The Prognostic Value of Rotterdam Computed Tomography Score in Predicting Early Outcomes Among Children with Traumatic Brain Injury

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■ BACKGROUND: **Prediction of traumatic brain injury (TBI) among children is of great importance for accurate clinical decision making.**

■ OBJECTIVES: **This study aimed to determine the prognostic value of the Rotterdam scoring system in predicting early outcome among children with TBI.**

■ METHODS: **This study was conducted in 2017 on 506 children with brain injury in Kashan, Iran. A checklist was used to collect demographic and clinical characteristics of patients such as age, sex, mechanism of trauma, Glasgow Coma Scale (GCS) score, need for surgery, and brain injury outcome. Moreover, each participant's computed tomography scan was evaluated and scored using the Rotterdam system. Sensitivity, specificity, positive and negative predictive values, and the best cut-off score were calculated for the Rotterdam system. The relationships of the Rotterdam score with participants' characteristics were examined using the χ^2 test, whereas the predictors of brain injury outcome were identified using the logistic regression analysis.**

■ RESULTS: **Pediatric death rate was 4.3%. Most deaths were among children who were male, aged <4, had developed brain injury owing to traffic accidents, had a GCS score of 3–8, suffered from compressed skull fracture and frontal lobe injury, had cerebral edema, and had a Rotterdam score of 5. The sensitivity and specificity of a Rotterdam score 3 were 86.4% and 97.9%, respectively. The logistic regression analysis indicated that only GCS and Rotterdam scores were significant predictors of brain injury outcome.**

■ CONCLUSIONS: **At a cut-off score of 3, the Rotterdam system can be used to predict TBI outcome among children with acceptable sensitivity and specificity.**

INTRODUCTION

Traumatic brain injury (TBI) is one of the leading causes of morbidity and mortality among children. Estimates reflect that in the Unites States annually 475,000 TBIs occur among children aged 0–14 years, and 2685 of which result in death.[1] The management of pediatric TBI is different from adult TBI because of the differences in the pattern of the trauma and the anatomy and physiology of the body. Moreover, neurologic assessment among children is more difficult than adults.[2]

Patients with TBI usually have an intratracheal tube in place and receive sedative agents[3-5] or neuromuscular-blocking agents. Therefore, neurologic assessment of TBI is difficult and is associated with some limitations.[6] However, advances in diagnostic imaging techniques have overcome most of the limitations of neurologic assessment of TBI and improved the quality of TBI care.[2]

Imaging techniques, particularly computed tomography (CT), are the primary methods for determining TBI severity.[6] CT is a standard diagnostic technique for diagnosing intracranial injuries among children with TBI.[7] CT use for pediatric TBI assessment has significantly increased in the last decade.[8] CT indices that can be used to determine TBI severity include midline shift,[9-12] intraventricular hemorrhage (IVH),[9,13] subarachnoid hemorrhage,[12,14,15] and cerebral edema.[11,12,16] However, only a handful of studies have assessed the usefulness of these indices for TBI assessment in children.[10,13,16]

Key words
- Children
- Computed tomography
- Head injury
- Rotterdam scoring system

Abbreviations and Acronyms
CT: Computed tomography
EPH: Epidural hematoma
GCS: Glasgow Coma Scale
IVH: Intraventricular hemorrhage
TBI: Traumatic brain injury

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Table 1. Rotterdam Computed Tomography Scoring System

Indices	Score
Basal cistern	
Normal	0
Compressed	1
Absent	2
Midline shift	
Absent or <5 mm	0
>5 mm	1
Epidural mass lesion	
Present	1
Absent	0
IVH or SAH	
Present	1
Absent	0
Sum score	+1

IVH, intraventricular hemorrhage; SAH, subarachnoid hemorrhage.

In 1991, Marshall et al.[17] presented a TBI classification system based on CT findings for determining patient outcomes. Their system was primarily used to predict the risk of increased intracranial pressure and patient outcomes among patients with severe TBI. However, despite its wide use and easy applicability, the Marshall System has some limitations such as failure to assess epidural hematomas (EPH) and intracranial hemorrhages.[18]

To address the limitations of the Marshall System, the Rotterdam CT scoring system was developed in 2005. This system includes 5 main CT indices, namely basal cistern, midline shift, subarachnoid hemorrhage, IVH, and EPH.[19] The Rotterdam system can differentiate among different types of tumor lesions and can provide more reliable information about the prognosis of EPH.[6] Some previous studies reported this system as an independent predictor of TBI outcomes among adults.[20,21] However, there are limited studies on the usefulness of this system for determining pediatric TBI outcomes.[6,22,23] Therefore, this study was conducted to determine the prognostic value of the Rotterdam scoring system in predicting early in-hospital death among children with TBI.

METHODS

This retrospective study was conducted in 2017 on children with TBI, who had been admitted from March 1, 2012 to March 1, 2016, to 1 of the teaching hospitals in Kashan, Iran. Participants were 506 children aged 2–18 years who had undergone a brain CT scan during their hospital admission. Exclusion criteria were incomplete medical records, inaccessibility of brain CT scan, coexistence of brain lesions (such as brain tumor, hydrocephalus, and congenital lesions), and death due to non-TBI causes.

Sample Size

The sample size in this study was based on 1 study in which 3% of children survived and 38% of children that died had a Rotterdam score ≥5.[6] Therefore with a confidence level of 95% and power of

Table 2. Frequency Distributions of the Rotterdam System Indices Based on Glasgow Coma Scale

Rotterdam Indices	Glasgow Coma Scale			Total N (%)	*P* Value
	Mild N (%)	Moderate N (%)	Severe N (%)		
Basal cistern					
Normal	475 (97.1)	4 (0.8)	10 (2)	489 (96.6)	>0.001
Compressed	1 (11.1)	0 (0)	8 (88.9)	9 (1.8)	
Absent	0 (0)	0 (0)	8 (100)	8 (1.6)	
Midline shift					
<5 mm	475 (95)	4 (0.8)	21 (4.2)	6 (1.2)	>0.001
>5 mm	1 (16.7)	0 (0)	5 (83.3)	500 (98.8)	
Epidural mass lesion					
Present	6 (50)	1 (8.3)	5 (41.7)	12 (2.4)	>0.001
Absent	470 (95.1)	3 (0.6)	21 (4.3)	494 (97.6)	
IVH or SAH					
Present	0 (0)	0 (0)	8 (100)	8 (1.6)	>0.001
Absent	476 (95.6)	4 (0.8)	18 (3.6)	498 (98.4)	

IVH, intraventricular hemorrhage; SAH, subarachnoid hemorrhage.

Table 3. Prognostic Value Indices of the Rotterdam System Based on its Scores

	TBI Outcome		Prognostic Value Indices			
Rotterdam Score	Survived	Died	Sensitivity	Specificity	PPV	NPV
2						
<2	4	0	100	0.8	4.3	100
≥2	480	22				
3						
<3	476	3	86.4	97.9	65.5	99.3
≥3	10	19				
4						
<4	483	12	45.5	99.8	90.9	97.5
≥4	1	10				
5						
<5	484	20	9.1	100	100	96
5	0	2				

TBI, traumatic brain injury; PPV, positive predictive value; NPV, negative predictive value.

90%, the minimum required sample size was 515 patients. In 4 patients, the medical records were incomplete. Three patients had no CT scan and 2 children died because of a non-TBI cause. Finally, 506 patients were assessed.

Measurements

The medical records of eligible children were retrieved, and a checklist was used to collect data on their demographic and clinical characteristics such as age, sex, mechanism of trauma, Glasgow Coma Scale (GCS) score, duration of hospitalization, need for surgery, and TBI outcome (either death or survival). Moreover, participants' CT scans were retrieved from the Picture Archiving and Communication System (also known as PACS [MARCO PACS, Iran]) of the study setting and then, for prevention of information bias, 2 radiologists independently evaluated the CT scans regarding the site of skull fracture and the indices of the Rotterdam system (Table 1). The total score of the Rotterdam system for each patient plus 1 gave the final score in the range of 1–6.[19,24]

Ethical Issue

This study has the ethical approval of the ethics committee of Kashan University of Medical Sciences, Kashan, Iran. Because this study was a retrospective study on existing data, there was no need for a patient consent form. However, all permissions to access the medical records of the patients were obtained.

Data Analysis

Data were analyzed via the SPSS software version 13 (SPSS Inc., Chicago, Illinois, USA). The relationships of the Rotterdam score with other study variables were examined through the χ^2 test, whereas its relationship with TBI patient outcome was examined through the logistic regression analysis. The best cut-off score of the Rotterdam system was determined through calculating Youden's index based on sensitivity and specificity. The level of significance was set at <0.05.

RESULTS

Approximately 62.3% of children who had experienced TBI were boys, and 50.6% of them were aged >10 years. The most common mechanism of trauma was motorcycle-car accidents (39.3%). Approximately 94.1% of children had a GCS score of 13–15, and mortality rate was 4.3%. Mean and standard deviation of hospitalization was 1.63 ± 1.94 days (median = 1). CT scan analyses showed midline shift in 1.2% of cases, compressed basal cistern in 1.8% of cases, epidural mass lesion in 2.4% of cases, and IVH in 1.6% of cases (Table 2). This Table also shows that there is a statistically significant difference between TBI severity and each component of the Rotterdam scoring system ($P < 0.001$).

The Rotterdam score is significantly related to TBI outcome ($P < 0.001$). Death rate was 0% at the Rotterdam score of one, 0.6% at the score of two, 50% at the score of three, 88.9% at the score of 4, and 100% at the score of 5. The most prevalent Rotterdam score was 2 (93.4%). Moreover, death rate at scores <3 was 0.6%, whereas at scores ≥3 was 65.5%.

The highest sensitivity was observed at score 1, and the highest specificity were observed at score 5. The greatest negative predictive value was 100% and was related to score 1, whereas the greatest positive predictive value was 100% and was related to score 5. Based on Youden's index, the best Rotterdam cut-off score for the prediction of TBI-related death was 3, which had a death predictive value of 65.5% (Table 3).

Table 4. Relationships of Participant Characteristics with Traumatic Brain Injury Outcome

Characteristics	TBI Outcome: Survived N (%)	TBI Outcome: Died N (%)	Total	*P* value*
Age group (years)				
<4	72 (92.3)	6 (7.7)	78 (100)	0.283
5–9	166 (96.5)	6 (3.5)	172 (100)	
>10	246 (96.1)	10 (3.9)	256 (100)	
Sex				
Female	185 (96.9)	6 (3.1)	191 (100)	0.3
Male	299 (94.9)	16 (5.1)	315 (100)	
Glasgow Coma Scale score				
3–8	5 (19.2)	21 (80.8)	26 (100)	<0.001
9–12	4 (100)	0 (0)	4 (100)	
13–15	475 (99.8)	1 (0.2)	476 (100)	
Need for surgery				
Yes	9 (45)	11 (55)	20 (100)	<0.001
No	475 (97.7)	11 (2.3)	486 (100)	
Skull fracture				
Compressed	12 (66.7)	6 (33.3)	18 (100)	<0.001
Not compressed	17 (94.4)	1 (5.6)	18 (100)	
Normal	455 (100)	0 (0)	455 (100)	
Suspected	0 (0)	15 (100)	15 (100)	
Site of TBI				
Frontal	15 (51.7)	14 (48.3)	29 (100)	<0.001
Parietal	20 (83.3)	4 (16.7)	24 (100)	
Occipital	5 (100)	0 (0)	100 (100)	
Temporal	3 (75)	1 (25)	4 (100)	
Unknown	441 (99.3)	3 (0.7)	444 (100)	

TBI, traumatic brain injury.
*The results of the χ^2 test.

Pediatric TBI outcome had no statistically significant relationships with age and sex, whereas it had statistically significant relationships with GCS score, surgery, skull fracture, and the site of brain injury (Table 4).

Our findings also showed that cure rate in medical or surgical treatment was 100% in Rotterdam score 1, and with increasing the Rotterdam score the cure rate decreased in both type of treatments (Table 5).

The results of the logistic regression analysis showed Rotterdam and GCS scores as the significant predictors of TBI outcome. Therefore, each one-point increase in Rotterdam score was associated with a 10.5-time increase in the odds of death, and each one-point increase in GCS score was associated with a 0.37-time decrease in the odds of death (Table 6).

DISCUSSION

Mortality rate among children with TBI in the present study was 4.3%, which is much lower than the rates reported in previous studies. For instance, this rate in 3 previous studies were 19%,[6] 16%,[12] and 16.7%.[25] This difference in pediatric TBI mortality rate is attributable to the differences in the populations and the follow-up periods of the studies. Participants of the present study suffered from mild to severe TBIs and the primary outcome was in-hospital death, whereas those studies assessed death rates

Table 5. Cure Rate of Patients Based on Type of Treatment in Different Rotterdam Scores

	Type of Treatment				
	Medical		Surgical		
TBI Outcome	Cure	Died	Cure	Died	Total
Rotterdam Score					
1	2 (100)	0 (0)	2 (100)	0 (0)	4 (100)
2	468 (100)	0 (0)	2 (40)	3 (60)	473 (100)
3	5 (38.5)	8 (61.5)	4 (80)	1 (20)	18 (100)
4	0 (0)	1 (100)	1 (12.5)	7 (87.5)	9 (100)
5	0 (0)	2 (100)	0 (0)	0 (0)	2 (100)

TBI, traumatic brain injury.

among children with moderate to severe TBIs over 6- to 12-month follow-up assessment periods.

Findings also showed a significant relationship between Rotterdam score and TBI outcome, so that increases in Rotterdam score were associated with increases in death rate. An earlier study also found that children with lower Rotterdam scores had better outcomes than adults, whereas children with higher Rotterdam scores had worse outcomes than adults. Therefore, the death rate among children with Rotterdam scores 2 and 3 was lower than adults, whereas the death rate among children with scores 4–6 was more than adults. Moreover, only 1 case of death was observed at Rotterdam score 1 and most children had a Rotterdam score of 2,[6] which is in line with the findings of the present study. Similarly, another study reported that most children obtained a Rotterdam score 2 and increases in the score were associated with higher mortality rates.[22]

The present study also showed that the highest sensitivity of a Rotterdam score in determining TBI outcome was at score 1, whereas the highest specificity was at score 5. Moreover, the greatest negative predictive value was related to score 1 (100%) and the greatest positive predictive value was related to score 5 (100%). Youden' index also indicated that the best Rotterdam cut-off score was 3, at which both sensitivity and specificity were high. We did not find any similar study on the predictive value of the Rotterdam score among children for the sake of comparison. However, a study on adults reported that the sensitivity and the specificity of the Rotterdam system at score ≥ 4 was 84.2% and 96.2%, respectively. Moreover, mortality rate was 84.2% at scores ≥ 4 and 3.8% at scores <4. That study also found a significant relationship between Rotterdam score and mortality rate.[21] Another study on patients who had undergone decompressive craniotomy also showed that the sensitivity and the specificity of the Rotterdam system at score 4.5 was 62.5% and 75%, respectively, with a significant correlation between Rotterdam score and death rate.[20] The differences among the findings of our study and the findings of these 2 studies can be attributed to the differences in the populations of the studies; our study was conducted on children, whereas those 2 studies were conducted on adults. It is noteworthy that TBI characteristics and outcomes among adults differ from those among children.

Our findings also revealed that factors such as age, sex, skull fracture, site of brain injury, and need for surgery were not significant predictors of TBI outcome. Similarly, a study reported that age had no significant effects on TBI outcome among children.[26] However, most previous studies reported the significant positive correlation of age with death rate among adults.[12,21,24,27-29] Regarding sex, several previous studies on adults reported the insignificant relationship of sex with TBI outcome.[12,24,27] However, a study on adults found sex as a significant predictor of TBI outcome.[21]

Table 6. Results of the Logistic Regression Analysis for the Predictors of Early Death Among Children with Traumatic Brain Injury

Factors	B	SE	Odds Ratio	*P* Value
Glasgow Coma Scale score	−0.975	0.409	0.377	0.017
Skull fracture	2.114	1.551	8.285	0.173
Surgery	−3.795	3.756	0.022	0.312
Site of TBI	0.958	1.082	2.607	0.376
Rotterdam score	2.357	0.936	10.559	0.012

B, unstandardized coefficients; SE, standard error; TBI, traumatic brain injury.

Based on treatment type and cure rate, findings showed that with increasing Rotterdam score, the cure rate was decreased in both surgical and medical treatments. It is obviously in severe TBI that the survival rate is low even with surgical management.

Our findings also showed that GCS score is a significant predictor of TBI outcome, so that each one-point increase in GCS score was associated with a 0.37-time decrease in mortality rate. Several earlier studies also reported the same finding,[21,24-28,30] whereas 2 studies showed no significant correlation between GCS score and TBI outcome.[6,12]

The Rotterdam score was the other significant predictor of TBI outcome in the present study even after adjusting, through the logistic regression analysis, the effects of age, sex, GCS score, need for surgery, and sites of skull fracture and brain injury. Our findings showed that each one-point increase in Rotterdam score was associated with a 10.5-time increase in mortality rate. An earlier study also showed that after adjusting for the effects of confounders, the Rotterdam score had significant effects on pediatric TBI outcome with an odds ratio of 1.75.[22] Two other studies also reported the significant correlation of Rotterdam score with mortality rate.[21,27] Another study also reported that although the Rotterdam score at hospital admission had no significant effects on in-hospital mortality rate, it had significant effects on 6-month mortality rate.[28] Moreover, a study on patients with severe TBI who had undergone decompressive craniotomy showed that mortality rate increased with Rotterdam score, so that at score 2 the mortality rate was 7.7% and at score 6 it was 66.7%. The Rotterdam score was an independent predictor of mortality and prognosis in that study.[24] However, a study on patients with mild TBI found that the highest prevalence was related to Rotterdam score 3 (51%), mortality rate was 1%, and the Rotterdam score had no significant relationship with mortality rate. Therefore, that study concluded that Rotterdam score is not a reliable method for outcome prediction among patients with mild TBI.[29]

The present study was among the few studies that evaluated the value of the Rotterdam score in predicting TBI outcome among children, thus, its findings can have different applications to clinical practice. One of the strengths of this study was TBI outcome assessment during hospitalization that helped precisely determine TBI mortality rate through ruling out non-TBI causes of death (such as deep vein thrombosis and pneumonia) that occur after hospital discharge. Moreover, this study was performed on children with TBIs of different severities, whereas most previous studies only evaluated moderate to severe TBIs. However, among the weaknesses of the study were the use of a retrospective design and the collection of the data from patients' medical records. Future studies are recommended to evaluate the relationships of the Rotterdam score with long-term TBI-related mortality and disability.

CONCLUSIONS

This study concludes that the Rotterdam CT scoring system is a significant independent predictor of pediatric TBI outcome. At a cut-off score of 3, the Rotterdam system can predict pediatric TBI outcome with acceptable sensitivity and specificity. Therefore, given its simplicity, objectivity, and easy applicability, the Rotterdam system is recommended for primary assessment of pediatric TBI.

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