frontal lobes (as the rotational axis of the head is posterior, hence creating higher anterior momentum), corpus callosum, internal capsules, thalamus, midbrain and/or pons [16-18].

DAI findings depicted on CT or MR images are the signpost revealing underlying axonal injury [19, 20]. Conversely, cognitive and neurological impairment due to DAI is, sometimes, disproportionate to the CT brain imaging abnormalities [21]. On CT, identification of DAI is dependent upon the presence of foci of hemorrhage at the sites of white matter bundles within the cerebrum and brainstem [22, 23]. Our study showed that most CT findings associated with DAI were brain contusion (81.8%) (**Figure 1A**), subarachnoid hemorrhage (66.66%), intracerebral hemorrhage (42.42%), subdural hemorrhage (30.30%), brain herniation (27.27%), extradural hemorrhage (18.18%), brainstem injury (18.18%), pneumocephalus (15.15%), hydrocephalus (6.06%), and cerebellar injury (3.03%). The fraction of the different CT brain findings in our study is not uniform with previous studies [16, 24-27], but the percentage of DAI cases was still comparable with those studies. This may be attributed to the wide variety of brain injuries that can cause DAI and due to different patterns of TBI between different study populations. Still, it was shown that some brain findings on CT are correlated well with DAI, such as midline SAH (61% sensitivity and 82% specificity) [16], with significant progression of contusions [28], and intraventricular hemorrhage (with univariate and multivariate odds ratios of 3.7 and 4.2) [29].

Detection of no significance non-contrast brain CT imaging is the cornerstone of initial investigation following TBI [16], while DAI is poorly identified with this modality, especially in non-hemorrhagic lesions, and is only able to detect

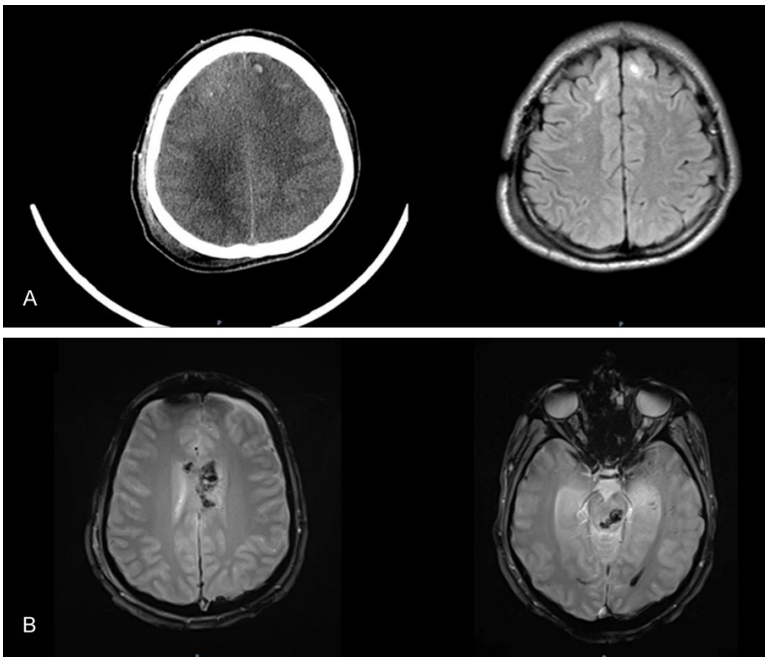

Figure 1. A: CT and MRI showed diffused axonal injury with hemorrhagic contusions at the grey-white matter junction. B: Gradient echo MRI showing the effect of hemosiderin deposition in the corpus callosum and midbrain (Adams grade 3).

19% of such lesions, compared to 92% using MRI (**Figure 1B**) [30]. On the other hand, although brain MRI imaging serves as the best imaging modality for DAI detection [31], the time frame for its execution delays its utilization, particularly in ventilated sick patients [32]. Also, notably, it should be renowned that even with modern MRI scanners, the absenteeism of DAI signs does not unconditionally exclude the presence of axonal injury. So, CT remains the first available imaging choice for assessment of TBI and prediction of the outcome [33, 34]. Previous studies [35-37] showed that the Marshall score is worthy in predicting the outcome, but the Rotterdam score with its individual CT parameters was shown to surpass it due to its incorporation of individual CT parameters underlying the CT classification [38]. Our results, are in contrast to those previous studies, and show no apparent association between Marshall, Rotterdam, and MRI Adam scores with mortality rate.

We used the One-Way ANOVA to compare the means of Marshal, Rotterdam, and MRI Adam grades with each other as well as with age and different brain lesions. The Rotterdam Grade was correlated with more variables (age, brain contusion, subarachnoid hemorrhage, Intracerebral hemorrhage, subdural hemorrhage, Brain herniation, extradural hemorrhage, and hydrocephalus) compared to Marshal Grade (brain contusion and pneumocephalus) and to Adam MRI grade (Subarachnoid hemorrhage, Subdural hemorrhage, Cerebellar injury). This correlation analysis is heterogeneous between different studies [26, 39-43] and therefore confusing. This may be partially illuminated if we think it through, that DAI occurs mainly due to the forces associated with rapid acceleration-deceleration rather than to the direct impact on the brain itself [44]. The CT findings correlated with DAI are characteristically limited to microhemorrhages within the subcortical and cerebral white matter (Grade I), corpus callosum (Grade II), and brainstem (Grade III) [45]. Accordingly, patients with DAI might have cognitive impairment that looks disproportionate to the imaging lesions shown on CT [16]. On the other hand, MRI grading is more sensitive than CT in visualizing microscopic amounts of blood-related to DAI [46] and it may have a good future role in predicting the length of coma in DAI patients [47, 48].

Our study demonstrated a correlation between Marshal, Rotterdam, and MRI Adams grades. Although Marshall CT grading has strong predictive power, greater discrimination (and hence more strong correlation) is obtained when the individual CT parameters are included in the Rotterdam score model [38]; however, MRI grading was shown to be a better predictor of neurological outcome in DAI compared to the CT obtained grading. Indeed, conventional Brain MRI has low resolution and can only detect DAI in approximately half of DAI cases [51] as 80% of DAI lesions are microscopic or nonhemorrhagic [52, 53]. By contrast, diffusion tensor imaging (DTI) has been shown to have higher sensitivity for the detection of DAI lesions than that of conventional brain MRI

[54, 55]. Furthermore, diffusion tensor tractography, which is a derivative of DTI, enables three-dimensional (3-D) visualization and estimation of specific neural tracts with the advantage that the characteristics of an entire neural tract can be determined and analyzed providing marked improvements in detecting the site and extent of DAIs within the examined tracts [55, 56]; however, studies to launch DTI-based diagnostic criteria for DAI are required.

There are some limitations to our study. First, our cohort does not represent the pediatric population who may have TBI and be imperiled to DAI. In addition, our sample is only representative of one tertiary hospital in the southern region of KSA, with a relatively small number of included patients. Further similar multicenter studies that include pediatric patients are warranted to obtain more visible and comprehensive results. Afterward, with the retrospective design of our study, we were not capable of controlling the timing, as well as the technical specifications of the CT and MRI scan. However, we do not expect slight variations in the timing of CT and MRI to have a significant impact on our used grading systems, given the stability of DAI imaging studies.

Conclusion

Road traffic accidents account for a high percentage of DAI among young males (15-25 years), while a high rate of our studied population improved (64%). No detected significance was found for the patient's mortality outcome concerning CT scan Marshal score, CT scan Rotterdam score, and MRI Adams grade.

Disclosure of conflict of interest

None.

Address correspondence to: Dr. Ali Al Bshabshe, Department of Medicine and Adult Critical Care, College of Medicine, King Khalid University, Abha 25216, Saudi Arabia. Tel: +966504740409; E-mail: albshabshe@yahoo.com

References

[1] Siedler DG, Chuah MI, Kirkcaldie MT, Vickers JC and King AE. Diffuse axonal injury in brain trauma: insights from alterations in neurofilaments. Front Cell Neurosci 2014; 8: 429.

[2] Cullen DK, Harris JP, Browne KD, Wolf JA, Duda JE, Meaney DF, Margulies SS and Smith DH. A porcine model of traumatic brain injury via head rotational acceleration. Methods Mol Biol 2016; 1462: 289-324.

[3] Johnson VE, Stewart W and Smith DH. Axonal pathology in traumatic brain injury. Exp Neurol 2013; 246: 35-43.

[4] Mckee AC and Daneshvar DH. The neuropathology of traumatic brain injury. Handb Clin Neurol 2015; 127: 45-66.

[5] Abu Hamdeh S. Clinical consequences of axonal injury in traumatic brain injury (PhD dissertation). 2018. Retrieved from http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-341914.

[6] Mesfin FB, Gupta N, Hays Shapshak A, et al. Diffuse Axonal Injury. [Updated 2022 May 2]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2022. Available from: https://www.ncbi.nlm.nih.gov/books/NBK448102/.

[7] Vieira RC, Paiva WS, de Oliveira DV, Teixeira MJ, de Andrade AF and de Sousa RM. Diffuse axonal injury: epidemiology, outcome and associated risk factors. Front Neurol 2016; 7: 178.

[8] Marshall LF, Marshall SB, Klauber MR, Van Berkum Clark M, Eisenberg H, Jane JA, Luerssen TG, Marmarou A and Foulkes MA. The diagnosis of head injury requires a classification based on computed axial tomography. J Neurotrauma 1992; 9 Suppl 1: S287-92.

[9] Maas AI, Hukkelhoven CW, Marshall LF and Steyerberg EW. Prediction of outcome in traumatic brain injury with computed tomographic characteristics: a comparison between the computed tomographic classification and combinations of computed tomographic predictors. Neurosurgery 2006; 57: 1173-82.

[10] Adams JH, Doyle D, Ford I, Gennarelli TA, Graham DI and McLellan DR. Diffuse axonal injury in head injury: definition, diagnosis, and grading. Histopathology 1989; 15: 49-59.

[11] Gentry LR. Imaging of closed head injury. Radiology 1994; 191: 1-17.

[12] Ahuja A, Verma S and Choudhary AN. Outcome of traumatic head injury in unknown patients. Int Surg J 2018; 5: 633-7.

[13] Javeed F, Rehman L, Afzal A and Abbas A. Outcome of diffuse axonal injury in moderate and severe traumatic brain injury. Surg Neurol Int 2021; 12: 384.

[14] Ng SY and Lee AYW. Traumatic brain injuries: pathophysiology and potential therapeutic targets. Front Cell Neurosci 2019; 13: 528.

[15] Yasin YJ, Grivna M and Abu-Zidan FM. Global impact of COVID-19 pandemic on road traffic collisions. World J Emerg Surg 2021; 16: 51.

[16] Schweitzer AD, Niogi SN, Whitlow CT and Tsiouris AJ. Traumatic brain injury: imaging patterns and complications. Radiographics 2019; 39: 1571-95.

[17] Drew LB and Drew WL. The contrecoup-coup phenomenon: a new understanding of the mechanism of closed head injury. Neurocrit Care 2004; 1: 385-90.
[18] Cepeda S, Gómez PA, Castaño-Leon AM, Munarriz PM, Paredes I and Lagares A. Contrecoup traumatic intracerebral hemorrhage: a geometric study of the impact site and association with hemorrhagic progression. J Neurotrauma 2016; 33: 1034-46.
[19] Jang SH. Diagnostic problems in diffuse axonal injury. Diagnostics (Basel) 2020; 10: 117.
[20] Stewan Feltrin F, Zaninotto AL, Guirado VMP, Macruz F, Sakuno D, Dalaqua M, Magalhães LGA, Paiva WS, Andrade AF, Otaduy MCG and Leite CC. Longitudinal changes in brain volumetry and cognitive functions after moderate and severe diffuse axonal injury. Brain Inj 2018; 32: 1208-17.
[21] Liu J, Kou Z and Tian Y. Diffuse axonal injury after traumatic cerebral microbleeds: an evaluation of imaging techniques. Neural Regen Res 2014; 9: 1222-30.
[22] Bruggeman GF, Haitsma IK, Dirven CMF and Volovici V. Traumatic axonal injury (TAI): definitions, pathophysiology, and imaging-a narrative review. Acta Neurochir (Wien) 2021; 163: 31-44.
[23] Mutch CA, Talbott JF and Gean A. Imaging evaluation of acute traumatic brain injury. Neurosurg Clin N Am 2016; 27: 409-39.
[24] Gusmão SN and Pittella JE. Acute subdural hematoma and diffuse axonal injury in fatal road traffic accident victims: a clinico-pathological study of 15 patients. Arq Neuropsiquiatr 2003; 61: 746-50.
[25] Lee SY, Kim SS, Kim CH, Park SW, Park JH and Yeo M. Prediction of outcome after traumatic brain injury using clinical and neuroimaging variables. J Clin Neurol 2012; 8: 224-9.
[26] Figueira Rodrigues Vieira G and Guedes Correa JF. Early computed tomography for acute post-traumatic diffuse axonal injury: a systematic review. Neuroradiology 2020; 62: 653-60.
[27] Lee I, Park K, Jeong TS, Kim WS, Kim WK, Rhee DY and Park CW. Clinical outcomes of diffuse axonal injury after traumatic brain injury according to magnetic resonance grading. J Korean Soc Geriatr Neurosurg 2020; 16: 71-7.
[28] Chieregato A, Fainardi E, Morselli-Labate AM, Antonelli V, Compagnone C, Targa L, Kraus J and Servadei F. Factors associated with neurological outcome and lesion progression in traumatic subarachnoid hemorrhage patients. Neurosurgery 2005; 56: 671-680.
[29] Mata-Mbemba D, Mugikura S, Nakagawa A, Murata T, Kato Y, Tatewaki Y, Li L, Takase K, Ishii K, Kushimoto S, Tominaga T and Takahashi S. Intraventricular hemorrhage on initial computed tomography as a marker of diffuse axonal injury after traumatic brain injury. J Neurotrauma 2015; 32: 359-65.
[30] Gentry LR, Godersky JC, Thompson B and Dunn VD. Prospective comparative study of intermediate-field MR and CT in the evaluation of closed head trauma. AJR Am J Roentgenol 1988; 150: 673-82.
[31] Kou Z, Wu Z, Tong KA, Holshouser B, Benson RR, Hu J and Haacke EM. The role of advanced MR imaging findings as biomarkers of traumatic brain injury. J Head Trauma Rehabil 2010; 25: 267-282.
[32] Skandsen T, Kvistad KA, Solheim O, Strand IH, Folvik M and Vik A. Prevalence and impact of diffuse axonal injury in patients with moderate and severe head injury: a cohort study of early magnetic resonance imaging findings and 1-year outcome. J Neurosurg 2009; 113: 556-63.
[33] Alcock S, Batoo D, Ande SR, Grierson R, Essig M, Martin D, Trivedi A, Sinha N, Leeies M, Zeiler FA and Shankar JJS. Early diagnosis of mortality using admission CT perfusion in severe traumatic brain injury patients (ACT-TBI): protocol for a prospective cohort study. BMJ Open 2021; 11: e047305.
[34] Brossard C, Lemasson B, Attyé A, de Busschère JA, Payen JF, Barbier EL, Grèze J and Bouzat P. Contribution of CT-scan analysis by artificial intelligence to the clinical care of TBI patients. Front Neurol 2021; 12: 666875.
[35] Mohammadifard M, Ghaemi K, Hanif H, Sharifzadeh G and Haghparast M. Marshall, and Rotterdam computed tomography scores in predicting early deaths after brain trauma. Eur J Transl Myol 2018; 28: 7542.
[36] Asim M, El-Menyar A, Parchani A, Nabir S, Ahmed MN, Ahmed Z, Ramzee AF, Al-Thani A, Al-Abdulmalek A and Al-Thani H. Rotterdam and Marshall scores for prediction of in-hospital mortality in patients with traumatic brain injury: an observational study. Brain Inj 2021; 35: 803-11.
[37] Mahadewa TGB, Golden N, Saputra A and Ryalino C. Modified revised trauma-marshall score as a proposed tool in predicting the outcome of moderate and severe traumatic brain injury. Open Access Emerg Med 2018; 10: 135-9.
[38] Murakami S. A comparative study between Marshall and Rotterdam CT scores in predicting early deaths in patients with traumatic brain injury in a major tertiary care hospital in Nepal. Chin J Traumatol 2016; 19: 25-7.
[39] Aoki Y, Inokuchi R, Gunshin M, Yahagi N and Suwa H. Diffusion tensor imaging studies of mild traumatic brain injury: a meta-analysis. J Neurol Neurosurg Psychiatry 2012; 83: 870-876.

[40] Deepika A, Prabhuraj AR, Saikia A and Shukla D. Comparison of predictability of Marshall and Rotterdam CT scan scoring system in determining early mortality after traumatic brain injury. Acta Neurochir (Wien) 2015; 157: 2033-8.
[41] Mittl RL, Grossman RI, Hiehle JF, Hurst RW, Kauder DR, Gennarelli TA and Alburger GW. Prevalence of MR evidence of diffuse axonal injury in patients with mild head injury and normal head CT findings. AJNR Am J Neuroradiol 1994; 15: 1583-9.
[42] Henninger N, Compton RA, Khan MW, Carandang R, Hall W and Muehlschlegel S. "Don't lose hope early": hemorrhagic diffuse axonal injury on head computed tomography is not associated with poor outcome in moderate to severe traumatic brain injury patients. J Trauma Acute Care Surg 2018; 84: 473–82.
[43] Matsukawa H, Shinoda M, Fujii M, Takahashi O, Murakata A, Yamamoto D, Sumiyoshi S and Ishikawa R. Intraventricular hemorrhage on computed tomography and corpus callosum injury on magnetic resonance imaging in patients with isolated blunt traumatic brain injury. J Neurosurg 2012; 117: 334-9.
[44] Capizzi A, Woo J and Verduzco-Gutierrez M. Traumatic brain injury: an overview of epidemiology, pathophysiology, and medical management. Med Clin North Am 2020; 104: 213-238.
[45] Dekeyzer S, van den Hauwe L, Vande Vyvere T and Parizel P. Traumatic Brain Injury: Imaging Strategy. 2019; 10.1007/978-3-319-68536-6_27.
[46] Abu Hamdeh S, Marklund N, Lannsjö M, Howells T, Raininko R, Wikström J and Enblad P. Extended anatomical grading in diffuse axonal injury using MRI: hemorrhagic lesions in the substantia Nigra and mesencephalic tegmentum indicate poor long-term outcome. J Neurotrauma 2017; 34: 341-52.
[47] Edlow BL, Claassen J, Schiff ND and Greer DM. Recovery from disorders of consciousness: mechanisms, prognosis, and emerging therapies. Nat Rev Neurol 2021; 17: 135-56.
[48] Bansal M, Sinha VD and Bansal J. Diagnostic and prognostic capability of newer magnetic resonance imaging brain sequences in diffuse axonal injury patient. Asian J Neurosurg 2018; 13: 348-56.
[49] Tjerkaski J, Nyström H, Raj R, Lindblad C, Bellander BM, Nelson DW and Thelin EP. Extended analysis of axonal injuries detected using magnetic resonance imaging in critically ill traumatic brain injury patients. J Neurotrauma 2022; 39: 58-66.
[50] Janas AM, Qin F, Hamilton S, Jiang B, Baier N, Wintermark M, Threlkeld Z and Lee S. Diffuse axonal injury grade on early mri is associated with worse outcome in children with moderate-severe traumatic brain injury. Neurocrit Care 2022; 36: 492-503.
[51] Humble SS, Wilson LD, Wang L, Long DA, Smith MA, Siktberg JC, Mirhoseini MF, Bhatia A, Pruthi S, Day MA, Muehlschlegel S and Patel MB. Prognosis of diffuse axonal injury with traumatic brain injury. J Trauma Acute Care Surg 2018; 85: 155-9.
[52] Gentry LR, Godersky JC and Thompson B. MR imaging of head trauma: review of the distribution and radiopathologic features of traumatic lesions. AJR Am J Roentgenol 1988; 150: 663-72.
[53] Chung SW, Park YS, Nam TK, Kwon JT, Min BK and Hwang SN. Locations and clinical significance of non-hemorrhagic brain lesions in diffuse axonal injuries. J Korean Neurosurg Soc 2012; 52: 377-83.
[54] Brandstack N, Kurki T and Tenovuo O. Quantitative diffusion-tensor tractography of long association tracts in patients with traumatic brain injury without associated findings at routine MR imaging. Radiology 2013; 267: 231-9.
[55] Grassi DC, Conceicao DMD, Leite CDC and Andrade CS. Current contribution of diffusion tensor imaging in the evaluation of diffuse axonal injury. Arq Neuropsiquiatr 2018; 76: 189-99.
[56] Jang SH and Seo YS. Difference between injuries of the corticospinal tract and corticoreticulospinal tract in patients with diffuse axonal injury: a diffusion tensor tractography study. Int J Neurosci 2020; 130: 124-9.