

Complementary Predictive Values of the Glasgow Coma Scale–Pupils Score and Rotterdam CT Score for Outcomes in Adults With Acute Epidural Hematoma and Glasgow Coma Scale of 8 or Lower

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Research Article

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Abstract

Objective

This study aimed to evaluate the prognostic factors associated with 6-month mortality and functional outcomes in adult patients with severe acute epidural hematoma (AEDH; GCS $\leq$ 8), focusing on comparing the predictive performance of the Glasgow Coma Scale–Pupils (GCS-P) score and the Rotterdam computed tomography (CT) score.

Methods

We retrospectively analyzed data from 84 adults with severe AEDH (GCS $\leq$ 8) registered in the Korean Neurotrauma Data Bank System. Multivariable logistic regression and receiver operating characteristic (ROC) curve analyses were performed. For GCS-P score ROC analysis, the analysis direction was set to detect adverse events with lower scores (lower GCS-P values as the positive class) to ensure reproducibility. Paired areas under the receiver operating characteristic curves (AUCs) were compared using DeLong's test.

Results

At 6 months, the mortality rate was 22.6% (n = 19), and 40.5% (n = 34) had unfavorable functional outcomes, defined as a Glasgow Outcome Scale-Extended (GOSE) score of 1–4. In multivariable analysis, the Rotterdam score was an independent predictor of 6-month mortality (OR = 1.972, p = 0.0226), while the GCS-P score was a strong independent predictor of both mortality (OR = 0.660, p = 0.0293) and unfavorable functional outcome (OR = 0.519, p = 0.0002). ROC analysis showed acceptable and comparable mortality prediction for both the Rotterdam score (AUC = 0.759, 95% CI: 0.633–0.872) and GCS-P score (AUC = 0.739, 95% CI: 0.606–0.857; DeLong's p = 0.814). However, for predicting unfavorable functional outcome, the GCS-P score (AUC = 0.764, 95% CI: 0.648–0.865) demonstrated statistically significant superiority over the Rotterdam score (AUC = 0.641, 95% CI: 0.522–0.757; DeLong's p = 0.046).

Conclusion

The GCS-P and Rotterdam CT scores provide distinct and complementary prognostic value. The Rotterdam score is highly effective for acute mortality risk stratification by reflecting morphological mass effect, whereas the GCS-P score offers superior accuracy in predicting long-term functional recovery.

Clinical trial number

Not applicable.

1. Introduction

Acute epidural hematoma (AEDH) is a distinct subtype of traumatic brain injury (TBI) characterized by a focal extra-axial mass lesion that is often amenable to prompt surgical evacuation [1, 2]. Compared with other intracranial hemorrhages, AEDH may be associated with relatively favorable outcomes when diagnosed early and treated appropriately; however, severe cases still carry substantial risks of death and disability [1, 2]. Prognosis in AEDH is influenced by both neurological status at presentation and radiological severity, including hematoma burden and secondary mass effect [1, 3]. A prospective study reported that no patient with a preoperative Glasgow Coma Scale (GCS) score of 8 or higher died [2].

Several complementary tools have been proposed to improve prognostic assessment in TBI [4]. The Glasgow Coma Scale–Pupils (GCS-P) score integrates pupillary reactivity into the conventional GCS and was developed as a simple extension of clinical severity assessment [5]. Similarly, the Rotterdam computed tomography (CT) score was designed to summarize key CT features associated with outcome and has been shown to be useful for predicting mortality in moderate-to-severe TBI [6]. The Glasgow Outcome Scale–Extended (GOSE) has also become a standard measure of long-term functional outcome after TBI [7]. Despite these advances, evidence focusing specifically on severe AEDH remains limited. Most previous studies have evaluated heterogeneous TBI populations or emphasized surgical case series rather than examining both mortality and long-term functional outcome in a clearly defined cohort with severe AEDH [8, 9]. In particular, the relative prognostic values of the GCS-P and Rotterdam CT scores, as well as their potentially distinct or complementary roles in predicting different outcome dimensions (i.e., mortality versus long-term functional morbidity), have not been fully established in adults with AEDH and severe initial neurological impairment. Therefore, this study aimed to evaluate prognostic factors associated with 6-month mortality and functional outcome in adults with acute epidural hematoma and a GCS score of 8 or less.

We specifically examined the predictive values of the GCS-P and Rotterdam CT scores and sought to clarify their distinct and complementary clinical utility for predicting 6-month mortality and functional recovery.

2. Materials and Methods

This retrospective cohort study used data from the Korean Neurotrauma Data Bank System, a nationwide registry established by the Korean Neurotraumatology Society. Between January 2018 and June 2021, a total of 1,109 adults with TBI and an initial GCS score of 8 or less were prospectively registered at 18 hospitals across South Korea. Patients with a history of craniotomy or craniectomy were excluded from the registry [10]. For the present study, we identified patients with acute epidural hematoma within this cohort. Of 99 eligible patients, 15 were excluded because they were lost to follow-up at 6 months. Consequently, 84 patients were included in the final analysis (Fig. 1).

Demographic and clinical data, including age, sex, body mass index, injury mechanism, and treatment setting (trauma center vs. non-trauma center), were collected from institutional databases. Initial physiological parameters at hospital admission included body temperature, pulse rate, systolic and diastolic blood pressure, and respiratory rate. Neurological status at admission was assessed using the GCS and GCS-P score. GCS-P was calculated as the GCS score minus the pupil reactivity score (0–2), using the first reliable neurological examination performed at admission [5]. Radiological variables were obtained from initial brain CT scans and included hematoma volume, midline shift, and Rotterdam CT score. Treatment modality was categorized as surgical or conservative management. The primary outcomes were 6-month mortality and 6-month functional outcome. Mortality was defined as a GOSE score of 1. Functional outcome was dichotomized as unfavorable (GOSE scores of 1–4, indicating death, vegetative state, or severe disability) or favorable (GOSE scores of 5–8, indicating moderate disability or good recovery).

Statistical Analysis

Statistical analyses were performed in *Python* (version 3.10) using the *SciPy*, *statsmodels*, and *scikit-learn* packages. Continuous variables were assessed for normality using the Shapiro–Wilk test. Because most continuous clinical and radiological variables were nonnormally distributed, data were presented as medians and interquartile ranges (IQRs) and compared using the Mann–Whitney U test. Categorical variables were presented as frequencies and percentages and analyzed using the chi-square test or Fisher exact test, as appropriate. Median imputation was performed for missing values in continuous variables (body mass index, hematoma volume, and midline shift) to avoid excluding observations from the analysis.

Variables considered clinically relevant or with $p < 0.10$ in univariate analysis were entered into multivariable logistic regression models to identify independent prognostic factors for 6-month mortality and unfavorable functional outcome. Potential multicollinearity among highly correlated variables (e.g., GCS vs. GCS-P and midline shift vs. Rotterdam CT score) was assessed, and the more clinically comprehensive measures (GCS-P and Rotterdam CT score) were retained in the final models. Overall model fit was assessed using likelihood ratio tests and McFadden's pseudo- R^2 values. Adjusted odds ratios (ORs) and 95% confidence intervals (CIs) were calculated. The prognostic validity and discriminative performance of the GCS-P and Rotterdam CT scores were evaluated using receiver operating characteristic (ROC) curve analysis. The area under the curve (AUC) was calculated for each score. For the GCS-P score ROC analysis, because higher scores are clinically associated with lower odds of adverse outcomes, the analysis direction was set to detect adverse events with lower scores (i.e., treating lower GCS-P values as indicative of the positive class) to ensure the reported AUCs remain reproducible and above 0.50. To account for the sample size and assess robustness, 95% CIs for the AUCs were estimated by bootstrapping with 2,000 resamples. All statistical tests were two-tailed, and $p < 0.05$ was considered statistically significant.

3. Results

3.1 Baseline Characteristics and Univariate Analysis

The baseline demographic, clinical, and radiological characteristics of the overall cohort and the univariate analyses of factors associated with 6-month mortality and functional outcome are presented in Table 1. The median age of the cohort was 53.5 years (IQR, 40.8–61.0 years), and 65 patients (77.4%) were male. Traffic accidents were the most common cause of injury (35.7%, $n = 30$), followed by falls (26.2%, $n = 22$) and slip-down injuries (22.6%, $n = 19$). Overall, 51 patients (60.7%) were treated at a regional trauma center, and 49 patients (58.3%) underwent surgical intervention.

Table 1
Baseline characteristics and univariate analysis of factors associated with 6-month mortality and functional outcome

Characteristics		Total (n = 84)	6-Month Mortality			6-Month Functional Outcome		
			Survivors (n = 65)	Non-survivors (n = 19)	p-value	Favorable (n = 50)	Unfavorable (n = 34)	p-value
Demographics	Age (years)	53.5 [40.8–61.0]	51.0 [37.0–61.0]	61.0 [56.0–65.0]	0.011 ^a	49.5 [34.0–59.8]	59.5 [50.3–67.0]	0.001 ^a
	Sex, male	65 (77.4%)	49 (75.4%)	16 (84.2%)	0.619 [¶]	41 (82.0%)	24 (70.6%)	0.336 [¶]
	BMI (kg/m ²)	22.6 [20.8–24.7]	22.8 [20.8–24.8]	22.6 [21.1–24.2]	0.578 ^a	22.6 [20.7–24.8]	22.6 [21.2–24.6]	0.942 ^a
Injury Mechanism, n (%)	Traffic accident	30 (35.7%)	23 (35.4%)	7 (36.8%)	0.579 [¶]	16 (32.0%)	14 (41.2%)	0.661 [¶]
	Fall	22 (26.2%)	19 (29.2%)	3 (15.8%)		15 (30.0%)	7 (20.6%)	
	Slip down	19 (22.6%)	13 (20.0%)	6 (31.6%)		10 (20.0%)	9 (26.5%)	
	Unknown	11 (13.1%)	9 (13.8%)	2 (10.5%)		8 (16.0%)	3 (8.8%)	
	Others	2 (2.4%)	1 (1.5%)	1 (5.3%)		1 (2.0%)	1 (2.9%)	
Initial Vital Signs	BT (°C)	36.3 [36.0–36.9]	36.3 [35.9–36.9]	36.3 [36.0–37.3]	0.641 ^a	36.3 [35.8–37.0]	36.3 [36.0–36.9]	0.873 ^a
	PR (beats/min)	90.5 [77.0–110.0]	88.0 [76.0–100.0]	100.0 [90.5–122.0]	0.016 ^a	89.0 [77.5–104.5]	95.0 [79.8–115.0]	0.245 ^a
	sBP (mmHg)	130.0 [116.5–144.0]	131.0 [120.0–144.0]	130.0 [110.0–152.0]	0.748 ^a	137.5 [121.3–144.0]	121.5 [106.3–143.0]	0.097 ^a
	dBp (mmHg)	80.0 [70.0–90.0]	80.0 [71.0–90.0]	78.0 [60.0–92.0]	0.283 ^a	80.0 [75.5–90.0]	74.5 [60.0–95.3]	0.169 ^a
	RR (breaths/min)	20.0 [17.8–22.0]	20.0 [18.0–22.0]	20.0 [16.0–20.0]	0.552 ^a	20.0 [18.0–22.0]	20.0 [16.3–20.0]	0.289 ^a
Clinical & Radiological Scores	GCS score	6.0 [4.0–7.0]	7.0 [6.0–8.0]	4.0 [3.0–6.0]	< 0.001 ^a	7.0 [6.0–8.0]	5.0 [3.0–6.0]	< 0.001 ^a
	GCS-P score	6.0 [4.0–7.0]	7.0 [5.0–8.0]	4.0 [3.0–6.0]	0.001 ^a	7.0 [6.0–8.0]	4.0 [3.0–6.0]	< 0.001 ^a
	CT volume of EDH (cc)	48.5 [29.5–95.1]	45.3 [22.0–89.0]	54.0 [44.0–100.0]	0.065 ^a	46.1 [28.5–88.8]	51.2 [34.1–95.2]	0.173 ^a
	CT midline shift (mm)	4.0 [0.0–8.6]	4.0 [0.0–6.0]	9.5 [3.5–15.5]	0.012 ^a	4.0 [0.0–6.0]	4.0 [0.0–12.7]	0.184 ^a

Values are presented as median [interquartile range] for continuous variables and number (percentage) for categorical variables. GOSE, Glasgow Outcome Scale–Extended; BMI, body mass index; BT, body temperature; PR, pulse rate; sBP, systolic blood pressure; dBp, diastolic blood pressure; RR, respiratory rate; GCS, Glasgow Coma Scale; GCS-P, Glasgow Coma Scale–Pupils; EDH, epidural hematoma; CT, computed tomography.

^ap-values were determined using the Mann–Whitney U test.

[¶]p-values were determined using the chi-square test or Fisher exact test.

*p < 0.05 indicates statistical significance.

	Rotterdam CT score	3.0 [2.0–4.0]	3.0 [2.0–3.0]	4.0 [3.0–4.5]	< 0.001 ^a	3.0 [2.0–3.8]	3.0 [2.0–4.0]	0.025 ^a
Treatment & Environment	Admitted to Regional Trauma Center	51 (60.7%)	43 (66.2%)	8 (42.1%)	0.105 [‡]	34 (68.0%)	17 (50.0%)	0.153 [‡]
	Surgical Treatment	49 (58.3%)	39 (60.0%)	10 (52.6%)	0.758 [‡]	30 (60.0%)	19 (55.9%)	0.881 [‡]
Values are presented as median [interquartile range] for continuous variables and number (percentage) for categorical variables. GOSE, Glasgow Outcome Scale–Extended; BMI, body mass index; BT, body temperature; PR, pulse rate; sBP, systolic blood pressure; dBP, diastolic blood pressure; RR, respiratory rate; GCS, Glasgow Coma Scale; GCS-P, Glasgow Coma Scale–Pupils; EDH, epidural hematoma; CT, computed tomography.								
^a p-values were determined using the Mann–Whitney U test.								
[‡] p-values were determined using the chi-square test or Fisher exact test.								
*p < 0.05 indicates statistical significance.								

At the 6-month follow-up, overall mortality was 22.6% (n = 19). Univariate analysis showed that non-survivors were significantly older than survivors (median age, 61.0 vs. 51.0 years; p = 0.011) and had a significantly higher median initial pulse rate (100.0 vs. 88.0 beats/min; p = 0.016). Non-survivors also had significantly lower baseline GCS scores (median, 4.0 vs. 7.0; p < 0.001) and GCS-P scores (median, 4.0 vs. 7.0; p = 0.001). On radiological evaluation, non-survivors had a significantly greater CT midline shift (median, 9.5 vs. 4.0 mm; p = 0.012) and higher Rotterdam CT scores (median, 4.0 vs. 3.0; p < 0.001) than survivors. Initial AEDH volume on CT showed a borderline association but did not reach statistical significance (p = 0.065). Other clinical parameters, including blood pressure and treatment modality, did not differ significantly between survivors and non-survivors (p > 0.05).

Regarding long-term functional status, 50 patients (59.5%) had a favorable outcome, whereas 34 patients (40.5%) had an unfavorable outcome at 6 months. Univariate analysis showed that older age was significantly associated with an unfavorable outcome (median, 59.5 vs. 49.5 years; p = 0.001). Baseline neurological status was strongly associated with functional outcome: patients with unfavorable outcomes had significantly lower median GCS scores (5.0 vs. 7.0; p < 0.001) and GCS-P scores (4.0 vs. 7.0; p < 0.001). Among radiological parameters, a higher Rotterdam CT score was significantly associated with an unfavorable outcome (p = 0.025). In contrast to the mortality findings, initial pulse rate (p = 0.245), AEDH volume on CT (p = 0.173), and CT midline shift (p = 0.184) were not significantly associated with 6-month functional outcome.

3.2 Multivariate Logistic Regression Analysis

To adjust for potential confounding and identify independent prognostic indicators, variables that were statistically significant or clinically relevant in univariate screening were entered into multivariable logistic regression models. Highly correlated parameters were assessed for multicollinearity, and the more clinically comprehensive measures (GCS-P and Rotterdam CT scores) were selected for the final models. The results are summarized in Table 2. The multivariable model for 6-month mortality was statistically significant (likelihood ratio test, p < 0.0001; pseudo-R² = 0.3348). After adjustment for other clinical factors, age, GCS-P score, and Rotterdam CT score were significant independent predictors of mortality. Each 1-year increase in age was associated with higher odds of mortality (OR = 1.060; 95% CI: 1.013–1.108; p = 0.012). Conversely, each 1-point increase in baseline GCS-P score was associated with lower odds of death (OR = 0.660; 95% CI: 0.454–0.959; p = 0.0293). Each 1-point increase in the initial Rotterdam CT score nearly doubled the odds of 6-month mortality (OR = 1.972; 95% CI: 1.100–3.535; p = 0.0226). Initial pulse rate was not statistically significant after multivariable adjustment (p = 0.1125).

Table 2
Multivariable logistic regression analysis of 6-month mortality and unfavorable functional outcome

Variable	6-Month Mortality		6-Month Unfavorable Functional Outcome ¹	
	Odds Ratio (95% CI)	p-value	Odds Ratio (95% CI)	p-value
Age (per 1-year increase)	1.060 (1.013–1.108)	0.012	1.060 (1.021–1.102)	0.0025
Pulse Rate (per 1-bpm increase)	1.024 (0.994–1.054)	0.1125	Not included	Not included
GCS-P score (per 1-point increase)	0.660 (0.454–0.959)	0.0293	0.519 (0.370–0.730)	0.0002
Rotterdam CT score (per 1-point increase)	1.972 (1.100–3.535)	0.0226	1.310 (0.837–2.049)	0.2373
CI, confidence interval; GCS-P, Glasgow Coma Scale–Pupils; CT, computed tomography; bpm, beats per minute.				
¹ Unfavorable functional outcome was defined as a Glasgow Outcome Scale–Extended (GOSE) score of 1–4.				
² Pulse rate was excluded from the final multivariable model for unfavorable functional outcome because it was not statistically significant in the preceding univariate analysis.				

The multivariable model for 6-month unfavorable functional outcome was also statistically significant (likelihood ratio test, $p < 0.0001$; pseudo- $R^2 = 0.2962$). In this model, age and GCS-P score remained independent predictors of long-term functional status, whereas the Rotterdam CT score did not. Each 1-year increase in age was associated with higher odds of an unfavorable outcome (OR = 1.060; 95% CI: 1.021–1.102; $p = 0.0025$). Each 1-point increase in baseline GCS-P score was associated with lower odds of an unfavorable outcome at 6 months (OR = 0.519; 95% CI: 0.370–0.730; $p = 0.0002$). Although significant in univariate analysis, the initial Rotterdam CT score was not an independent predictor of 6-month functional outcome after adjustment for age and neurological status (OR = 1.310; 95% CI: 0.837–2.049; $p = 0.2373$).

3.3 Prognostic Validity and Discriminative Accuracy of Prognostic Scores

As shown in Table 3 and Fig. 2, ROC curve analyses were performed to compare the prognostic validity of the GCS-P and Rotterdam CT scores for 6-month clinical outcomes. For 6-month mortality, both scoring systems showed acceptable and comparable discriminative performance. The Rotterdam CT score had an AUC of 0.759 (95% CI: 0.633–0.872), whereas the GCS-P score had an AUC of 0.739 (95% CI: 0.606–0.857). The overlapping ROC curves in Fig. 2A suggest comparable discrimination for mortality. Although the ROC curves in Fig. 2A overlapped, a formal paired AUC comparison using DeLong's test confirmed that this difference was not statistically significant (difference in AUC = 0.020; DeLong's test, $p = 0.814$), demonstrating comparable discriminative performance for mortality.

Table 3
Predictive performance (AUC) of the GCS-P and Rotterdam CT scores for 6-month clinical outcomes

Target Outcome	Predictor	AUC	95% CI	Predictive Level
6-Month Mortality	Rotterdam CT Score	0.759	0.633–0.872	Acceptable
	GCS-P Score	0.739	0.606–0.857	Acceptable
6-Month Unfavorable Outcome	GCS-P Score	0.764	0.648–0.865	Excellent
	Rotterdam CT Score	0.641	0.522–0.757	Poor
AUC, area under the receiver operating characteristic curve; CI, confidence interval; GCS-P, Glasgow Coma Scale–Pupils score; CT, computed tomography. Unfavorable outcome was defined as a Glasgow Outcome Scale–Extended (GOSE) score of 1–4 at 6 months after injury. The 95% CIs were calculated by bootstrapping with 2,000 resamples.				

By contrast, the scores differed more clearly in their ability to predict 6-month unfavorable functional outcome. The GCS-P score showed greater discriminative performance, with an AUC of 0.764 (95% CI: 0.648–0.865). Conversely, the Rotterdam CT score showed poorer discriminative performance, with an AUC of 0.641 (95% CI: 0.522–0.757). As illustrated in Fig. 2B, the ROC curve for the GCS-P score lies closer to the upper-left quadrant, and a paired comparison via DeLong's test verified that the GCS-P score was a statistically superior predictor of long-term functional outcome compared to the Rotterdam CT score (difference in AUC = 0.123; DeLong's test, $p = 0.046$).

Discussion

In this retrospective cohort study, the Rotterdam CT and GCS-P scores showed different prognostic patterns for 6-month mortality and functional outcome. These findings suggest that clinical and radiological measures may have distinct prognostic roles in patients with AEDH and $GCS \leq 8$. Although structural measures such as the Rotterdam CT score and midline shift may be more closely related to mortality, patient and neurological factors—specifically age and GCS-P score—may be more relevant to long-term functional outcome.

In multivariable analysis, a higher Rotterdam CT score independently predicted 6-month mortality ($OR = 1.972$, $p = 0.0226$) but not unfavorable functional outcome ($p = 0.2373$). This finding was consistent with the ROC analysis, which showed better discrimination for mortality ($AUC = 0.759$) than for functional outcome ($AUC = 0.641$). This difference may reflect the components captured by the Rotterdam CT score: morphological abnormalities, structural mass effect, and impending intracranial hypertension [6]. In severe AEDH, a high Rotterdam CT score indicates severe mass effect that can precipitate brain herniation and early mortality. However, after this acute insult is relieved—often by prompt surgical evacuation, which was performed in nearly 60% of our cohort—the initial radiological abnormalities may be less likely to determine long-term neurological recovery. Leitgeb et al. [8] reported that the Rotterdam CT score was significantly associated with long-term functional outcome but not in-hospital mortality, in contrast to our findings. This discrepancy may be explained by differences in the study populations. Leitgeb et al. [8] analyzed patients with severe TBI and EDH, many of whom had concomitant intracranial injuries, including cerebral contusions, traumatic subarachnoid hemorrhage, and subdural hematoma. These associated injuries may have been major determinants of long-term functional impairment. In contrast, the present study focused on a more homogeneous, high-risk cohort of adults with AEDH and an initial GCS score ≤ 8 .

Conversely, the GCS-P score remained predictive across both endpoints and was significantly associated with 6-month functional outcome ($OR = 0.519$, $p = 0.0002$; $AUC = 0.764$). By incorporating pupillary reactivity, the GCS-P score reflects baseline neurological and brainstem integrity. Thus, although structural measures primarily help delineate immediate mortality risk, the baseline GCS-P score may better capture the neurological status from which subsequent functional recovery proceeds. Leitgeb et al. [8] reported that pupillary reactivity influenced in-hospital mortality but had no effect on long-term prognosis. In contrast, our study showed that the GCS-P score was an independent predictor of both mortality and long-term functional outcome at 6 months (GOSE) ($OR = 0.519$, $p = 0.0002$). These findings suggest that the GCS-P score, as an integrated clinical measure, may offer greater clinical value than separate evaluation of the level of consciousness and pupillary reactivity.

This prognostic difference is further supported by the univariate findings for initial pulse rate and CT midline shift. Both were significantly associated with mortality ($p = 0.016$ and $p = 0.012$, respectively) but not with long-term functional outcome ($p = 0.245$ and $p = 0.184$). An elevated pulse rate reflects acute physiological stress, whereas midline shift indicates structural mass effect. Once these acute insults are successfully managed through emergency treatment, their initial severity may no longer determine long-term recovery. Instead, functional outcome may depend more on the brain's intrinsic capacity for neurological recovery. Onodera et al. [9] investigated whether a larger intracranial hematoma burden resulted in irreversible brain injury by evaluating CT parameters, including hematoma thickness, length, volume, and midline shift, in surgically treated patients with AEDH. They found that none of these radiological variables were independently associated with long-term functional outcome (GOS), whereas younger age (< 55 years) and a higher preoperative GCS score (> 12) remained significant prognostic factors. The authors suggested that this finding was likely attributable to prompt surgical evacuation of large hematomas before irreversible brain injury developed. This observation may be consistent with our hypothesis that, when reversible brain compression is promptly relieved by surgical evacuation, the influence of initial CT-defined morphological severity on long-term disability is reduced.

Several factors adversely affect prognosis, including advanced age, prolonged time from injury to intervention, immediate coma, pupillary abnormalities, and low preoperative GCS scores [11]. Among these factors, age remained an independent risk factor for both mortality ($p = 0.012$) and unfavorable functional outcome ($p = 0.0025$). This finding is consistent with previous reports showing that increasing age is associated with higher mortality and poorer functional recovery after traumatic intracranial hematoma, including AEDH [13, 14]. Older patients may have lower physiological reserve, more medical comorbidities, a reduced capacity for neurological recovery, and greater vulnerability to secondary brain injury [8, 11, 12]. In addition, greater susceptibility to systemic complications during prolonged intensive care may increase acute mortality and limit long-term functional rehabilitation.

Our univariate analysis showed that admission to a designated regional trauma center was not significantly associated with 6-month mortality ($p = 0.105$) or 6-month functional outcome ($p = 0.153$). Although trauma centers have consistently been shown to reduce mortality in heterogeneous TBI populations, the absence of a statistically significant difference between trauma and non-trauma centers in this cohort may be attributable to several clinical and pathophysiological characteristics of AEDH [15]. The absence of outcome differences between regional trauma centers and non-trauma academic hospitals may also reflect the characteristics of severe AEDH and nationwide triage patterns. Severe AEDH is a time-dependent neurosurgical emergency in which rapid surgical decompression is a

primary determinant of survival and neurological recovery. Because non-trauma academic hospitals in South Korea provide 24-hour neurosurgical coverage and emergency operative capabilities comparable to those of regional trauma centers, timely hematoma evacuation may often be achieved regardless of trauma center designation. In addition, nationwide triage patterns may have introduced selection bias. Whereas regional trauma centers frequently receive patients with more severe multisystem injuries, patients with isolated AEDH are generally transported to the nearest facility capable of immediate neurosurgical intervention [15]. Consequently, prompt neurosurgical care at non-trauma academic hospitals may have offset the systemic advantages of dedicated trauma centers. These findings suggest that, in patients with severe AEDH, rapid access to a facility capable of immediate neurosurgical intervention may be more important for survival and long-term functional recovery than treatment at a designated trauma center itself.

Conclusion

The initial GCS-P and Rotterdam CT scores have distinct and complementary clinical utility in adults with severe AEDH and a GCS score of 8 or less. The initial Rotterdam CT score is useful for stratifying 6-month mortality risk and reflects morphological mass effect and secondary brain compression. Conversely, the GCS-P score, which incorporates pupillary reactivity, provides greater predictive accuracy for 6-month functional outcome and neurological recovery. In addition, the absence of a significant prognostic difference between designated trauma centers and non-trauma academic hospitals underscores the importance of rapid geographic access to a hospital equipped for immediate emergency neurosurgical intervention. These findings suggest that timely access to neurosurgical intervention may be important regardless of center designation

Declarations

Ethics approval and consent to participate:

This study was conducted in accordance with the Declaration of Helsinki and was approved by the Institutional Review Board (IRB) of Wonkwang University Hospital (IRB Approval No. WKUH 20260425). Due to the retrospective nature of the study and the use of anonymized data from the Korean Neurotrauma Data Bank System, the requirement for informed consent was waived by the IRB.

Consent for publication:

Not applicable.

Conflict of Interest:

The author declares that they have no conflicts of interest.

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The author declares that no funding was received for this study.

Author Contribution

K.S.E. performed all aspects of this study and approved the final manuscript.

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Data Availability

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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Figures

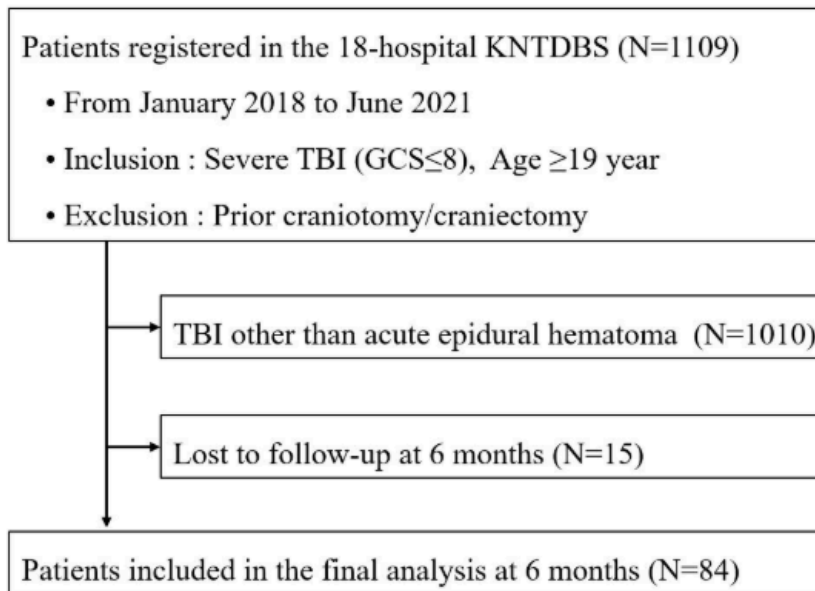


Figure 1

Flow diagram of patient selection

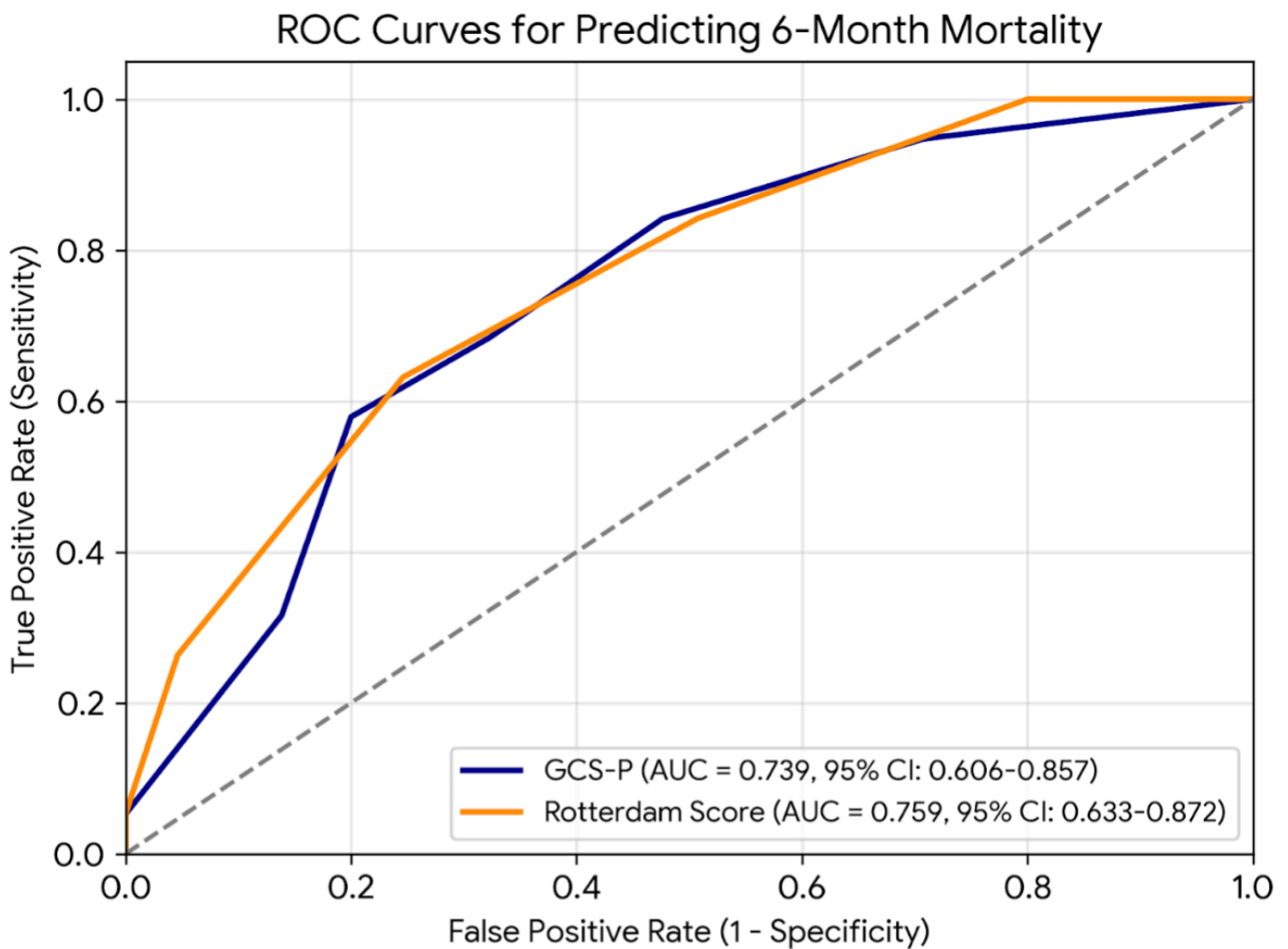


Figure 2

Figure 2A. ROC curves for predicting 6-month mortality

Receiver operating characteristic (ROC) curves for the Glasgow Coma Scale–Pupils (GCS-P) and Rotterdam CT scores in predicting 6-month mortality in adults with severe acute epidural hematoma. The area under the curve (AUC) was 0.759 (95% CI: 0.633–0.872) for the Rotterdam CT score and 0.739 (95% CI: 0.606–0.857) for the GCS-P score. The dashed diagonal line represents the reference line for chance performance (AUC = 0.50). The 95% confidence intervals (CIs) were estimated by bootstrapping with 2,000 resamples.

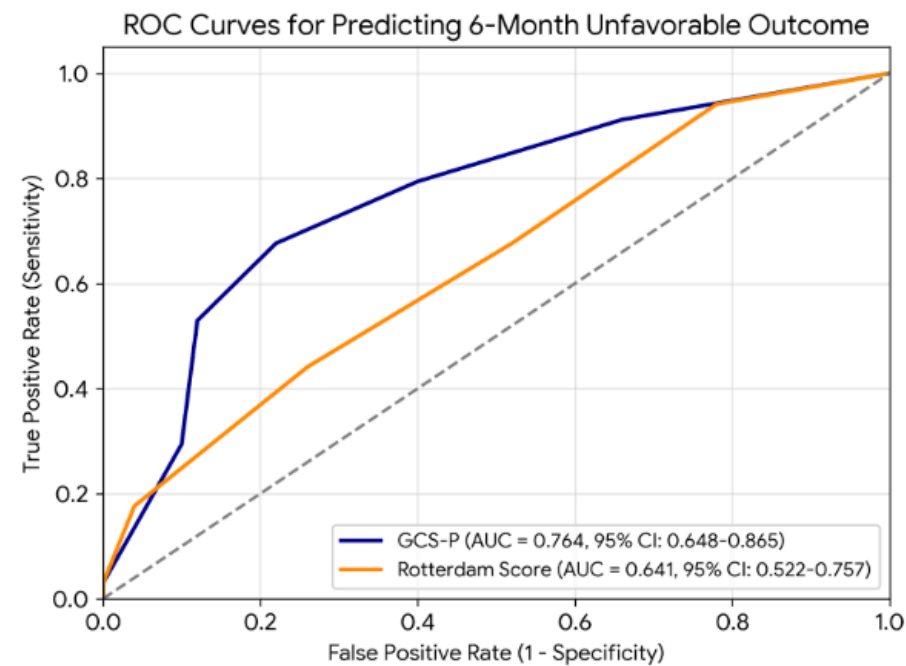


Figure 3

Figure 2B. ROC curves for predicting 6-month unfavorable functional outcome

Receiver operating characteristic (ROC) curves for the Glasgow Coma Scale–Pupils (GCS-P) and Rotterdam CT scores in predicting 6-month unfavorable functional outcome. Unfavorable outcome was defined as a Glasgow Outcome Scale–Extended (GOSE) score of 1–4 (death, vegetative state, or severe disability). The GCS-P score had an AUC of 0.764 (95% CI: 0.648–0.865), whereas the Rotterdam CT score had an AUC of 0.641 (95% CI: 0.522–0.757). The 95% confidence intervals (CIs) were estimated by bootstrapping with 2,000 resamples.