Traumatic Brain Injury Outcome Associations with Computed Tomography and Glasgow Coma Scale Score Interactions: A Retrospective Study

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Abstract

Introduction

Following traumatic brain injury (TBI) early Glasgow Coma Scale (GCS) and brain computed tomography (CT) scores have been associated with clinical outcomes. We aimed to determine if interactive GCS and CT findings would be associated with outcomes.

Methodology

Included TBI patients had GCS scores of 3-12 and required mechanical ventilation for ≥five days. The GCS Deficit was 15 minus the GCS score. The mass-effect CT score was calculated as lateral ventricular compression plus basal cistern compression plus midline shift. Each value was 1 for present and 0 for absent. A prognostic CT score was the mass-effect score plus subarachnoid hemorrhage (2 for present and 0 for absent). The CT-GCS-Deficit score was the sum of the GCS Deficit and the prognostic CT score.

Results

In total, 112 consecutive TBI patients met the inclusion criteria. Patients with a need for surgical decompression had a lower GCS score (6.0 ± 3.0) than those without (7.7 ± 3.3; P = 0.0078; Cohen d = 0.54). Patients with a need for surgical decompression had a higher mass-effect CT score (2.8 ± 0.5) than those without (1.7 ± 1.0; P < 0.0001; Cohen d = 1.4). The GCS Deficit was greater in patients not following commands at hospital discharge (9.6 ± 2.6) than in those following commands (6.8 ± 3.2; P < 0.0001; Cohen d = 0.96). The prognostic CT score was greater in patients not following commands at hospital discharge (3.7 ± 1.2) than in those following commands (3.1 ± 1.1; P = 0.0053; Cohen d = 0.52). The CT-GCS-Deficit score was greater in patients not following commands at hospital discharge (13.3 ± 3.1) than in those following commands (10.5 ± 3.4; P < 0.0001; Cohen d = 1.06). Logistic regression stepwise analysis showed that the failure to following commands at hospital discharge was associated with the CT-GCS-Deficit score (P = 0.0001), but not with the GCS Deficit (P > 0.20). Three-month Glasgow Outcome Scale data were available for 98.2% (110/112) of the patients. The GCS Deficit was greater in patients not following commands at three months (9.7 ± 2.8) than in those following commands (7.4 ± 3.2; P < 0.0001; Cohen d = 0.78). The CT-GCS-Deficit score was greater in patients not following commands at three months (15.6 ± 5.1) than in those following commands (10.5 ± 3.4; P < 0.0001; Cohen d = 0.94). Logistic regression stepwise analysis showed that failure to following commands at three months was associated with the CT-GCS-Deficit score (P < 0.0001), but not with GCS Deficit (P > 0.20). The proportion of patients not following commands at three months was greater with a GCS Deficit of 9-12 (50.9%) than with a GCS Deficit of 3-8 (21.1%; P = 0.0014; odds ratio = 3.9; risk ratio = 2.1). The proportion of patients not following commands at three months was greater with a CT-GCS-Deficit score of 15-17 (56.0%) than with a CT-GCS-Deficit score of 4-12 (18.3%; P = 0.0001; odds ratio = 5.7; risk ratio = 3.1).

Conclusion

The mass-effect CT score had a substantially better association with the need for surgical decompression than did the GCS score. The degree of association for not following commands at hospital discharge and three months was greater with the CT-GCS-Deficit score than with the GCS Deficit. These observations support the notion that a mass-effect and subarachnoid hemorrhage composite CT score can interact with the GCS score to better prognosticate TBI outcomes than the GCS score alone.

Categories: Neurosurgery, Radiology, Trauma

Keywords: brain ct scan, glasgow outcome scale, glasgow coma scale, neurotrauma, decompressive craniotomy, traumatic brain injury

Introduction

Numerous investigators have shown that early postinjury Glasgow Coma Scale (GCS) values are associated
with later clinical outcomes in patients with traumatic brain injury (TBI). Research also demonstrates that
early postinjury GCS score are associated with in-hospital mortality [1-3]. Investigations also show that early
postinjury GCS scores are associated with post-hospital discharge Glasgow Outcome Scale (GOS) results [1-
7].

Several studies have also shown that early TBI computed tomography (CT) scores are associated with
subsequent clinical outcomes. A number of investigations have shown that early CT score findings have
associations with in-hospital mortality [2,8-13]. Several studies have also shown that early CT scores are
associated with post-hospital discharge GOS findings [2,5,6,13,14]. Some of the CT score result
investigations have focused solely on the Rotterdam score [2,5,6,13]. Yet, other studies compare the
Rotterdam and Marshall CT score results [8-11]. Additional investigations have contrasted the CT score
results among Rotterdam, Marshall, and Helsinki CT score findings [12,14].

We have found only one study that combined GCS scores with CT scan results to demonstrate an interaction
with in-hospital mortality and GOS results [2]. In that investigation, the authors used specific
subcomponents of the GCS and the Rotterdam score [2]. The aim of the current study was to demonstrate an
interactive effect of the GCS score and a customized brain CT scoring system with outcomes.

Materials And Methods

Study design and population

The patients had been admitted to a Level I trauma center from 2012 to 2016. Inclusion criteria of this
retrospective study were blunt trauma, age 18-70 years, intracranial hemorrhage with head Abbreviated
Injury Scale scores of ≥2, GCS score of 3-12, and mechanical ventilation for ≥five days. The data for the
current study emanates from that used in a hypertonic saline investigation [15].

The CT score used in the hypertonic saline investigation was constructed to quantify the intracranial mass-
effect. The mass-effect CT score was calculated as the sum of midline shift, lateral ventricle compression,
and basal cistern compression. Each of the three findings was given a value of 0 if absent and 1 if present
(theoretical range, 0-5). We added an intraventricular or subarachnoid hemorrhage (SAH) component to the
mass-effect CT score to create a current study prognostic CT score. When SAH was present the value was 2,
whereas if it was absent the value was 0. The theoretical range of the current study prognostic CT score was
0-5. The GCS Deficit was computed as 15 (normal GCS) minus the admission GCS value (study range, 3-12).
The CT-GCS-Deficit score was the sum of the prognostic CT score and the GCS Deficit (theoretical study
range, 3-17).

Statistical analysis

Continuous data are presented as the mean ± standard deviation, whereas categorical variables are reported
as frequency count and percentage. Because the mass-effect score, prognostic CT score, GCS Deficit, and CT-
GCS-Deficit score are non-parametric, the Wilcoxon rank sum test was used to compare them between two
independent groups. T-tests were also performed. When the p-values of the Wilcoxon and t-tests were
similar, Cohen d values were computed to assess the magnitude of two intergroup mean differences. For
dichotomous proportional data displayed in a 2 x 2 contingency table format, the two-tailed Fisher exact test
was employed to assess the odds ratio and risk ratio. Multivariable logistic regression analysis was used to
assess independent variable associations relative to dichotomous dependent variables. The results were
entered into Excel 2010 (Microsoft Corp., Redmond, WA, USA) and imported into SAS System for Windows,
release 9.2 (SAS Institute Inc., Cary, NC, USA). For receiver operating characteristic curve analyses, data
were exported from SAS into MedCalc® Statistical Software, version 22.016 (MedCalc Software Ltd, Ostend,
Belgium). The significance level for the P-value was set at < 0.05.

Results

Patient characteristics

A total of 112 consecutive TBI patients met the study inclusion criteria. The CT hemorrhage distribution was
epidural hematoma (EDH), 8 (7.1%); subdural hematoma (SDH), 80 (71.4%); SAH, 62 (55.4%); brain
contusion, 35 (31.3%); and cerebral hematoma, 25 (22.3%). The mean GCS score was 6.8 ± 3.2. The mean GCS
Deficit was 8.2 ± 3.2. The GCS score and GCS Deficit distributions are depicted in Table 1. The mean age was
45.5 ± 14.2 years (18-70).
The mean mass-effect CT score was 2.3 ± 0.9. The mass-effect CT score distribution was as follows: 0, 5 patients (4.5%); 1, 21 (18.8%); 2, 23 (20.5%); and 3, 63 (56.3%). The mean prognostic CT score was 3.4 ± 1.2. The prognostic CT score distribution was as follows: 1, 7 patients (6.3%); 2, 15 (11.6%); 3, 49 (43.8%); 4, 15 (13.4%); and 5, 28 (25.0%). The GCS score was not associated with the prognostic CT score (P = 0.1035).

Among 62 patients with SAH, only 5 (8.1%) had no other CT intracranial hemorrhage pathology. The mean CT-GCS-Deficit score was 11.6 ± 3.6. The CT-GCS-Deficit score distribution is presented in Table 2.

<table>
<thead>
<tr>
<th>CT-GCS-Deficit Score</th>
<th>Number</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-9</td>
<td>32</td>
<td>28.6</td>
</tr>
<tr>
<td>10-12</td>
<td>29</td>
<td>25.9</td>
</tr>
<tr>
<td>13-14</td>
<td>22</td>
<td>19.6</td>
</tr>
<tr>
<td>15-17</td>
<td>29</td>
<td>25.9</td>
</tr>
</tbody>
</table>

Surgical decompression

The mass-effect CT score and CT-GCS-Deficit score had better Cohen d associations with need for surgical decompression than with the GCS score (Table 3).

<table>
<thead>
<tr>
<th>Surgical Decompression</th>
<th>No</th>
<th>Yes</th>
<th>Wilcoxon-P</th>
<th>T-test-P</th>
<th>Cohen d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>54 (48.2%)</td>
<td>58 (51.8%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GCS Score</td>
<td>7.7 ± 3.3</td>
<td>6.0 ± 3.0</td>
<td>0.0111</td>
<td>0.0078</td>
<td>0.54</td>
</tr>
<tr>
<td>Mass-Effect CT Score</td>
<td>1.7 ± 1.0</td>
<td>2.8 ± 0.5</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>1.4</td>
</tr>
<tr>
<td>CT-GCS-Deficit Score</td>
<td>10.3 ± 3.4</td>
<td>12.8 ± 3.4</td>
<td>0.0003</td>
<td>0.0001</td>
<td>0.74</td>
</tr>
</tbody>
</table>

The proportions of surgical decompression were similar for EDH (75.0% (6/8)) and no EDH (50% (52/104); P = 0.1757). The proportion of surgical decompression was greater for SDH (61.3% (49/80)) than for no SDH (28.1% (9/32); P = 0.0015). The proportion of surgical decompression was lower for cerebral contusion/hematoma (41.5% (22/53)) than for no cerebral contusion/hematoma (61.0% (36/59); P = 0.0394). Logistic regression analyses showed that surgical decompression was associated with the mass effect score.
(P < 0.0001), but not with SDH (P = 0.3197) or no cerebral contusion/hematoma (P = 0.4022). The proportion of surgical decompression was greater for midline shift (67.9% (55/81)) than no midline shift (9.7% (3/31); P < 0.0001; OR = 19.7). The proportion of surgical decompression was greater for lateral ventricle compression (68.8% (55/77)) than for no lateral ventricle compression (14.3% (5/35); P < 0.0001; OR = 13.3). The proportion of surgical decompression was greater for basal cistern compression (56.1% (55/98)) than for no basal cistern compression (21.4% (3/14); P = 0.0149; OR = 4.7). Surgical decompression had independent associations with midline shift (P = 0.0003) and lateral ventricle compression (P = 0.0004).

EDH and SAH

EDH was not associated with hospital mortality (P = 0.2523) or hospital discharge following commands status (P = 0.4676). The proportion not following commands at three months was lower in those with EDH (0% (0/7)) than in those without EDH (37.9% (39/103); P = 0.0427). Logistic regression stepwise analysis showed an association for not following commands at three months with the CT-GCS-Deficit score (P < 0.0001), but not with EDH (P > 0.20). The proportion of SAH was greater in those not following commands at hospital discharge (67.9% (38/56)) than in those following commands (42.9% (24/56); P = 0.0081). The proportion not following commands at three months was greater in those with SAH (47.5% (29/61)) than in those without SAH (20.4% (10/49); P = 0.0031; odds ratio = 3.5; risk ratio = 2.1).

Hospital mortality

The hospital mortality proportion was 13.4% (15/112). The GCS Deficit and CT-GCS-Deficit score were significantly greater in patients dying in the hospital than in the survivors (Table 4). The Cohen d for the CT-GCS-Deficit score was slightly larger than that for the GCS Deficit.

<table>
<thead>
<tr>
<th>Density</th>
<th>Number</th>
<th>Wilcoxon-P</th>
<th>T-test-P</th>
<th>Cohen d</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>97 (86.6%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>15 (13.4%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GCS Score</td>
<td>7.1 ± 3.3</td>
<td>4.8 ± 2.2</td>
<td>0.0130</td>
<td>0.0091</td>
</tr>
<tr>
<td>GCS Deficit</td>
<td>7.9 ± 3.3</td>
<td>10.2 ± 2.2</td>
<td>0.0130</td>
<td>0.0091</td>
</tr>
<tr>
<td>Prognostic CT Score</td>
<td>3.4 ± 1.2</td>
<td>3.6 ± 1.1</td>
<td>0.4368</td>
<td>0.4619</td>
</tr>
<tr>
<td>CT-GCS-Deficit Score</td>
<td>11.2 ± 3.6</td>
<td>13.8 ± 2.8</td>
<td>0.0111</td>
<td>0.0098</td>
</tr>
</tbody>
</table>

TABLE 4: Hospital mortality associations

GCS: Glasgow Coma Scale; CT: computed tomography; continuous results are mean ± standard deviation

Not following commands at hospital discharge

The GCS Deficit, prognostic CT score, and CT-GCS-Deficit score values were significantly greater in patients not following commands at hospital discharge than in those following commands (Table 5). The Cohen d was slightly higher for the CT-GCS-Deficit score, than for the GCS Deficit. Logistic regression stepwise analysis showed that failure to follow commands at hospital discharge was associated with the CT-GCS-Deficit score (P < 0.0001), but not with either the GCS Deficit (P > 0.20) or prognostic CT score (P > 0.20).
TABLE 5: Associations with not following commands at hospital discharge
GCS: Glasgow Coma Scale; CT: computed tomography; continuous results are mean ± standard deviation

<table>
<thead>
<tr>
<th>Following Commands</th>
<th>Yes</th>
<th>No</th>
<th>Wilcoxon-P</th>
<th>T-test-P</th>
<th>Cohen d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>56 (50%)</td>
<td>56 (50%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GCS Score</td>
<td>8.2 ± 3.2</td>
<td>5.4 ± 2.6</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>0.96</td>
</tr>
<tr>
<td>GCS Deficit</td>
<td>6.8 ± 3.2</td>
<td>9.6 ± 2.6</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>0.96</td>
</tr>
<tr>
<td>Prognostic CT Score</td>
<td>3.1 ± 1.1</td>
<td>3.7 ± 1.2</td>
<td>0.0071</td>
<td>0.0053</td>
<td>0.52</td>
</tr>
<tr>
<td>CT-GCS-Deficit Score</td>
<td>9.9 ± 3.2</td>
<td>13.3 ± 3.2</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>1.06</td>
</tr>
</tbody>
</table>

Not following commands at three months

Three-month GOS data were available for 98.2% (110/112) of the patients. The proportion following commands at three months (64.5%) was greater than the proportion following commands at hospital discharge (50.0%; P = 0.0308; OR = 1.8). The proportion not following commands at three months was similar with and without SDH (P = 0.4678), cerebral contusion (P = 0.8004), and cerebral hematoma (P = 0.8127). The GCS Deficit, prognostic CT score, and CT-GCS-Deficit score values were greater in patients not following commands at three months than in those following commands (Table 5). The Cohen d was greater for the CT-GCS-Deficit score than for the GCS score and GCS Deficit.

TABLE 6: Associations with not following commands at three months (continuous data)
GCS: Glasgow Coma Scale; CT: computed tomography; continuous results are mean ± standard deviation

<table>
<thead>
<tr>
<th>Following Commands</th>
<th>Yes</th>
<th>No</th>
<th>Wilcoxon-P</th>
<th>T-test-P</th>
<th>Cohen d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>71 (64.5%)</td>
<td>39 (35.5%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GCS Score</td>
<td>7.6 ± 3.2</td>
<td>5.3 ± 2.7</td>
<td>0.0004</td>
<td>0.0002</td>
<td>0.78</td>
</tr>
<tr>
<td>GCS Deficit</td>
<td>7.4 ± 3.2</td>
<td>9.7 ± 2.8</td>
<td>0.0004</td>
<td>0.0002</td>
<td>0.78</td>
</tr>
<tr>
<td>Prognostic CT Score</td>
<td>3.2 ± 1.1</td>
<td>3.9 ± 1.1</td>
<td>0.0033</td>
<td>0.0028</td>
<td>0.64</td>
</tr>
<tr>
<td>CT-GCS-Deficit Score</td>
<td>10.5 ± 3.4</td>
<td>13.6 ± 3.1</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>0.94</td>
</tr>
</tbody>
</table>

Not following commands at three months was independently associated with the GCS score (P = 0.0013) and the prognostic CT score (P = 0.0120). Logistic regression stepwise analysis showed that the failure to following commands at three months was associated with the CT-GCS-Deficit score (P < 0.0001), but not with either the GCS Deficit (P > 0.20) or prognostic CT score (P > 0.20).

Results were dichotomized to show three-month outcome associations with the GCS Deficit (Table 7) and the CT-GCS-Deficit score (Table 8). For the two GCS Deficit and the two CT-GCS-Deficit score cohorts, the mean GCS scores were virtually identical for the two lower value groups (9.5 and 9.2) and for the two higher value groups (5.9 and 3.9). For the CT-GCS-Deficit scores, the odds ratio and risk ratio values were higher but the P-value was lower for not following commands at three months, when compared with those for the GCS Deficit scores (Table 7 and Table 8). The areas under the receiver operating characteristic curve (AUC) for no commands at three months were 0.70 (P < 0.001) for the GCS score and 0.75 (P < 0.001) for the CT-GCS-Deficit score.
### TABLE 7: Association for not following commands at three months according to GCS Deficit Score 3–8 versus 9–12

GCS: Glasgow Coma Scale; GCS score results are mean ± standard deviation

<table>
<thead>
<tr>
<th>GCS Deficit Score</th>
<th>3–8</th>
<th>9–12</th>
<th>P-value</th>
<th>Odds Ratio</th>
<th>Risk Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>GCS Score</td>
<td>9.5 ± 2.0</td>
<td>3.9 ± 1.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number</td>
<td>57 (51.8%)</td>
<td>53 (48.2%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Commands</td>
<td>12 (21.1%)</td>
<td>27 (50.9%)</td>
<td>0.0014</td>
<td>3.9</td>
<td>2.1</td>
</tr>
</tbody>
</table>

### TABLE 8: Association for not following commands at three months according to CT-GCS-Deficit Score 4–12 versus 13–17

CT: computed tomography; GCS: Glasgow Coma Scale; GCS score results are mean ± standard deviation

<table>
<thead>
<tr>
<th>CT-GCS-Deficit Score</th>
<th>4-12</th>
<th>13-17</th>
<th>P-value</th>
<th>Odds Ratio</th>
<th>Risk Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>GCS Score</td>
<td>9.2 ± 2.2</td>
<td>3.9 ± 1.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number</td>
<td>60 (54.5%)</td>
<td>50 (45.5%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Commands</td>
<td>11 (18.3%)</td>
<td>28 (56.0%)</td>
<td>0.0001</td>
<td>5.7</td>
<td>3.1</td>
</tr>
</tbody>
</table>

### Discussion

The inclusion criteria of the current study required the presence of intracranial hemorrhage, which is prima facie evidence for TBI. The exclusion of patients with GCS scores of 12–15 eliminated those with minor TBI. The requirement for ≥five days of mechanical ventilation excluded those dying of devastating TBI in the first four hospital days. These criteria portend a balance between TBI homogeneity and heterogeneity that we believe likely fosters the ability to identify proximal TBI conditions that can better be associated with distal TBI outcomes. This is in contradistinction to including the whole spectrum of TBI that can create noise that mitigates the ability to identify proximal TBI conditions as they relate to distal TBI outcomes. However, excessive inclusion criteria might create misrepresentative associations that lack erudition.

**GCS score and GCS Deficit associations**

Most of the patients in the current study had GCS scores of 3–8. The GCS Deficit in the current study had a large association (Cohen d) with in-hospital mortality. A similar GCS relationship with hospital mortality has also been found by other investigators [1-3]. The current study demonstrated that the admission GCS score has a large association with not following commands at hospital discharge. Another investigation also showed that hospital GOS results were associated with admission GCS scores [16]. The GCS score has also been found to have an association with the Rotterdam score, in general, and midline shift, in particular [7]. The current study also showed a large association (Cohen d) between the GCS score and not following commands at three months. A similar relationship of the GCS score with post-hospital discharge GOS results was demonstrated by several other researchers [1-7].

These findings from the current study and literature suggest that the observed investigational GCS values were credible. The study finding and literature coherency also suggest that the exclusion of the clinical extremes of patients with TBI did not distort the importance of the GCS score in the current investigation. The GCS Deficit was created to convert lower GCS values, which imply worse neurological function, into positive expressions. We thought that this would make a more aesthetic representation for interacting with positive or worse prognostic CT scores. Of relevance another TBI investigation has inverted GCS motor scores for the same purpose [17].

**Mass-effect CT score**

The CT score used in the hypertonic saline investigation was constructed to quantify the intracranial mass effect [15]. In kind, the current study’s mass-effect CT score also considered the presence or absence of midline shift, basal cistern compression, and lateral ventricle compression. The presence of midline shift is
also considered a risk condition for the Rotterdam and Marshall scoring systems [11,12]. One investigation reported a significant univariate association of midline shift with in-hospital mortality and post-discharge GOS results [2]. The presence of basal cistern compression is also considered a risk condition for the Rotterdam, Marshall, and Helsinki scoring systems [11,12]. An investigation specifically showed a significant univariate association of basal cistern compression with in-hospital mortality and post-discharge GOS results [2]. Lateral ventricle compression (asymmetry) has been shown to be associated with the development of a midline shift [18], failure of conservative treatment with SDH [19], and decreased brain compliance (impaired intracranial pressure control) [20]. In the current study, the need for surgical decompression had univariate associations with midline shift, basal cistern compression, and lateral ventricle compression. Although lateral ventricle compression (asymmetry) has not been widely reported as a CT risk condition, the need for surgical decompression had independent associations with midline shift and lateral ventricle compression. Ostensibly, the validity of the mass-effect CT schema lies in the strong association (Cohen d) with the need for surgical decompression. Other investigators have provided evidence that midline shift and basal cistern compression are associated with surgical decompression in TBI [21].

**Prognostic CT score**

We created a prognostic CT score, by adding SAH (no or yes) to the mass-effect CT score. SAH was found to have an association with not following commands at hospital discharge and at the three-month follow-up. SAH or intraventricular hemorrhages are considered risk conditions for the Rotterdam and Helsinki CT scoring systems [11,12]. Pargaonkar et al. showed that SAH is associated with early TBI mortality [12]. In-Suk et al. specifically demonstrated a significant univariate and multivariate association of SAH with in-hospital mortality and post-discharge GOS results [2]. Another investigation reported that six-month mortality and unfavorable outcomes were associated with SAH in univariate and multivariate analyses [17]. The current study assigned a value of 2, when SAH was present, based on the substantial effect size associations (odds ratio and risk ratio values) with adverse 3-month outcomes. Other esteemed TBI researchers have also assigned a value of 2 when SAH was present and 0 when absent as a prognosticator of 6-month unfavorable outcomes [17]. It is relevant that the three-month outcome univariate odds ratio and risk ratio values for SAH in the current study were similar to those in the 6-month unfavorable outcomes investigation [17].

We found that EDH had no association with either hospital mortality or following commands at hospital discharge. Although a lower proportion of patients with EDH were not following commands at three months than those without EDH, this finding became insignificant when also considering the prognostic CT score results. The construction of the Rotterdam and Helsinki scoring systems consider the presence of EDH as a decreased risk condition for adverse clinical outcomes [12]. A large analysis by Steyerberg et al. specifically found that EDH was a decreased risk condition in univariate analysis for unfavorable outcomes at six-month [17]. Another investigation found that EDH had a univariate association with decreased six-month unfavorable outcomes; however, the effect size was weak (risk ratio 0.83), indicating little-to-no decrease in risk [13]. In univariate analysis, In-Suk et al. found that EDH was a decreased risk condition (odds ratio 0.48) for 12-month post-discharge unfavorable outcomes; however, they found an increased risk in multivariate analysis (odds ratio 4.5) [2]. Thus, evidence exists to demonstrate that EDH has a decreased risk, a minimal-to-no decreased risk, and an increased risk for post-hospital discharge adverse outcomes. Owing to these conflicting literature observations and the current study findings, we recommend that EDH not be a routine stratification component for TBI prognostic brain CT scoring systems.

The prognostic CT score was higher in patients not following commands at hospital discharge than in those following commands; however, the Cohen d value of the GCS score was larger. Numerous researchers have shown that early CT score findings have associations with in-hospital mortality [2,8-13]. Unfortunately, we have been unable to readily identify any publication describing GOS results at the time of hospital discharge in relationship to early CT score results. The prognostic CT score was also higher in patients not following commands at three months than in those following commands; yet, the Cohen d value of the GCS score was greater. Several research investigations have shown that early CT score results have associations with post-hospital discharge GOS results [2,5,6,13,14].

**Prognostic CT score and GCS Deficit interaction associations**

The CT-GCS-Deficit score was the sum of the prognostic CT score and the GCS Deficit. Because the GCS Deficit was not associated with the prognostic CT score, it becomes plausible that the two entities could create an interactive effect regarding outcomes. The CT-GCS-Deficit score was higher in patients with in-hospital mortality than in the survivors. The Cohen d value of the CT-GCS-Deficit score was slightly greater for in-hospital mortality than that for the GCS Deficit. Although the prognostic CT score was not different for those dying, the slightly larger Cohen d value of the CT-GCS-Deficit score suggests that the prognostic CT score and GCS Deficit had an interactive effect.

The CT-GCS-Deficit score was higher in patients not following commands at hospital discharge than in those following commands. For patients not following commands at hospital discharge, the Cohen d value of the CT-GCS-Deficit score was slightly higher than that for the GCS Deficit, implying that the prognostic CT score and GCS Deficit had an interactive result. This observation is further supported by the fact that during the stepwise multivariate logistic regression analysis for no commands at hospital discharge, the CT-GCS-Deficit score was higher in patients without EDH than those with EDH. Unfortunately, we were not able to readily identify any publication describing GOS results at the time of hospital discharge in relationship to early CT score results. The prognostic CT score was also higher in patients not following commands at three months than in those following commands; yet, the Cohen d value of the GCS score was greater. Several research investigations have shown that early CT score results have associations with post-hospital discharge GOS results [2,5,6,13,14].
score was selected; yet, the prognostic CT score and GCS Deficit were excluded. These data indicate that a mass effect and SAH composite CT score can interact with the GCS score to better prognosticate TBI outcomes than the GCS score alone.

The CT-GCS-Deficit score was higher in patients not following commands at three months than in those following commands. For those not following commands at three months, the Cohen d value of the CT-GCS-Deficit score was substantially greater than that for the GCS Deficit. This observation is compelling for an interactive effect between the prognostic CT score and GCS Deficit. Multivariate logistic regression analysis corroborated this impression in that it demonstrated not following commands at three months was independently associated with the prognostic CT score and GCS Deficit. This advantage of the prognostic CT score and GCS Deficit interaction was further depicted in that during stepwise multivariate logistic regression analysis for no commands at three months, the CT-GCS-Deficit score was selected; yet, the prognostic CT score and GCS Deficit were excluded. The proportion of those not following commands at three months was greater among those with a GCS Deficit of 9-12 than among those with a GCS Deficit of 3-8. Similarly, the proportion of those not following commands at three months was greater among those with a CT-GCS-Deficit score of 13-17 than in those with a CT-GCS-Deficit score of 4-12. It is important to note that the mean GCS score was similar for the lower GCS Deficit and CT-GCS-Deficit score groups. Likewise, the mean GCS score was similar for the higher GCS Deficit and CT-GCS-Deficit score groups. These observations imply that the comparisons of the GCS Deficit and the CT-GCS-Deficit score occurred in similar patients.

When comparing the GCS Deficit and the CT-GCS-Deficit score results, the P-value was lower and the odds ratio and risk ratio values were higher for the CT-GCS-Deficit score results. This indicates that the CT-GCS-Deficit score, which combines the prognostic CT score and GCS Deficit, has a greater association with no commands at three months than the GCS score alone. The AUC for the CT-GCS-Deficit score was slightly higher for discriminating patients not following commands at three months, when compared to the GCS Deficit. This also suggests that the prognostic CT score and GCS Deficit have an interactive effect. Because the proportion of patients following commands at three months was significantly greater than that at hospital discharge, it may be important to assess potential post-discharge outcomes on the basis of interactive effects of the prognostic CT score and GCS Deficit. Finally, in TBI prospective trials and retrospective analyses, there may be value in displaying intergroup similarities, or heterogeneities, using the GCS score, prognostic CT score, and CT-GCS-Deficit score. In summary, the data indicate that a mass-effect and SAH composite CT score can interact with the GCS score to better prognosticate TBI outcomes than the GCS score alone.

The authors have several observations regarding an investigation that interacted GCS score and Rotterdam CT score subcomponents [2]. Importantly, the study included the extremes of TBI (GCS scores of 3-8 and 13-15) with marked distinctions. The very low mortality for the GCS scores of 13-15 markedly contrasts with the quite high mortality for GCS scores of 3-8 (risk ratio = 337). Likewise, the very low unfavorable outcome for GCS scores of 13-15 is substantially distinct from the quite high unfavorable outcome for GCS scores of 5-8 (risk ratio = 238). From table 7 in the manuscript, we computed the mean Rotterdam scores to be 2.0 for patients with GCS scores of 13-15 patients and 4.0 for patients with GCS scores of 5-8 patients. The AUCs for the GCS score, Rotterdam CT score, and New TBI score were nearly 1.0 for in-hospital mortality and post-discharge unfavorable outcomes. Such a large AUC is astonishing and atypical for most clinical investigations. This near-perfect sensitivity-specificity discrimination seems likely to be related to the inclusion of the extremes of patients with TBI. That is, the inclusion of GCS scores of 13-15, the majority of patients, and all GCS scores of 3-8, including early deaths with devastating TBI, may overstate evident group traits or over-look more subtle intra-group variances that are clinically important to those managing patients with TBI. Although the AUCs for not following commands at three months in the current study are less than the In-Suk et al. investigation [2], it may be, in part, related to the exclusion of the extremes of TBI severity. We are perplexed as to how EDH could be found to be a decreased univariate risk condition for in-hospital mortality and post-discharge unfavorable outcomes, but an increased risk condition when conducting multivariate analyses [2]. The current authors have neither an intuitive, rational, or clinical reason for this statistical paradox. Further, the AUC for EDH relative to in-hospital mortality and unfavorable outcomes was <0.60 [2]. Although the In-Suk et al. investigation [2] used the GCS components, verbal and motor, to include in their New TBI score, other investigators have shown that the total GCS score is more sensitive than the motor score for identifying trauma patients with serious injury [22]. Despite some perplexities, we commend In-Suk et al. for advancing the notion that TBI GCS and brain CT findings are likely to have an interactive effect relative to clinical outcomes.

Limitations of the study

The main limitation of the current study is that it was a retrospective analysis. The study findings need to be confirmed in a prospective observational investigation. Preferably the investigation would include a larger sample size and possibly include a study design where the inclusion criteria are less restrictive.

Conclusions

The mass-effect CT score had a substantially better association with need for surgical decompression than
did the GCS score. The associations for not following commands at hospital discharge were greater with the CT-GCS-Deficit score than with the GCS Deficit. The associations for not following commands at three months were also greater with the CT-GCS-Deficit score than with the GCS Deficit. These observations support the notion that a mass-effect and SAH composite CT score can interact with the GCS score to better prognosticate TBI outcomes than the GCS score alone. These findings need corroboration in a larger cohort during prospective observation. Owing to inconsistent literature observations and the current study findings, we recommend that EDH not be a routine stratification component for TBI brain CT scoring systems.

Additional Information
Author Contributions
All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

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