Early CT Findings to Predict Early Death in Patients with Traumatic Brain Injury:

Marshall and Rotterdam CT Scoring Systems Compared in the Major Academic Tertiary Care Hospital in Northeastern Japan

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Rationale and Objectives: Computed tomography (CT) plays a crucial role in early assessment of patients with traumatic brain injury (TBI). Marshall and Rotterdam are the mostly used scoring systems, in which CT findings are grouped differently. We sought to determine the scoring system and initial CT findings predicting the death at hospital discharge (early death) in patients with TBI.

Materials and Methods: We included 245 consecutive adult patients with mild-to-severe TBI. Their initial CT and status at hospital discharge (dead or alive) were reviewed, and both CT scores were calculated. We examined whether each score was related to early death; compared the two scoring systems' performance in predicting early death, and identified the CT findings that are independent predictors of early death.

Results: More deaths occurred among patients with higher Marshall and Rotterdam scores (both $P < .05$, Mann–Whitney U test). The areas under the receiver operating characteristic curve (AUCs) indicated that both scoring systems had similarly good discriminative power in predicting early death (Marshall, AUC = 0. 85 vs. Rotterdam, AUC = 0.85). Basal cistern absence (odds ratio [OR] = 771.5, $P < .0001$), positive midline shift (OR = 56.2, $P = .0011$), hemorrhagic mass volume $\geq$25 mL (OR = 12.9, $P = .0065$), and intraventricular or subarachnoid hemorrhage (OR = 3.8, $P = .0395$) were independent predictors of early death.

Conclusions: Both Marshall and Rotterdam scoring systems can be used to predict early death in patients with TBI. The performance of the Marshall score is at least equal to that of the Rotterdam score. Thus, although older, the Marshall score remains useful in predicting patients' prognosis.

Key Words: CT; Marshall; Rotterdam; early death; traumatic brain injury.

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Because traumatic brain injury (TBI) is a leading cause of mortality and morbidity among young people worldwide, outcome prediction at admission is crucial for clinical decision making, resource allocation, and counseling of patients' families.

Computed tomography (CT) currently plays an important role in the rapid assessment of patients with TBI in that it detects posttraumatic hemorrhagic lesions and allows selection of patients who require emergency neurosurgery. To predict the outcome of patients with TBI, two scoring systems that use initial CT findings but group them differently have been introduced: Marshall score in 1991 (1) which was followed by Rotterdam score in 2005 (2) in an attempt to improve the performance yield in predicting patients' outcome. Both scoring systems are currently used widely in studies assessing patients with TBI either to show subject demographics (3,4) or as independent predictor of patients' outcome (5–7).

However, only a handful of studies (5,6) have assessed the performance of the two CT scoring systems. In all these studies, which unanimously reported that Rotterdam score to be better than Marshall score, the endpoint was the long-term outcome, such as mortality at 6 months after TBI. To our knowledge, no reported study has exclusively compared the performance of the two scoring systems in predicting death at hospital discharge (early death). Moreover, most assessments of CT scoring systems have included only patients with

moderate (Glasgow coma scale [GCS] score 9–12) and severe (GCS ≤ 8) TBI (1–5,7,8). In patients with mild TBI (GCS 13–15) at admission, the New Orleans criteria (8) or Canadian CT head rule (9) is applied to identify patients with elevated risks of trauma-related complications who should undergo CT, thereby avoiding unnecessary CT scans (10). Only Nelson et al. (5) reported a relatively large-scale study wherein the performances of Rotterdam and Marshall scores were evaluated in patients with mild-to-severe TBI. In our opinion, however, they also compared the performance of both scoring systems in predicting long-term outcome, but not early death.

In this study, we compared the performance of the Marshall and Rotterdam CT scoring systems in predicting early death and identified specific CT findings independently predicting early death in 245 consecutive patients with TBI. The patient sample included not only moderate and severe cases but also mild cases of TBI with indications for CT examination according to the New Orleans criteria or Canadian CT head rule (8,9).

METHODS

Patients

We retrospectively reviewed the medical records of all consecutive patients who sustained TBI with or without associated extracranial traumatic lesions and were admitted to our institution, the major academic tertiary care hospital in northeastern Japan, in 2009 and 2010. Patients fulfilling the following criteria were included in the study: (1) recent history (<24 hours) of TBI, (2) age ≥ 15 years (as Marshall and Rotterdam scores have not been validated in patients aged < 14 years), (3) initial CT performed within 24 hours after injury, and (4) moderate (GCS 9–12) or severe (GCS ≤ 8) TBI. Patients with mild TBI (GCS 13–15) were also included if they underwent CT examinations in accordance with the New Orleans criteria and/or the Canadian CT head rule (8,9). Using above inclusion criteria, we selected 249 patients with TBI from our hospital database. Of the 249, four patients who fulfilled the criteria, but showed only chronic subdural hematoma on initial CT, which was probably unrelated to the recent TBI history, were excluded, leaving 245 patients for this study.

GCS and the following demographic data were gathered for each patient: age, sex, mechanism of injury, time from admission to hospital discharge, cause of death (when applicable), and status at hospital discharge (dead or alive). These general characteristics are summarized in Table 1. At the time of admission to the emergency room, clinical symptoms were mild (GCS 13–15) in 154 (62.8%), moderate (GCS 9–12) in 46 (18.8%), and severe (GCS ≤ 8) in 45 (18.4%) patients.

Patient Status at Hospital Discharge

At the time of hospital discharge, 220 of 245 (89.8%) patients were alive and 25 (10.2%) were dead. The median length of

TABLE 1. General Characteristics of the Study Population (n = 245)

Characteristic	Patients n (%)
GCS at ED*	12 (3.9)
Sex	
Male	165 (67.3)
Female	80 (32.7)
Age (years)*	49.4 (22.6)
Mechanism of injury	
Traffic accident	121 (49.4)
Fall	106 (43.3)
Other	18 (7.3)
Discharge status	
Alive	220 (89.8)
Dead	25 (10.2)

ED, emergency department; GCS, Glasgow coma scale.
*Mean (standard deviation).

TABLE 2. Five CT Items Included in the Marshall and/or Rotterdam Score

CT Finding	Marshall	Rotterdam
Basal cistern status	Included	Included
Midline shift	Included	Included
EDH	Not included	Included
SAH/IVH	Not included	Included
Hemorrhagic mass volume	Included	Not included

CT, computed tomography; EDH, epidural hematoma; SAH/IVH, subarachnoid hemorrhage/intraventricular hemorrhage.

hospitalization (from admission to discharge) was 4 days (lower quartile, 2 days; upper quartile, 16 days) and did not differ significantly between patients who were alive (median [lower quartile, upper quartile], 4 [2, 17] days) and dead (3 [1.5, 15.5] days) before or at the time of discharge (P = .79). The cause of death was TBI in all 25 patients who died before discharge; no patient died from an extracranial cause. Four of 154 (2.6%) patients with mild TBI, 3 of 46 (6.5%) with moderate TBI, and 18 of 45 (40%) patients with severe TBI died before discharge.

Evaluation of CT Findings

Two experienced neuroradiologists who were blinded to patients' clinical data independently reviewed initial CT findings obtained within 24 hours after injury. Disagreements were resolved by consensus.

Five initial CT findings used in Marshall and Rotterdam scoring systems (Table 2) were evaluated: basal cistern status, presence of midline shift, presence of epidural hematoma (EDH), presence of intraventricular hemorrhage and/or subarachnoid hemorrhage (IVH/SAH), and volume of the hemorrhagic mass. Basal cistern status was classified as normal,

TABLE 3. Marshall Scoring System

Score	Definition
1	No visible intracranial pathology on computed tomography
2	Cisterns are present with 0–5 mm midline shift and/or lesion densities present; no high- or mixed-density lesion >25 mL includes bone fragments or foreign bodies
3	Cisterns compressed or absent with 0–5 mm midline shift; no high- or mixed-density lesion >25 mL
4	Midline shift >5 mm; no high- or mixed-density lesion >25 mL
5	Any lesion surgically evacuated
6	High- or mixed-density lesion >25 mL; not surgically evacuated

Adapted from Mass et al. (2).

TABLE 4. Rotterdam Scoring System

CT Finding	Score	Definition
Basal cistern	0	Normal
	1	Compressed
	2	Absent
Midline shift	0	≤5 mm
	1	>5 mm
EDH	1	Absent
	0	Present
SAH/IVH	0	Absent
	1	Present

EDH, epidural hematoma; SAH/IVH, subarachnoid hemorrhage/intraventricular hemorrhage.

The final score (0–6) is calculated by summing the item scores and adding 1.

compressed, or absent. Midline shift was defined as displacement of the septum pellucidum in relation to the midline and was recorded in millimeters. A midline shift >5 mm was scored as present, and a shift ≤5 mm was scored as absent (1,2). SAH/IVH and EDH were classified as present or absent. Hemorrhagic mass was defined as any intracranial hemorrhagic lesion other than SAH/IVH, including subdural hematoma, EDH, parenchymal hematoma, and hemorrhagic brain contusion (1).

The overall volume of each hemorrhagic mass was calculated by digital measurement using a dedicated workstation by multiplying the sum area of hemorrhagic masses on each slice by the slice thickness (3,11,12). The volume of hemorrhagic mass in each patient was graded as absent, <25 mL, or ≥25 mL.

Calculation of Marshall and Rotterdam scores

Among the five CT findings, basal cistern status and the presence of a midline shift are included in both CT scoring systems. Hemorrhagic mass volume is included only in Marshall score (Table 3), and the presence of SAH/IVH and EDH are included only in Rotterdam score (Table 4).

Marshall scores range from 1 to 6 (Table 3), based on the three CT findings and/or the type of hemorrhagic mass management (surgical evacuation, yes/no) (1–3,13). Patients from whom any TBI-related lesion was removed surgically were assigned a score of 5, and those with hemorrhagic mass volumes ≥25 mL who did not undergo surgical removal were assigned a score of 6, regardless of other CT findings (Figs 1 and 2) (1,2,13).

Rotterdam scores (Table 4) were calculated as follows (2,7): (1) basal cistern status was classified as normal (0), compressed (1), or absent (2); (2) midline shift was classified as 0–5 mm (0) or >5 mm (1); (3) EDH was scored as present (0) or absent (1); and (4) SAH/IVH was scored as absent (0) or present (1). One point was added to each summed Rotterdam score to achieve numerical consistency with the six-point Marshall score (Figs 1 and 2; 1,2,7,13).

A representative case showing how to calculate both scoring systems in patients with TBI is shown in Figure 1.

Statistical Analysis

First, we examined whether Marshall and Rotterdam scores were related to early death by univariate analyses using the Mann–Whitney U test. Second, we calculated the areas under the receiver operating characteristic curve (AUCs) to quantify the comparative performance of the two CT scoring systems in predicting early death. Finally, to identify specific initial CT findings independently predicting early death, we applied univariate and multivariate logistic regressions with early death serving as the dependent variable and the five CT findings included in Marshall and/or Rotterdam systems serving as independent variables.

The Mann–Whitney U test and the multiple logistic regression analyses were performed using the JMP Pro software v 9.0 (SAS Institute Inc., Cary, NC) and P values <.05 were considered to indicate statistical significance. The AUCs were produced using ROC-kit Chicago (ROC library 1.0.3 v 2011), and AUC values of 0.50, ≥0.8, and 1.0 were considered to indicate poor, good, and perfect performances, respectively (14).

This study was approved by our institutional review board. The requirement for patients' provision of informed consent was waived.

RESULTS

Performance of Marshall and Rotterdam CT Scoring Systems in Predicting Early Death

Table 5 lists the distribution of patients according to Marshall and Rotterdam scores. Univariate analysis showed that Marshall (P < .0001; Fig 3a) and Rotterdam (P < .0001; Fig 3b) scores were significantly higher in patients who
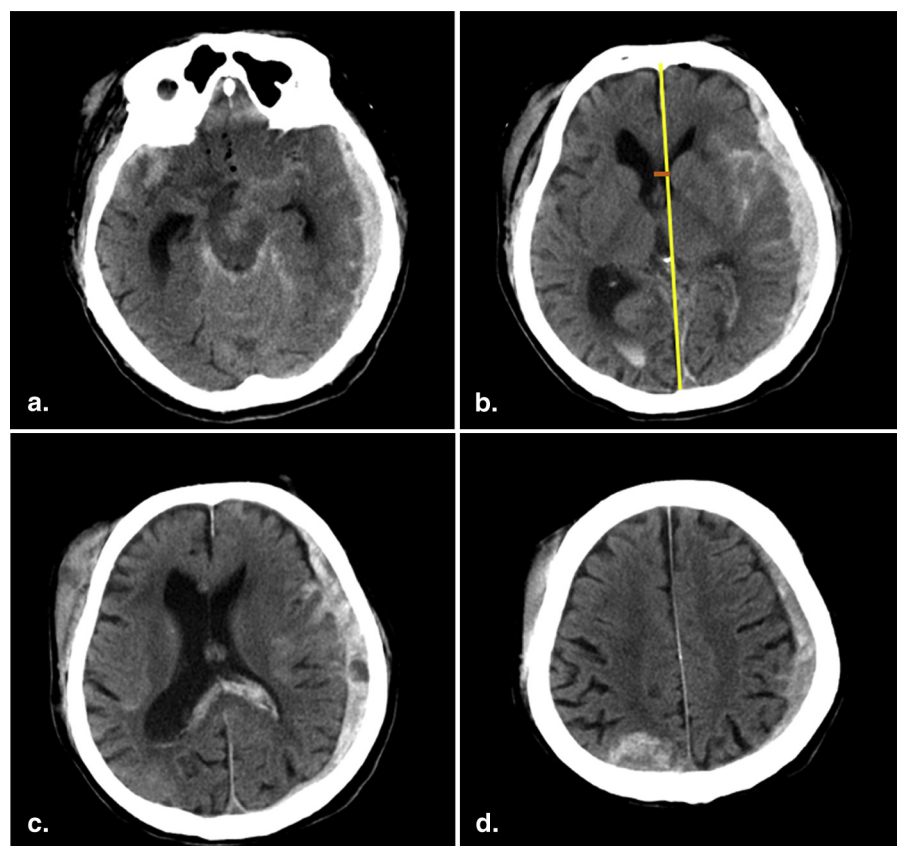
Figure 1. A representative case showing how to calculate both computed tomography (CT) scoring systems. It is about a 93-year-old man who fell from a second floor and who showed a Glasgow coma scale of 6/15 at admission in the emergency room. The initial CT scan performed 6 hours after injury reveals the following: (1) According to Marshall score, a "hemorrhagic mass" made of left subdural hematoma **(a–d)** and right parietal intracerebral hematoma **(d)**. The overall volume of these hemorrhages measures >25 mL (95.6 mL). Because no surgical evacuation of the mass was done, the Marshall score was equal to 6, regardless of other CT findings, (2) According to Rotterdam score, the basal cistern appears compressed **(a)** (=1) with a positive midline shift (**b**, *brown line*) (≥5 mm) (=1). SAH/IVH is noted **(a–c)** (=1), but no EDH is found (=1). The sum score of these four CT items was 4. Thus, the overall Rotterdam score was 5, resulting from summing up each item +1. The patient died from TBI 24 hours after admission. EDH, epidural hematoma; IVH, intraventricular hemorrhage; SAH, subarachnoid hemorrhage.
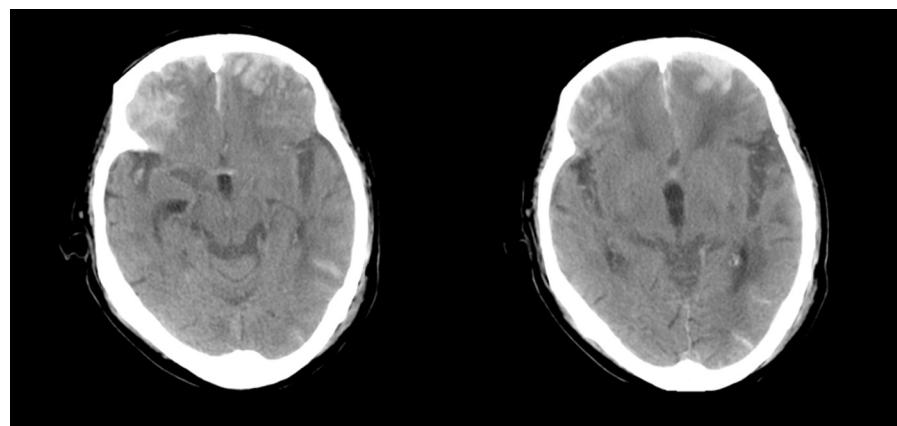
Figure 2. Showing the discrepancy between the Marshall and Rotterdam scoring systems in patient with "hemorrhagic mass". It is about an 83-year-old man who fell down the stairs and who showed a Glasgow coma scale of 10/15 at admission in the emergency room. His initial computed tomographic scan obtained 2 hours after injury reveals brain contusions (=hemorrhagic mass) involving the bases of bilateral frontal lobe. The total volume of the hemorrhagic mass was more than 25 mL (94.4 mL), and surgical removal of the lesion was not performed. In addition, SAH and nontraumatic lesion (ischemic changes) are also noted. The Marshall score was 6 (mass > 25 mL without surgical removal). In contrast, Rotterdam score was calculated as follows: normal basal cistern (=1) and no midline shift (=0), the EDH was absent (=1) and SAH/IVH was present (score = 1). The Rotterdam score was 2 + 1 = 3. The patient died 5 days after admission. EDH, epidural hematoma; IVH, intraventricular hemorrhage; SAH, subarachnoid hemorrhage.

were dead at the time of discharge than in those who were alive. Thus, both scores were significantly related to patient discharge status (dead or alive).

The AUCs (95% confidence intervals: lower–upper quartiles) indicated that both scoring systems had a similarly good discriminative power in predicting early death (Marshall

TABLE 5. Distribution of Patients (*n* = 245) According to Marshall and Rotterdam Scores

Computed Tomography Scoring System	Patients *n* (%)
Marshall score	
1	132 (53.9)
2	67 (27.4)
3	3 (1.2)
4	1 (0.4)
5	30 (12.2)
6	12 (4.9)
Rotterdam score	
1	2 (0.8)
2	149 (60.8)
3	62 (25.3)
4	11 (4.5)
5	14 (5.7)
6	7 (2.9)

score, AUC = 0. 85 [0.79–0.92] vs. Rotterdam score, AUC = 0.85 [0.78–0.93]).

CT Findings Independently Associated with Early Death

Associations of the five CT findings with the outcome of early death are summarized in Table 6. Univariate and multivariate logistic regression analysis (Table 6) identified basal cistern absence [score 0–2; adjusted odds ratio [aOR] = 771.5; $P < .0001$], positive midline shift (aOR = 56.2, $P = .0011$), hemorrhagic mass volume ≥25 mL (score 0–2; OR = 12.9; $P = .0065$), and positive SAH/IVH (aOR = 3.8, $P = .0395$) as independent predictors of early death, whereas EDH ($P = .3452$) was not a predictor.

DISCUSSION

We compared the performance of Marshall and Rotterdam CT scoring systems and individual CT findings included in these systems in predicting early death in patients with TBI. Both scores were significantly and positively associated with early death (Marshall score, AUC = 0.85 vs. Rotterdam score, AUC = 0.85). Furthermore, the multiple logistic regression analysis revealed that basal cistern absence and positive midline shift were the two strongest predictors of early death among CT findings, followed by voluminous hemorrhagic mass and positive SAH/IVH.

Our results suggest that Marshall and Rotterdam systems can be used to assess early death. We believe that this study constitutes the first validation of Rotterdam scoring system's role in predicting early death in patients with TBI and constitutes one of the rare validations of both scoring systems in the subjects including patients with mild TBI.

The positive relationships between the two scoring systems and early death can be explained by their inclusion of the two strongest predictors of early death on CT: basal cistern absence and positive midline shift. However, the discrepancy between the predictive power of the next two significant independent predictors (voluminous hemorrhagic mass [OR = 12.9, $P = .0065$] and positive SAH/IVH [OR = 3.8, $P = .0395$]) led us to speculate that, although older than Rotterdam score, the performance of Marshall score, in which the third strongest predictor (the voluminous hemorrhagic mass) is included, could be slightly stronger in predicting early death. Indeed, the three items included in Marshall score are interrelated (3), in that, the voluminous hemorrhagic mass often lead to midline shift and compression of basal cistern, which may result to the increased intracranial pressure, which is a critically life-threatening condition. In that sense, our findings are in accord with studies (2,15) that reported less death in patients with Marshall score of "5" compared to those with a score of "6". This may be explained by the fact that in former patients group, the voluminous mass (a threatening lesion) was surgically removed, thereby improving the outcome, whereas in the latter group, the threatening lesion remains present or is increased in size, compromising the outcome of the patient.

We would like to highlight the strength of our study. Most previous studies assessing CT scores in patients with TBI included only moderate and/or severe cases (1–3,6,7,11,14,15). We presume that the authors excluded mild cases because the main objective of most studies was to assess long-term mortality and functional outcomes after TBI (16) and because they were concerned that the inclusion of mild cases, many of whom might have not undergone CT (possibly with resultant selection bias), would increase the number of clinically insignificant cases in their series. In contrast to previous studies, we included a considerable number of patients with mild TBI who underwent CT examination according to the New Orleans criteria and/or Canadian CT head rule in the present study (8,9) and found ∼3% of deaths among the cases that were considered mild at admission. This result is consistent with that reported by Jacob et al. (17), who also evaluated the prognostic power of CT findings in patients with mild TBI whose CT examination was conducted according to some specific clinical criteria. The mild cases that died in these two studies may represent the well-known "talk and die" patients, those who present with a mild TBI (GCS 13–15) and then subsequently deteriorate and die from intracranial causes (18). Indeed, convincing evidence indicates that persistent dysfunction or death develops in a subset of patients with mild TBI; for this reason, such mild cases also deserve particular attention in the clinical and research fields (19,20). Thus, we sought to evaluate a wider spectrum of patients with TBI, including patients with mild TBI to reduce the selection bias as far as possible.

To date, to the best of our knowledge, only Nelson et al. (5) reported a relatively large-scale study wherein the performances of Rotterdam and Marshall scores were evaluated in patients with mild-to-severe TBI. These authors claimed that Rotterdam score was a better predictor than Marshall score of unfavorable outcome. Surprisingly, our findings
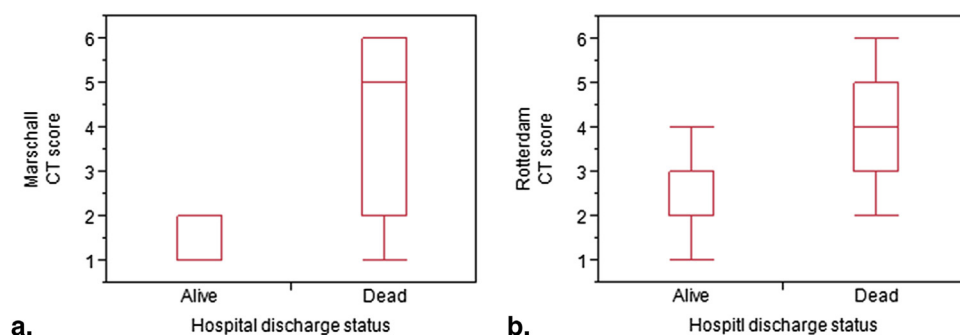
Figure 3. Showing the relationships between the Marshall **(a)** and Rotterdam **(b)** scores and early death, as determined by the Mann–Whitney U test. Marshall and Rotterdam scores were significantly higher among patients who were dead at the time of hospital discharge (median [lower, upper quartile]: Marshall, 5 [2, 6]; Rotterdam, 4 [3, 5]) than among those who were alive (Marshall, 1 [1, 2]; Rotterdam, 2 [2, 3]). *Upper and lower bars* indicate 75% and 25%, respectively.

TABLE 6. CT Findings Independently Predicting Early Death, Identified by Multiple Logistic Regressions

CT Finding	Number of Patients (%)	Nonadjusted OR	*P* Value	Adjusted OR	*P* Value
Basal cistern			<.0001*		<.0001*
Normal	119 (85.7)	13.4	<.0001*	47.7	<.0001*
Compressed	24 (9.8)	2.9	.1485	16.2	.0030*
Absent	11 (4.5)	39.1	<.0001*	771.5	<.0001*
Positive midline shift	31 (12.7)	7.9	<.0001*	56.2	.0011*
Positive EDH	14 (5.7)	2.6	.2013	2.35	.3452
Positive SAH/IVH	89 (36.3)	8.8	<.0001*	3.8	.0395*
Hemorrhagic mass			<.0001*		.0247*
Absent	154 (62.8)	7.8	.0004*	2.6	.2123
<25 mL	58 (23.7)	2.4	.0842	4.9	.0564
≥25 mL	33 (13.5)	18.7	<.0001*	12.9	.0065*

CT, computed tomography; EDH, epidural hematoma; OR, odds ratio; SAH/IVH, subarachnoid hemorrhage/intraventricular hemorrhage.
*Statistically significant.

disagree with their results. Indeed, Nelson et al. (5) calculated the Glasgow outcome scale (GOS) of patients in following three points: at discharge, at 3–6 months, and ≥1 year after TBI. Afterward, only the highest score at one of three points was used as the predictive target in the statistical analysis. In addition, these authors excluded a number of patients who showed a GOS of 2–4 at hospital discharge and who lacked long-term GOS data. Therefore, we can speculate that the overall endpoint in their study was a long-term GOS, not an early outcome like in our study (median time from admission to death = 4 days). In that sense, the superior performance of Rotterdam score over Marshall score reported in their study was in predicting long-term outcome, which is in accord with the previous literature (2,4,6). In contrast, our results show that the performance of Marshall score is equal or possibly slightly better than that of the Rotterdam scoring system in predicting early death. In that sense, we would like to suggest to clinicians and researchers the use of Marshall score to evaluate the early outcome of patients with TBI and Rotterdam score for long-term outcome, as

this constitute a clinical scenarios in which these two scoring systems were devised. We believe that this constitutes the first study to compare the performance of both scoring systems in predicting early death in a wide spectrum of patients with TBI, including those with mild TBI.

The limitations of our study should be recognized. First, the study had a retrospective design. Second, we used data from a single hospital, and our results may have been influenced by local treatment protocols. Third, the patient sample was small, and few patients died; thus, our results may not be applicable to other settings with different medical circumstances. Thus, external validation by large-scale prospective studies is needed to confirm our results. Moreover, we did not include well-known TBI clinical prognosticators such as age, GCS, and pupillary reactivity in our multiple logistic models. Because in this study, only 25 of 245 patients died. Therefore, to keep statistical power yield by multiple logistic regressions, only limited independent variables could be used. In that sense, we focused on the five CT parameters that constitute the two CT scoring systems.

CONCLUSIONS

Our data show that both Marshall and Rotterdam scoring systems can be used to predict early death in patients with TBI. The performance of Marshall scoring system is equal or possibly slightly better than that of Rotterdam scoring system. This statement is supported by our specific results showing that the two strongest predictors of early death—basal cistern absence and positive midline shift—are included in both CT scoring systems, but voluminous hemorrhagic mass, the next strongest predictor, is included only in Marshall score. Thus, although older than Rotterdam score, Marshall score remains useful for the purpose of outcome prediction after TBI.

REFERENCES

1. Marshall LF, Eisenberg H, Jane JA, et al. A new classification of head injury based on computed tomography. J Neurosurg 1991; 75:S14–S20.
2. Maas AI, Hukkelhoven CW, Marshall LF, et al. 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 2005; 57: 1173–1182. discussion 1173–1182.
3. Chun KA, Manley GT, Stiver SI, et al. Interobserver variability in the assessment of CT imaging facture of traumatic brain injury. J Neurotrauma 2010; 27:325–330.
4. Hilarioa A, Ramos A, Millan JM, et al. Severe traumatic head injury: prognostic value of brain stem injuries detected at MRI. AJNR Am J Neuroradiol 2012; 33:1925–1931.
5. Nelson DW, Nyström H, MacCallum RM, et al. Extended analysis of early computed tomography scans of traumatic brain injured patients and relations to outcome. J Neurotrauma 2010; 27:51–64.
6. Katsnelson M, Mackenzie L, Frangos S, et al. Are initial radiology and clinical scales associated with subsequent intracranial pressure and brain oxygen level after severe traumatic brain injury? Neurosurgery 2012; 70: 1095–1105.
7. Huang YH, Deng YH, Lee TC, et al. Rotterdam computed tomography score as a prognosticator in head-injured patients undergoing decompressive craniectomy. Neurosurgery 2012; 71:80–85.
8. Haydel MJ, Preston CA, Mills TJ, et al. Indications for computed tomography in patients with minor head injury. N Engl J Med 2000; 343:100–105.
9. Stiell IG, Lesiuk H, Wells GA, et al. Canadian CT head rule study for patients with minor head injury: methodology for phase II (validation and economic analysis). Ann Emerg Med 2001; 38:317–322.
10. Smits M, Dippel DW, Nederkoorn PJ, et al. Minor head injury: CT-based strategies for management—a cost-effectiveness analysis. Radiology 2010; 254:532–540.
11. Stocchetti N, Croci M, Spagnoli D, et al. Mass volume measurement in severe head injury: accuracy and feasibility of two pragmatic methods. J Neurol Neurosurg Psychiatry 2000; 68:14–17.
12. Jacobs B, Beems T, Van der Vliet TM, et al. Computed tomography and outcome in moderate and severe traumatic brain injury: hematoma volume and midline shift revisited. J Neurotrauma 2011; 28:203–215.
13. Maas AI, Steyerberg EW, Butcher I, et al. Prognostic value of computerized tomography scan characteristics in traumatic brain injury: results from the IMPACT study. J Neurotrauma 2007; 24:303–314.
14. Harrell FE. Regression modeling strategies: with applications to linear models, logistic regression, and survival analysis. Springer series in statistics, Springer-Verlag, New York, Inc, 2001.
15. Steyerberg EW, Mushkudiani N, Perel P, et al. Predicting outcome after traumatic brain injury: development and international validation of prognostic scores based on admission characteristic. PLoS Med 2008; 5:e165.
16. Lingsma HF, Roozenbeek B, Steyerberg EW, et al. Early prognosis in traumatic brain injury: from prophecies to predictions. Lancet Neurol 2010; 9: 543–554.
17. Jacobs B, Beems T, Stulemeijer M, et al. Outcome prediction in mild traumatic brain injury: age and clinical variables are stronger predictors than CT abnormalities. J Neurotrauma 2010; 27:655–668.
18. Goldschlager T, Rosenfeld JV, Winter CD. 'Talk and die' patients presenting to a major trauma centre over a 10 year period: a critical review. J Clin Neurosci 2007; 14:618–623.
19. National center for injury prevention and control. Report to congress on mild traumatic brain injury in the United States: steps to prevent serious public problem. Atlanta, GA: center for disease control and prevention, 2003.
20. Lee H, Wintermark M, Gean AD, et al. Focal lesions in acute mild traumatic brain injury and neurocognitive outcome: CT versus 3T MRI. J Neurotrauma 2008; 25:1049–1056.