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COMPUTED TOMOGRAPHY SCORING SCALES AS EARLY OUTCOME PREDICTORS IN PATIENTS WITH TRAUMATIC BRAIN INJURY: WHICH ONE TO USE?

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SUMMARY − Computed tomography (CT) is an essential tool in diagnosing and treating traumatic brain injury (TBI). Marshall CT classification, Rotterdam and Helsinki CT scores were consecutively developed as prediction outcome scales by computing TBI CT abnormalities. None of them classifies the pathological CT findings in the same manner. We aimed to determine which one is most accurate and has the best grading discriminatory power in determining early outcome. All TBI patients treated at a single center in a one-year period having undergone a CT scan on admission were retrospectively included. After calculation of all three scores, comparison among scale performances, as well as their accuracy in predicting patient 6-month outcome by the Glasgow Outcome Scale (GOS) was made. We used the Receiver Operating Characteristic curves to analyze correlation between all scales and early outcome. We calculated the area under the curve (AUC) to determine the power of each system while paired samples T-test was used to determine correlation among the scales. Mann-Whitney U test was performed to determine difference in outcome groups. A total of 1006 patients were included in final analysis. The mean patient age at presentation was 55.6 (±20.1) years, overall mortality was 6.4%, mean GOS was 3.00 (±1.4), and mean Glasgow Coma Score (GCS) was 13.9 (±0.2). Mortality was higher among patients with lower scores ($p<0.01$ all). The AUCs indicated that all scoring systems had a similarly high discriminative power in predicting early unfavorable outcome (Marshall AUC 0.86 *vs*. Rotterdam AUC 0.82 *vs*. Helsinki AUC 0.84). High correlation was found between Marshall and Rotterdam grading, $r = 0.78$, and moderate correlation between the other two pairs (Marshall *vs*. Helsinki, r=0.62, and Rotterdam *vs*. Helsinki, r=0.51). Additionally, low GCS and high injury severity score (ISS) could be identified as strong predictors of early death and poor outcome. In conclusion, all classification systems demonstrated a similar, strong predictive power for early outcome, but even greater discrimination results could be obtained if GCS and ISS were incorporated in the calculation. Helsinki CT score was least predictable of all three, and had the lowest correlation with the other two. Although Marshall CT classification was the oldest and simplest, it had at least the same prediction power as the newer scoring scales and should remain in use. Therefore, for prognostic purposes, this study recommends using one individual scale in clinical application to get the best possible prediction for TBI.

Key words: *Marshall CT classification; Rotterdam CT score; Helsinki CT score; Early death; Early outcome; Traumatic brain injury*

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Introduction

Traumatic brain injury (TBI) stands as a pervasive global health concern, emphasizing the need of an accurate diagnostic classification system that can reliably predict outcomes. Conventionally, individuals with TBI are stratified into mild, moderate, and severe categories based on the Glasgow Coma Scale (GCS)[1]. In cases of severe head injuries requiring intubation for airway protection and paralysis to manage heightened intracranial pressure (ICP), computed tomography (CT) becomes pivotal, particularly in situations where ICP monitoring or other intensive care unit (ICU) monitoring methods are not utilized[2,3]. When patients exhibit restlessness and necessitate sedation for compliance during CT head scans, assessing the GCS score accurately becomes a complex task[4,5]. In such circumstances, an effective and timely approach involves employing a classification system that integrates morphological criteria derived from radiological images. Although magnetic resonance imaging remains a valid option, the time frame for its acquisition, availability to trauma and intensive care departments (ICU), low specificity for blood detection combined, higher cost of operation, as well as the hindrance of its utilization in ventilated sick patients limits its role. It is therefore limited for detecting white matter changes in later phases of the disease[6,7]. Therefore, CT remains the quintessential imaging modality for the assessment of acute structural damage in TBI within the contemporary radiographic arsenal, holding its unrivaled position as the cornerstone of TBI imaging. CT scans have propelled substantial advancements, contributing significantly to the enhancement of overall outcomes in TBI patients. The prognostic significance of specific CT variables, such as basal cistern status, midline shift, traumatic subarachnoid hemorrhage, and distinct types of intracranial lesions, has garnered robust validation in previous studies, establishing them as class I or class II levels of evidence[8,9]. Over the past period, many CT scoring scales have been designed, but only 3 of them have stood out, i.e., Marshall[10], Rotterdam[11] and Helsinki[12] CT scales. Marshall scale was introduced in 1991. It included factors such as cistern compression, midline shift, volume of the intracranial lesion, and surgical treatment of TBI patient[10]. The last factor is questionable as it is not a CT feature but the surgeon decides whether or not to operate on the patient, which is in many cases still in the grey zone. Rotterdam scale was developed 14 years later, and besides cistern compression, midline shift and hematoma volume, it also included the presence of epidural hematoma and traumatic subarachnoid hemorrhage (tSAH)/intraventricular hemorrhage (IVH) in order to improve the predictability[11]. In 2014, the Helsinki CT score was introduced including previously mentioned traumatic fractures where the tSAH/IVH was replaced by IVH alone as it is more precise in determining prediction outcome according to the authors[12]. Comparing these scales on a single group of patients can enable physicians to determine which one should be the scale of choice so that the resource allocation and treatment steps could be predicted in order to get the best for the patient with TBI. Scales and their scores are illustrated in Table 1.

Materials and Methods

This retrospective study included consecutive 1006 traumatic neurosurgical patients with mild-to-severe TBI observed at the Department of Neurosurgery, Clinical Center of Vojvodina, Novi Sad, Serbia, from June 1, 2015 to May 31, 2016. The study included all patients with indications for head CT scan according to the National Institute for Health and Care Excellence (NICE) TBI CT criteria. Patients requiring urgent surgery were immediately transported to the operating room. After the procedure, they were transferred to the ICU, whereas patients with positive CT findings but without surgically treatable lesions were transferred to the department ward (mild TBI) or ICU (moderate and severe TBI), depending on the severity of TBI. Patients with negative CT scan and no adjacent injuries without serious symptoms were discharged home after a minimum 4-hour observation, whereas the group with significant symptoms but no CT verified lesions were admitted to the department ward. Age and sex, GCS, injury severity score (ISS), and timing of injury were also noted.

Clinical data were collected by the department neurosurgical team and retrospectively collected in a separate database. Outcome evaluation based on the Glasgow Outcome Scale (GOS)[3] was performed by senior neurosurgeons who were blinded for the initial CT score (10-12) at discharge. For statistical analysis, we dichotomized into good/satisfactory (GOS 4 and 5) poor recovery/outcome (GOS 1-3). Each CT

Table 1. Computed tomography (CT) score calculation with ranking

Marshall CT classification		Rotterdam CT score		Helsinki CT score	
CT does not show traumatic lesions	I	Basal cisterns	0 normal 1 compressed 2 absent	Compressive hematoma type	2 subdural 2 intracerebral -3 epidural
Midline shift 0-5 mm, maximal intracranial lesion volume <25 cm^3	II	Midline shift	0 0-5mm 1 >5mm	Maximal intracranial lesion volume	0 <25 cm^3 2 >25 cm^3
II + compression or absence of basal cisterns	III	Epidural compressive lesion	0 yes 1 no	Intraventricular hemorrhage	0 yes 3 no
Midline shift >5 mm, maximal intracranial lesion volume >25 cm^3	IV	Intraventricular/ subarachnoid hemorrhage	0 yes 1 no	Basal cisterns	0 normal 1 compressed 5 absent
Surgically evacuated lesion with compressive effect	V	Scale modification	1		
Non evacuated lesion with compressive effect	VI				
Rank I-VI		Rank 1-6		Rank -3-14	

score would be calculated by the individual team of radiologists and then tallied with the final score in the rounds. Inter-rater reliability was not determined in all steps of evaluation. The aim of this study was to evaluate how well did different scores correlate with early outcome. Furthermore, we wanted to evaluate which radiographic, clinical and demographic parameters predicted poor outcome.

Statistical analysis

The area under receiver operating characteristic (AUC) curve was used to assess the poor outcome predictive power of the scales, while paired samples T test was used to determine correlation among the scales, and Mann-Whitney U test was performed to determine the difference in outcome groups. The level of statistical significance was set at $p<0.05$. All tests were performed using the IBM Corp. SPSS 21.0 Statistics software.

Results

Study cohort

A total of data on 1006 patients were included into final analysis. The majority of patients were males (66.0%). The mean age was 55.6±20.1 standard deviation (SD) years. The mean GCS was 13.9±0.2, divided into mild/moderate/severe TBI of 85.5%/6.7%/8.8%. The mortality rate at the end of hospitalization was 6.4%. The mean GOS was 3.00 (±1.4).

Impact of demographics and clinical characteristics on the outcome

Age was not found to be a significant factor for the outcome. GCS and ISS were found to play a statistically crucial role in the outcome of TBI patients ($p=0.02$ and $p=0.03$, respectively), while no other evaluated admission data had statistical significance in prediction ($p>0.05$ all).

CT TBI scores and prediction of early outcome

Precise difference of outcome groups with Mann-Whitney U test analysis in terms of prediction scales is shown in Table 2. The outcome was worse in patients with higher scores in all three scales, but a Marshall score of 5 had lower scores of poor outcomes than some of lower Marshall scores. All 3 scales had a high discriminative power for poor outcome (Marshall 0.86, Rotterdam 0.82, and Helsinki 0.84 AUC ROC curve) (Fig. 1), and there was no statistical difference in scale

powers (one-way ANOVA ranks p=0.543). Marshall and Rotterdam scales showed high correlation (Pearson's correlation coefficient r=0.78), while Helsinki scoring system had moderate correlation with Marshall scale (r=0.62) and Rotterdam scale (r=0.51) when using paired samples T test.

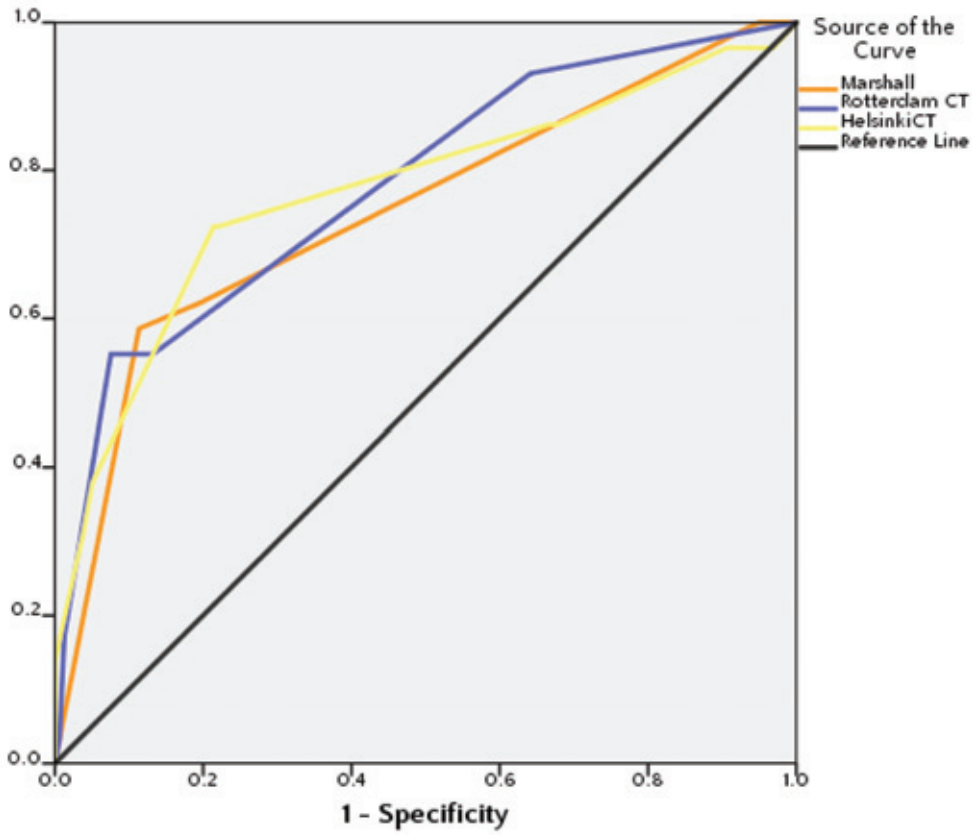

Fig. 1. ROC curves comparing all 3 scales according to early unfavorable outcome.

ROC curve = receiver operating characteristic curve

Table 2. Outcome differences among computed tomography (CT)scales

Scale	Outcome	Average rank	Median	U	Z	p
Marshall CT classification	Poor	272.78	4.0	2031.0	-80.9	0.000
	Good	484.80	0.0			
Rotterdam CT score	Poor	272.15	4.0	1690.5	-10.0	0.000
	Poor	496.15	1.0			
Helsinki CT score	Poor	273.30	4.0	2308.5	-85.0	0.000
	Good	475.55	0.0			

Discussion

Since the development of CT, many different scoring systems have been developed in order to classify TBI or predict its outcomes. Marshall system has proved as a valuable predictor for these patients. Still, it has many limitations such as surgically treated patients, which is not a CT characteristic but surgeon's decision and as such is not uniform, as also confirmed by our research having better outcome in cases of Marshall 5 (surgically treated patients)[13]. We validated outcome predictability with all 3 scales. Despite some papers claiming that Rotterdam CT score is superior to Marshall, this group of authors did not find such difference or between Helsinki CT scale and the other two[12,14,15]. On the other hand, good correlation was only found between Marshall and Rotterdam scales, while Helsinki showed only moderate correlation. This is explained by higher similarity of examined factors in Marshall and Rotterdam scales (as well as indications for operative treatment) than with Helsinki score. The same prediction power was described by other authors[9]. As the 6-month outcome is largely influenced by rehabilitation and therapy, we choose discharge outcome status as the measuring criterion as all the examined patients received the same in-hospital treatment[16]. Other studies focused only on moderate/severe TBI and therefore used early mortality as the outcome criterion. As most mild TBI (mTBI) patients survive the injury, according to Mata-Mbenba *et al.*, mortality might not be the right outcome criterion for mTBI, so the outcome based on GOS scale was used in the study[10]. In the future, it will be important to develop study models that will incorporate not just the imaging characteristics but also include the clinical parameters which play a pivotal role in predicting outcome following TBI[17]. Marshall and Helsinki score were developed from the group designed for those scales for CT classification, whereas Rotterdam scale was designed as a byproduct from a project. All of the initial CT findings had individual strong correlation with outcome results, which is consistent with the previously published papers. None of the 3 scales includes characteristics such as diffuse axonal injury (DAI) and brainstem lesions, as well as no degree of tSAH the predictive power of which is described in Morris-Marshall classification[18]. DAI can often have different CT characteristics and different outcomes. Therefore, no uniform model for its classification based on CT scan can be developed[19]. At the same time, the majority of brainstem lesions and infarctions are considered to be lethal and therefore do not have a scalable value in the CT prediction scales[20].

Limitations

The results were formulated from retrospective analysis of the characteristics of the earliest patient CT scans. Studies have verified the higher predictive value in better assessment of the outcome from inclusions of the variables of the worst CT scan[19]. Outcome analysis was performed at discharge from the hospital, which can lead to false summations as the outcome can get worse by pneumonia, sepsis, etc., and significantly higher by good rehabilitation and proper medication on later follow-up points[20]. To limit this, some authors have even suggested taking mortality at 1 week into account[21-23]. Another drawback in the use of CT scans is human error when interpreting the scan. According to Havill *et al.*, up to around one-third of observer errors can be made in one variable[24]. There was also a significant difference in defining and categorizing mass lesions in almost half of the cases[25-27]. Despite limitations, initial CT scan in TBI, which was the main interest of this study, is often used as a baseline guideline and its prognostic impact can direct further treatment plans in order to achieve satisfactory outcome[28].

Conclusion

Predicting the outcome following TBI stands as the ultimate objective in our endeavors to plan and manage resources for patients with TBI. Its profound impact on the economy of developing countries cannot be overstated. For prognostication to be clinically meaningful, outcomes must accurately mirror future life. In summary, this study concludes that all three scores exhibit high predictability for assessing early mortality/outcome. No preferable scale was identified among the three examined, although the Helsinki score requires further validation. Therefore, for prognostic purposes, this study recommends utilization of a single individual scale in clinical applications to obtain the best possible prediction for TBI.

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Sažetak

LJESTVICE BODOVANJA KOMPJUTORIZIRANE TOMOGRAFIJE KAO PREDIKTORI RANOG ISHODA KOD BOLESNIKA S TRAUMATSKIM OŠTEĆENJIMA MOZGA: KOJU LJESTVICU PRIMIJENITI?

J. Golubović, P. Vuleković, Dj. Djilvesi, N. Krajčinović, I. Horvat, B. Jelača, F. Pajičić, N. Lasica, S. Stošić, A. Rotim i *L. Rasulić*

Kompjutorizirana tomografija (CT) je osnovno sredstvo u dijagnosticiranju i liječenju traumatskih oštećenja mozga (TOM). Marshallova CT klasifikacija, Rotterdam CT i Helsinki CT zbrojevi su sukcesivno razvijeni kao ljestvice za predviđanje ishoda na osnovi patoloških nalaza prikazanih na CT snimcima bolesnika s TOM. Nijedna od njih ne klasificira patološke CT nalaze na isti način. Cilj ove studije je bio utvrditi koja je ljestvica najpreciznija i ima najbolju diskriminatornu moć u predviđanju ranog ishoda. Svi bolesnici s TOM liječeni u tercijarnom centru unutar razdoblja od jedne godine kojima je načinjen CT snimak endokranija kod prvog pregleda su retrospektivno uključeni u studiju. Nakon izračunavanja svih triju ljestvica uspoređene su performanse ljestvica, kao i njihova točnost u predviđanju šestomjesečnog ishoda liječenja bolesnika prema Glasgowskoj ljestvici ishoda (*Glasgow Outcome Scale*, GOS). Korištene su krivulje karakteristika prijamnika (ROC krivulje) kako bi se analizirala korelacija između svih ljestvica i ranog ishoda liječenja. Izračunata je površina ispod krivulje (AUC) kako bi se utvrdila moć svakog sustava, dok je upareni t-test korišten za utvrđivanje korelacije među ljestvicama. Mann-Whitneyjev U test je primijenjen kako bi se utvrdila razlika u skupinama s različitim ishodom. Ukupno je 1006 bolesnika uključeno u konačnu analizu. Prosječna starost bolesnika kod prijma je bila 55,6 (±20,1) godina, ukupna stopa smrtnosti je bila 6,4%, prosječan GOS je bio 3,00 (±1,4), a prosječna Glasgowska ljestvica kome (*Glasgow Coma Scale*, GCS) kod prijma je bila 13,9 (±0,2). Smrtnost je bila veća kod bolesnika s nižim vrijednostima na ljestvicama ($p<0,01$ za sve). AUC je pokazao da su svi sustavi bodovanja imali slično visoku diskriminativnu moć u predviđanju ranog nepovoljnog ishoda (Marshall AUC 0,86 prema Rotterdam AUC 0,82 prema Helsinski AUC 0,84). Visoka korelacija je nađena između Marshallove i Rotterdam ljestvice, $r = 0.78$, dok je umjerena korelacija nađena između ostala dva para (Marshall prema Helsinki, $r=0,62$ i Rotterdam prema Helsinki, $r=0,51$). Usto, nizak GCS i visok zbroj težine ozljede (*injury severity score*, ISS) su identificirani kao jaki prediktori rane smrti i lošeg ishoda. Zaključno, svi sustavi klasifikacije pokazali su sličnu, snažnu prediktivnu moć za rani ishod, ali bi se čak i bolji diskriminatorni rezultati mogu postići ako se GCS i ISS uključe u ljestvice procjene. Iako je Marshallova CT klasifikacija najstarija i najjednostavnija, ima barem jednaku prediktivnu moć kao i noviji sustavi bodovanja i stoga treba ostati u upotrebi. Zato za prognostičke svrhe ova studija preporučuje uniformnu uporabu jedne individualne ljestvice u kliničkoj primjeni kako bi se dobila najbolja moguća predikcija za liječenje TOM.

Ključne riječi: *Marshallova CT klasifikacija; Rotterdam CT zbroj; Helsinki CT zbroj; Rana smrtnost; Rani ishod; Traumatsko oštećenje mozga*