Subdural hematoma as a major determinant of short-term outcomes in traumatic brain injury

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OBJECTIVE Early radiographic findings in patients with traumatic brain injury (TBI) have been studied in hopes of better predicting injury severity and outcome. However, prior attempts have generally not considered the various types of intracranial hemorrhage in isolation and have typically not excluded patients with potentially confounding extracranial injuries. Therefore, the authors examined the associations of various radiographic findings with short-term outcome to assess the potential utility of these findings in future prognostic models.

METHODS The authors retrospectively identified 1716 patients who had experienced TBI without major extracranial injuries, and categorized them into the following TBI subtypes: subdural hematoma (SDH), traumatic subarachnoid hemorrhage, intraparenchymal hemorrhage (which included intraventricular hemorrhage), and epidural hematoma. They specifically considered isolated forms of hemorrhage, in which only 1 subtype was present.

RESULTS In general, the presence of an isolated SDH was more likely to result in worse outcomes than the presence of other isolated forms of traumatic intracranial hemorrhage. Discharge to home was less likely and perihospital mortality rates were generally higher in patients with SDH. These findings were not simply related to age and were not fully captured by the admission Glasgow Coma Scale (GCS) score. The presence of SDH had a much higher sensitivity for poor outcome than the presence of other TBI subtypes, and was more sensitive for these poor outcomes than having a low GCS score (3–8).

CONCLUSIONS In these ways, SDH was the most important finding associated with poor outcome, and the authors show that consideration of SDH, specifically, can augment age and GCS score in classification and prognostic models for TBI.

https://thejns.org/doi/abs/10.3171/2016.5.JNS16255

KEY WORDS head injury; traumatic brain injury; subdural hematoma; trauma

TRAUMATIC brain injury (TBI) is a significant cause of morbidity and mortality worldwide. Outcomes vary dramatically, and the determination of prognosis is very imprecise. Neurosurgeons in particular rely on prognostic clues to evaluate the indications for aggressive medical or surgical care, and to determine the goals of care with families. In a survey of clinicians by Perel et al.,31 in which neurosurgeons were among the main respondents, only 37% agreed that they currently assess prognosis accurately. In this same study, 67% of clinicians believed that a more accurate prognostic model would change the way that they managed patients with TBI, and 88% believed that this model would change the way they report the prognosis to a patient’s family.

Studies throughout the last few decades have attempted to elucidate the most important factors that predict outcome in TBI.5,11,21,22,25,27,30 The Glasgow Coma Scale (GCS) score38 is one of the most widely used assessments of TBI, and has been shown to have a strong association with short-term outcome.5,27 Older age also has been consistently associated with increased mortality rates in patients with TBI.4,27,29

ABBREVIATIONS AIS = Abbreviated Injury Scale; EDH = epidural hematoma; GCS = Glasgow Coma Scale; ICD-9 = International Classification of Diseases, Ninth Revision; IPH = intraparenchymal hemorrhage; IVH = intraventricular hemorrhage; SDH = subdural hematoma; SNF = skilled nursing facility; TBI = traumatic brain injury; TBI–, TBI+ = TBI without major extracranial injury, TBI with major extracranial injury; tSAH = traumatic subarachnoid hemorrhage.


INCLUDE WHEN CITING Published online February 10, 2017, DOI: 10.3171/2016.5.JNS16255.
Additionally, the advancements in CT scanning have led to the development of prognostic models based on characteristics of intracranial lesions.\textsuperscript{11,21,22,25} In an early, large, retrospective study, Gennarelli et al.\textsuperscript{11} argued that categorization of injury severity based on GCS score and by subtype of intracranial lesion demonstrated on CT scans was important in predicting the outcome in patients with head injury. Numerous classification schemes based on anatomical features found on CT scans have been used, including the Marshall\textsuperscript{22} and the Rotterdam CT scoring systems;\textsuperscript{22} these classification methods were fairly accurate predictors of outcome in early TBI.\textsuperscript{26} The Marshall CT classification system assesses CT characteristics, such as the presence or absence of any nonspecific mass lesion, basal cistern status, the presence or absence of midline shift, and the volume of any nonspecific hemorrhagic mass.\textsuperscript{25} The Rotterdam CT scoring system builds upon the Marshall classification scheme by considering the presence or absence of an epidural hematoma (EDH) and the presence or absence of either a traumatic subarachnoid hemorrhage (tSAH) or intraventricular hemorrhage (IVH), but omits the Marshall system’s feature of hemorrhagic mass volume.\textsuperscript{26}

Among specific subtypes of hemorrhage in TBI, acute subdural hematoma (SDH) has been associated with significant short-term mortality rates, which may range as high as 40%–90% depending on GCS score and age.\textsuperscript{12,17,20} Even with prompt surgical evacuation, mortality rates remained as high as 42%.\textsuperscript{20} Gennarelli et al.\textsuperscript{11} reported that acute SDH had a higher mortality rate compared with other focal intracranial lesions, such as EDH. However, no widely used CT classification system uses the presence or absence of SDH as a direct characteristic; the Rotterdam score only broadly differentiates between epidural and intradural lesions.\textsuperscript{22}

Although these studies have been influential in advancing the understanding of TBI prognostication, no large-scale study has focused on the comprehensive comparison of isolated (i.e., no additional intracranial abnormalities) subtypes of traumatic intracranial hemorrhage as a window into the prognostic influence of each. Studies that have focused on isolated SDH were limited by their consideration of comparatively small numbers of patients,\textsuperscript{8,19,39} and few studies attempted to exclude patients with major systemic injuries, thus limiting our ability to understand the contribution of the TBI alone.

Furthermore, current classification schemes that attempt to define the most important prognostic CT features in patients with TBI have substantial limitations. The Marshall score does not classify what type of hematoma is present, if any, and has difficulty classifying patients with multiple subtypes of TBI.\textsuperscript{26} The Rotterdam score’s incorporation of certain CT characteristics (e.g., tSAH) was not derived from the study of these characteristics in isolation (i.e., without the presence of other simultaneous intracranial injuries). These characteristics were also not studied in patient populations across all ages and all GCS scores (3–15) and in patients without major extracranial injuries.

The goal of our study was to compare short-term outcomes of various isolated subtypes of TBI in patients without major extracranial injuries, to determine the most important intracranial radiographic findings related to short-term outcome. We examined how the presence of acute SDH, compared with other TBI subtypes, affected the likelihood of poor short-term outcome when used in conjunction with the established knowledge of age and GCS score. To investigate these issues, we conducted a review of a large sample of patients admitted to our Level 1 trauma center over an 11-year span, from 2003 to 2013.

**Methods**

**Patient Population**

We used the Rhode Island Hospital trauma registry database to retroactively identify all patients presenting to the emergency department during the 11-year period between January 1, 2003, and December 31, 2013. We used the *International Classification of Diseases, Ninth Revision* (ICD-9) codes and the Abbreviated Injury Scale (AIS) codes to identify patients with traumatic head injuries, including extraaxial and intraxial hemorrhages and skull fractures (ICD-9 800, 801, 803, 804, 850–854, 900, 907, 950, and 951).

From this traumatic head injury population, we created classes of patients by using combinations of the following 4 TBI subtypes: subdural hematoma (SDH); traumatic subarachnoid hemorrhage (tSAH); intraparenchymal hemorrhage (IPH), which included IVH; and EDH. Only patients who had injuries identified by both ICD-9 and AIS codes were included in each class to maximize classification accuracy. For instance, when searching for patients with isolated (no additional intracranial abnormalities) SDH, we excluded patients who had AIS codes for SDH but lacked ICD-9 codes for SDH, and vice versa. We refer to the population of patients collected thus far as the “initial TBI” population in our study.

We presumed that all injury codes from the trauma database designated acute injuries. Our database is compiled from trauma team activations that are typically in response to acute trauma; patients with chronic injuries (e.g., chronic SDH) resulting from unclear or distant injury usually do not trigger a trauma team activation, and so they would not be included in this database.

Isolated classes included patients who had no additional intracranial abnormalities other than the specified TBI subtype. All-inclusive classes included all patients who suffered a TBI subtype in any pattern (e.g., in isolation or with additional TBI subtypes). Additionally, we created 3 classes according to the number of TBI subtypes present (those with 1, 2, or ≥3 subtypes of intracranial hemorrhage).

From this initial TBI population we excluded patients who had penetrating head injuries, including gunshot wounds to the head. We then excluded all patients with major systemic injuries, defined as severe extracranial injuries (e.g., multiple bone fractures, internal injuries to vital organs, crushing injuries, injuries to major blood vessels), by excluding all patients who had the following ICD-9 codes: 800–813, 817–824, and 827. Our intention in excluding patients with major extracranial injuries was to eliminate injuries that could potentially confound the impact of the intracranial hemorrhage itself on patient out-
come. We then excluded patients in whom a GCS score had not been recorded. We refer to this distinct population as the TBI− (TBI without major extracranial injury) population throughout this report. Excluding all TBI− patients from the initial TBI population yielded the population of patients with TBI and major systemic injury; we refer to this population as the TBI+ (TBI with major extracranial injury) population throughout this report.

**Covariate Analysis**

For the TBI+ population, we reviewed medical records to determine the age and sex of the patients. For the TBI− population, we determined the following patient demographic data: age, sex, admission GCS score, Injury Severity Score, hospital transfers from a referring facility, ICU admission rates, length of ICU and hospital stays, and posthospital disposition. To calculate the mean number of ICU days, we only considered patients who were admitted to the ICU (i.e., had at least 1 day in the ICU). To calculate the length of stay, we excluded patients who died during their hospital stay.

We categorized mechanism of injury into the following categories: motor vehicle accident bicycle accident, pedestrian injury, fall, violence (includes unarmed brawl, assault, and abuse), struck (by object), and other. The management of the patients was directed by a diverse and changing array of clinicians over a span of 11 years; accordingly, we presumed there was unlikely to be any systematic bias in their care.

We categorized posthospital disposition as follows: discharged to home, to a skilled nursing facility (SNF), to rehabilitation, or died. Patients who left the hospital against medical advice or who were transferred to the psychiatry department were classified as having been discharged home. We classified patients who were discharged to a short-term hospital, SNF, or intermediate care facility as having been discharged to an SNF. We categorized patients who died or were discharged to hospice in the same posthospital disposition category due to the similarity of ultimate outcome; in general, we refer to patients in this category as those who died during our study.

**Statistical Analysis**

Our statistical methods were identical to those used previously.18 We used nonparametric bootstrap testing to calculate the significance of observed data compared with a resampled null distribution. For comparisons of the means of age or GCS score between 2 groups (e.g., isolated SDH and isolated EDH), we randomly chose from all data 2 distributions of sizes equivalent to our empirical samples and calculated the difference in the i_th sample’s means (Δμ_i). We performed this resampling N times (10^4), generating a distribution of differences representing the null hypothesis. The p value was obtained by taking the fraction of estimates greater than our empirical calculation of the difference of means (Δμ) divided by N + 1; p values < 0.025 were used to reject the null hypothesis.

To test for significance that percentages of populations were different between groups (e.g., posthospital dispositions for isolated SDH and isolated EDH), we performed 10^4 random samples from our data as detailed above, and calculated the difference in proportions of the resampled distributions to generate the null distribution of differences. The p values were obtained as above. All analyses were performed in MATLAB (Mathworks) and Python 2.7.10 (Python Software Foundation).

The ORs and 95% CIs are reported; ORs were considered significant if the 95% CIs did not cross 1.

**Results**

**Patient Population**

We identified 8412 patients with traumatic head injury by the initial trauma registry query. When we queried patients with traumatic head injury for the AIS and ICD-9 codes specific to the TBI subtypes of interest (SDH, tSAH, IPH [which included IVH], and EDH), we identified 981 patients who had only AIS codes, 1196 patients who had only ICD-9 codes, and 3100 patients who had both AIS and ICD-9 codes that could identify a given injury. Thus, our “initial TBI” population included 3100 patients (36.9% of the traumatic head injury population) with the aforementioned TBI subtypes in isolation (e.g., isolated SDH) or with co-occurring subtypes (e.g., SDH + tSAH). A total of 2177 patients were excluded because they did not have an injury that could be identified by both AIS and ICD-9 codes (981 patients with AIS codes only and 1196 patients with ICD-9 codes only), in accordance with the conservative inclusion and exclusion criteria of our study.

We then excluded 5 patients with penetrating head injuries and 1057 patients with major extracranial injuries from this TBI population. We excluded an additional 322 patients in whom a GCS score had not been reported. Thus, our final TBI− population consisted of 1716 patients (55.4% of initial TBI population, 20.4% of traumatic head injury population). When we excluded TBI− patients (n = 1716) from the initial TBI population (n = 3100), we identified 1384 patients who had TBI with major extracranial injury (i.e., TBI+).

**Admission Demographic Data**

We compared the TBI− and TBI+ populations to broadly assess how representative our isolated TBI (no major extracranial injuries) group was of the larger TBI population. The TBI− population had a slightly but significantly lower mean age (58.4 years, SD 26.4 years) than the TBI+ population (62.5 years, SD 26.3 years; p = 0.0002). When we compared the percentage of males in these 2 populations (TBI−: 58.1%, SD 1.3%; TBI+: 57.7%, SD 1.2%), we found the difference to be insignificant (p = 0.418).

Table 1 displays patient demographic data for the TBI− population (n = 1716). Of all TBI subtypes, SDH had the highest incidence. Isolated SDH represented 45.2% (775/1716) of TBI− patients, and 61.4% (1054/1716) of all TBI− cases involved SDH (all-inclusive SDH). Figure 1 depicts the age distribution among all-inclusive TBI subtypes. Of all patients ≥ 60 years old, 68.3% (746/1093) had SDH, compared with 41.7% (456/1093), 9.8% (107/1093), and 2.3% (25/1093) who had tSAH, IPH, and EDH, respectively (p < 0.0001 for all 3 comparisons; % SDH vs % tSAH, % SDH vs % IPH, and % SDH vs % EDH). Among
isolated classes of TBI, patients with SDH had a significantly lower mean admission GCS score (13.5) compared with tSAH and IPH (isolated SDH vs isolated tSAH, p = 0.0003; isolated SDH vs isolated IPH, p = 0.0163; isolated SDH vs isolated EDH was not significant, p = 0.378). The isolated SDH group had a significantly higher pro-

### TABLE 1. Admission demographic data in 1716 patients with TBI−

<table>
<thead>
<tr>
<th>Subgroup</th>
<th>Total</th>
<th>% of Total TBI Pop (n = 1716)</th>
<th>Mean Age (yrs)</th>
<th>% Male</th>
<th>% w/ Admission GCS Score (n)</th>
<th>% w/ Injury Severity Score (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3–8</td>
<td>9–12</td>
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<tr>
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<td>775</td>
<td>45.2</td>
<td>67.6</td>
<td>64.1</td>
<td>13.5</td>
<td>12.3</td>
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<td>23.5</td>
<td>62.9</td>
<td>51.5</td>
<td>14.2</td>
<td>77.7</td>
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<td>68.6</td>
<td>14.1</td>
<td>39.5</td>
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<td>196</td>
<td>11.4</td>
<td>68.1</td>
<td>63.3</td>
<td>12.7</td>
<td>16.8</td>
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<td>2.0</td>
<td>52.1</td>
<td>71.4</td>
<td>12.7</td>
<td>8.6</td>
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<td>0.6</td>
<td>56.0</td>
<td>72.7</td>
<td>11.5</td>
<td>9.1</td>
</tr>
<tr>
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<td>2.4</td>
<td>66.5</td>
<td>54.8</td>
<td>13.4</td>
<td>33.3</td>
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<td>41.0</td>
<td>100</td>
<td>15.0</td>
<td>0</td>
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<td>19.0</td>
<td>100</td>
<td>5.0</td>
<td>0</td>
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<tr>
<td>SDH + tSAH + IPH</td>
<td>27</td>
<td>1.6</td>
<td>65.4</td>
<td>55.6</td>
<td>12.8</td>
<td>11.1</td>
</tr>
<tr>
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<td>9</td>
<td>0.5</td>
<td>65.8</td>
<td>55.6</td>
<td>9.9</td>
<td>22.2</td>
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<tr>
<td>tSAH + IPH + EDH</td>
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<td>0 NA</td>
<td>NA</td>
<td>NA</td>
<td>0</td>
<td>0</td>
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<tr>
<td>≥3 subtypes</td>
<td>37</td>
<td>2.2</td>
<td>64.6</td>
<td>56.8</td>
<td>12.2</td>
<td>13.5</td>
</tr>
</tbody>
</table>

NA = not applicable; Pop = population.

FIG. 1. Graph depicting age distribution among patients in the all-inclusive TBI− group (patients without major systemic injury). Patients with SDH and tSAH showed an age-dependent distribution, with higher prevalence in older age groups. A high proportion of young patients suffered an EDH.
portion of patients with a low GCS score (3–8) compared with groups with isolated tSAH and IPH (isolated SDH vs isolated tSAH, p = 0.0011; isolated SDH vs isolated IPH, p = 0.0015; isolated SDH vs isolated EDH was not significant, p = 0.278).

Table 2 depicts the mechanisms of injury among all TBI- patients. Among isolated subtypes of TBI, SDH was the most common subtype across nearly all mechanisms (excluding “other”).

**Short-Term Outcomes**

Table 3 shows that patients with isolated SDH were more likely to have a poor outcome: the isolated SDH subtype had a lower proportion of patients discharged to home (53.3%) compared with all other isolated TBI subtypes (p = 0.0001 for all 3 comparisons: isolated SDH vs isolated tSAH, isolated SDH vs isolated IPH, and isolated SDH vs isolated EDH) and a higher proportion of patients who died or were discharged to hospice (13.7%) compared with isolated tSAH and IPH, respectively; isolated SDH vs isolated tSAH, p = 0.012; isolated SDH vs isolated IPH, p = 0.0001; isolated SDH vs isolated EDH, p = 0.002), and a higher proportion of patients who died or were discharged to hospice compared with isolated tSAH and isolated IPH (6.0%, 1.4%, and 0% for isolated SDH, tSAH, and IPH, respectively; isolated SDH vs isolated tSAH, p = 0.009; isolated SDH vs isolated IPH, p < 0.0001; isolated SDH vs isolated EDH, p = 0.002), and a higher proportion of patients who died or were discharged to hospice compared with isolated tSAH and isolated IPH (6.0%, 1.4%, and 0% for isolated SDH, tSAH, and IPH, respectively; isolated SDH vs isolated tSAH, p = 0.012; isolated SDH vs isolated IPH, p = 0.0001; isolated SDH vs isolated EDH did not reach significance, p = 0.053).

Age and Short-Term Outcome

Figure 2 depicts posthospital disposition among all TBI- patients (n = 1716) solely according to age. Of all patients ≥ 60 years old, 14.0% (153/1093) were discharged to hospice or died, compared with 2.7% (17/623) of those < 60 years old (% who were discharged to hospice or died, ≥ 60 years old vs < 60 years old, p < 0.0001). Conversely, of all patients who were discharged to hospice or died, 90.0% (153/170) were ≥ 60 years old, compared with 46.5% (483/1038) of those discharged home (% ≥ 60 years old, patients who were discharged to hospice or died vs patients discharged to home, p < 0.0001).

Because increasing age is associated with worse outcomes, and also knowing that patients with SDH tended to be older (Fig. 1), we wondered whether the association between SDH and poor outcomes was primarily a function of age. When we restricted our analysis to posthospital disposition among patients < 60 years old, we found that the isolated SDH group had a lower proportion of patients who were discharged to home compared with all other isolated TBI subtypes (81.9%, 91.0%, 96.0%, and 100% for isolated SDH, tSAH, IPH, and EDH, respectively; isolated SDH vs isolated tSAH, p = 0.009; isolated SDH vs isolated IPH, p < 0.0001; isolated SDH vs isolated EDH, p = 0.002), and a higher proportion of patients who died or were discharged to hospice compared with isolated tSAH and isolated IPH (6.0%, 1.4%, and 0% for isolated SDH, tSAH, and IPH, respectively; isolated SDH vs isolated tSAH, p = 0.012; isolated SDH vs isolated IPH, p = 0.0001; isolated SDH vs isolated EDH did not reach significance, p = 0.052). When we analyzed patients ≥ 60 years old, we found that fewer patients with isolated SDH were discharged to home compared with those with isolated tSAH (42.2% and 53.7% for isolated SDH and tSAH, respectively; isolated SDH vs isolated tSAH, p = 0.0013; isolated SDH vs isolated IPH, p = 0.0566; and isolated SDH vs isolated EDH, p = 0.423—see Discussion), and relatively more patients with isolated SDH died or were discharged to hospice compared with isolated tSAH and isolated IPH (16.6%, 6.2%, and 2.1% for isolated SDH, tSAH, and IPH, respectively; isolated

### Table 2. Mechanism of injury among 1716 patients with TBI—

<table>
<thead>
<tr>
<th>Mechanism of Injury</th>
<th>MVA</th>
<th>Bicycle Accident</th>
<th>Pedestrian</th>
<th>Fall</th>
<th>Violence</th>
<th>Struck</th>
<th>Other</th>
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<tbody>
<tr>
<td>Isolated SDH</td>
<td>775</td>
<td>31.0 (53)</td>
<td>35.7 (10)</td>
<td>35.7 (10)</td>
<td>48.6 (637)</td>
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<tr>
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<td>404</td>
<td>26.3 (45)</td>
<td>28.6 (8)</td>
<td>14.3 (4)</td>
<td>22.9 (301)</td>
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<td>Isolated EDH</td>
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<td>7.1 (2)</td>
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<td>1.8 (24)</td>
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<td>1.8 (23)</td>
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<td>1.8 (23)</td>
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<td>0.6 (1)</td>
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**Discussion**

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**Figure 2** depicts posthospital disposition among all TBI- patients (n = 1716) solely according to age. Of all patients ≥ 60 years old, 14.0% (153/1093) were discharged to hospice or died, compared with 2.7% (17/623) of those < 60 years old (% who were discharged to hospice or died, ≥ 60 years old vs < 60 years old, p < 0.0001). Conversely, of all patients who were discharged to hospice or died, 90.0% (153/170) were ≥ 60 years old, compared with 46.5% (483/1038) of those discharged home (% ≥ 60 years old, patients who were discharged to hospice or died vs patients discharged to home, p < 0.0001).

Because increasing age is associated with worse outcomes, and also knowing that patients with SDH tended to be older (Fig. 1), we wondered whether the association between SDH and poor outcomes was primarily a function of age. When we restricted our analysis to posthospital disposition among patients < 60 years old, we found that the isolated SDH group had a lower proportion of patients who were discharged to home compared with all other isolated TBI subtypes (81.9%, 91.0%, 96.0%, and 100% for isolated SDH, tSAH, IPH, and EDH, respectively; isolated SDH vs isolated tSAH, p = 0.009; isolated SDH vs isolated IPH, p < 0.0001; isolated SDH vs isolated EDH, p = 0.002), and a higher proportion of patients who died or were discharged to hospice compared with isolated tSAH and isolated IPH (6.0%, 1.4%, and 0% for isolated SDH, tSAH, and IPH, respectively; isolated SDH vs isolated tSAH, p = 0.012; isolated SDH vs isolated IPH, p = 0.0001; isolated SDH vs isolated EDH did not reach significance, p = 0.052). When we analyzed patients ≥ 60 years old, we found that fewer patients with isolated SDH were discharged to home compared with those with isolated tSAH (42.2% and 53.7% for isolated SDH and tSAH, respectively; isolated SDH vs isolated tSAH, p = 0.0013; isolated SDH vs isolated IPH, p = 0.0566; and isolated SDH vs isolated EDH, p = 0.423—see Discussion), and relatively more patients with isolated SDH died or were discharged to hospice compared with isolated tSAH and isolated IPH (16.6%, 6.2%, and 2.1% for isolated SDH, tSAH, and IPH, respectively; isolated...
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SDH vs isolated tSAH, p < 0.0001; isolated SDH vs isolated IPH, p = 0.0009; isolated SDH vs isolated EDH was not significant, p = 0.425—see Discussion.

Admission GCS Score and Short-Term Outcome

Figure 3 shows posthospital disposition among all TBI− patients (n = 1716) solely according to admission GCS score. Of all patients with a GCS score of 3−8, 50.0% (78/156) died or were discharged to hospice, compared with 16.0% (12/75) of those with GCS 9−12, and 5.4% (80/1485) of those with GCS 13−15 (% who died or were discharged to hospice in the GCS 3−8 vs GCS 9−12 group, p < 0.0001; and in the GCS 3−8 vs GCS 13−15 group, p < 0.0001). Conversely, of all patients who were discharged to

![FIG. 2. Graph showing that increasing age is associated with worse short-term outcomes. Each point represents a 5-year age range.](image-url)
hospice or died, 45.9% (78/170) had a GCS score of 3–8, compared with 3.4% (35/1038) of those discharged to home (% GCS 3–8, patients who were discharged to hospice or died vs patients discharged to home, p < 0.0001). In general, lower GCS scores were associated with worse short-term outcomes, and higher GCS scores were associated with better ones, which is consistent with prior work. 28,30

Similar to our analysis with age, we wondered whether the association between SDH and poor outcomes was captured by the admission GCS score. Of those with a GCS score of 3–8, patients with isolated SDH had a lower proportion of discharge to home compared with patients in the isolated tSAH and EDH groups (11.5%, 35.0%, and 66.7% for isolated SDH, tSAH, and EDH, respectively; isolated SDH in patients with GCS 3–8 vs isolated tSAH in patients with GCS 3–8, p = 0.0127; isolated SDH in patients with GCS 3–8 vs isolated EDH in patients with GCS 3–8, p = 0.0175 [Fig. 4C]; isolated SDH vs isolated IPH did not reach significance, p = 0.0982), and a higher proportion of patients who were discharged to hospice or who died compared with isolated tSAH and isolated IPH (61.5%, 30.0%, and 4.35% for isolated SDH, tSAH, and IPH respectively; isolated SDH in patients with GCS 3–8 vs isolated tSAH in patients with GCS 3–8, p = 0.0043; isolated SDH vs isolated IPH, p = 0.0157 [Fig. 4A]; isolated SDH vs isolated EDH did not reach significance, p = 0.168).

When we analyzed isolated TBI subtypes in patients with a GCS score of 13–15, the isolated SDH group had a lower proportion of patients discharged to home compared with all other isolated subtypes (7.4%, 2.9%, 0%, and 2.8% for isolated SDH, tSAH, IPH, and EDH respectively—isolated SDH in patients with GCS 13–15 vs isolated tSAH in patients with GCS 13–15, p = 0.0016; isolated SDH in patients with GCS 13–15 vs isolated IPH in patients with GCS 13–15, p < 0.0001; isolated SDH in patients with GCS 13–15 vs isolated EDH in patients with GCS 13–15, p = 0.0007; Fig. 4A). Due to the relatively small number of patients with GCS scores of 9–12, we did not analyze the effect of TBI subtypes on posthospital disposition for these patients (see Discussion).

We arrived at comparable results when we analyzed all-inclusive subtype populations; patients in the all-inclusive SDH group with a GCS score of 3–8 had a lower proportion of discharge to home compared with all-inclusive IPH and all-inclusive EDH groups (18.2%, 34.8%, and 54.6% for all-inclusive SDH, IPH, and EDH, respectively—all-inclusive SDH in patients with GCS 3–8 vs all-inclusive IPH in patients with GCS 3–8, p = 0.0464; all-inclusive SDH in patients with GCS 3–8 vs all-inclusive EDH in patients with GCS 3–8, p = 0.005 [Fig. 4D]; all-inclusive SDH in patients with GCS 3–8 vs all-inclusive tSAH in patients with GCS 3–8 did not reach significance [p = 0.089]), and a higher proportion of patients who were discharged to hospice or who died compared with all-inclusive tSAH and all-inclusive IPH (57.0%, 44.1%, and 21.7% for all-inclusive SDH, tSAH, and IPH, respectively— all-inclusive SDH in patients with GCS 3–8 vs all-inclusive tSAH in patients with GCS 3–8, p = 0.0499; all-inclusive SDH in patients with GCS 3–8 vs all-inclusive IPH in patients with GCS 3–8, p = 0.0008 [Fig. 4B]; all-inclusive SDH in patients with GCS 3–8 vs all-inclusive EDH in patients with GCS 3–8 did not reach significance [p = 0.0928]).

When we analyzed all-inclusive subtypes with a GCS score of 13–15, the all-inclusive SDH group had a lower proportion of patients discharged to home compared with
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all other all-inclusive subtypes (59.0%, 63.7%, 77.4%, and 82.4% for all-inclusive SDH, tSAH, IPH, and EDH, respectively; all-inclusive SDH in patients with GCS 13–15 vs all-inclusive tSAH in patients with GCS 13–15, p = 0.0387; all-inclusive SDH in patients with GCS 13–15 vs all-inclusive IPH in patients with GCS 13–15, p = 0.0001; all-inclusive SDH in patients with GCS 13–15 vs all-inclusive EDH in patients with GCS 13–15, p = 0.0002; all-inclusive SDH in patients with GCS 13–15 vs all-inclusive tSAH in patients with GCS 13–15, p < 0.0082; all-inclusive SDH in patients with GCS 13–15 vs all-inclusive IPH in patients with GCS 13–15, p = 0.0003 [Fig. 4B]; all-inclusive SDH in patients with GCS 13–15 vs all-inclusive EDH in patients with GCS 13–15 was not significant, p = 0.352).

Sensitivity for Short-Term Outcome

We defined sensitivity for poor outcome as the relative proportion of patients who died or were discharged to hospice and who possessed the characteristic of interest (e.g., presence of SDH). We defined specificity for poor outcome as the relative proportion of patients who were discharged home, to SNF, or to rehabilitation (i.e., patients who did not die) and who possessed the characteristic of interest.

The presence of SDH was a more sensitive indicator for poor outcome than the presence of all other TBI subtypes (Fig. 5). Of all patients who died or were discharged to hospice, 86.5% (147/170) had SDH (Fig. 5A); in contrast, only 32.4% (55/170) had tSAH, 5.9% (10/170) had IPH, and 4.1% (7/170) had EDH (p < 0.0001 for all 3 comparisons: % with SDH vs % with tSAH; % with SDH vs % with IPH; and % with SDH vs % with EDH [Fig. 5C, E, and G, respectively]). The presence of SDH was a more sensitive, although less specific, indicator of poor outcome than was a GCS score of 3–8 (Fig. 5). Of all patients who died or were discharged to hospice, a smaller proportion of them were found to have a GCS score of 3–8 (45.9%, 78/170; Fig. 5I) than were found to have SDH (% with SDH vs % with GCS 3–8, p < 0.0001). Of patients discharged to home, to SNF, or to rehabilitation (Fig. 5B and J), 58.7% (907/1546) had SDH (41.3% had no SDH), and 5.0% had a GCS score of 3–8 (95.0% had a GCS > 8; % with SDH vs % with GCS 3–8, p < 0.0001).

Increasing Age, GCS Score, and SDH

Because older age, a low GCS score (3–8), and the presence of SDH were individually associated with poor short-term outcome, we investigated the population of patients who possessed all 3 of these factors. We found that the likelihood of having both a GCS score of 3–8 and SDH increased with increasing age (Fig. 6 upper), and there was
a nearly linear relationship between increasing age and mortality in patients with both SDH and a GCS score of 3–8 (Fig. 6 lower).

**Odds Ratio Analysis: Association Between Mortality and TBI Subtype**

Figures 7 and 8 show the odds ratios for mortality (in our study this included patients who died or were discharged to hospice) associated with specific TBI subtypes. In these analyses, patients with a designated TBI subtype (e.g., SDH) included patients with either the isolated form (no other TBI subtypes) or the all-inclusive form (with other co-occurring TBI subtypes) of the injury; patients without the designated TBI subtype (e.g., no SDH) included patients with at least 1 other TBI subtype other than the subtype of interest. To control for the relatively older ages of the patients in the SDH population, we performed separate analyses on patients < 60 and ≥ 60 years old (Figs. 7 and 8, respectively). After separating patients into the 2 age groups, we analyzed differences in 2 populations: the total TBI population (n = 1716) and in a subset of patients from this TBI population with a GCS score of only 3–8 (n = 156). Among patients < 60 years old and with a low GCS score (3–8), no single subtype was significantly associated with
mortality, confirming a low GCS score’s predictive ability in younger patients. Analyses for EDH were not performed in either population, given that no EDH patients < 60 years old died.

Among patients ≥ 60 years old and across all GCS scores (TBI–population), SDH showed the greatest association with mortality rate (OR 3.34, 95% CI 2.07–5.39; Fig. 8). In this age group, EDH also had a significant association with mortality rate (OR 2.46, 95% CI 1.01–5.98). Comparing all patients with tSAH (isolated or with co-occurring subtypes) versus all patients without tSAH (i.e., ≥ 1 TBI subtype other than tSAH) who were ≥ 60 years old in the TBI–population, those without tSAH were more likely to die than patients with tSAH (OR 0.68, 95% CI 0.48–0.98).

Whereas SDH (or any other TBI subtype) was not significantly associated with mortality in patients < 60 years old in the GCS 3–8 population, it was the only TBI subtype to have a significant association with mortality among patients ≥ 60 years old in the GCS 3–8 population (OR 3.93, 95% CI 1.32–11.72). In addition, the absence of IPH (i.e., ≥ 1 TBI subtype other than IPH) was more closely associated with mortality than the presence of IPH among patients ≥ 60 years old in the GCS 3–8 population (OR 0.19, 95% CI 0.05–0.69).

**Discussion**

The rapid evaluation of TBI severity is of paramount importance not only for the clinicians who must make prompt medical and surgical decisions but also for the families and caregivers who may require counseling or may be forced to determine the fates of their loved ones. Previously, researchers and clinicians have attempted to incorporate radiographic findings into classification schemes, such as the Marshall and Rotterdam CT scores, that aim to measure TBI severity and predict outcome. The CT characteristics assessed in these scoring systems were not derived from a consideration of radiographic findings in isolation (no other intracranial abnormalities), and were developed from patients with potentially complicating major extracranial injuries. Furthermore, those studies were limited to patients with relatively narrower GCS scores and age ranges.

We present a retrospective study analyzing a large population of patients with traumatic head injury without major extracranial injuries and across all GCS scores and ages that compares the outcomes of patients with various radiographic findings. We categorized these radiographic features into subtypes of TBI (SDH, tSAH, IPH [which included IVH], and EDH). A substantial part of our analyses...
investigated the effects of these TBI subtypes in isolation; studying isolated injuries is an effective model for analyzing the impact of particular forms of brain injury individually.6,10,18,33,34,40,41

Our methods of excluding patients with major extracranial injuries and studying injuries in isolation are important elements of our study that distinguish it from previous work. The aim of our study was not only to provide evi-

FIG. 7. Forest plot analyzing mortality associated with specific TBI subtypes in patients < 60 years old. The presence of SDH was significantly associated with mortality in the TBI– population, but not in the GCS 3–8 population. The *s denote statistical significance.

FIG. 8. Forest plot analyzing mortality associated with specific TBI subtypes in patients ≥ 60 years old. Even among patients with similar (i.e., older) ages, the presence of SDH was the only TBI subtype significantly associated with mortality in both the TBI– and GCS 3–8 populations. The *s denote statistical significance.
dence that early radiographic findings may contribute to assessing injury severity and predicting TBI outcomes but also to determine the most important radiographic findings associated with poor outcome. Our study provides evidence that SDH (isolated or with co-occurring injuries) is the most important TBI subtype in relation to poor short-term outcome.

We emphasize that the purpose of this study is not to argue that the evaluation of acute SDH should replace any current factors that measure TBI severity or prognosis. Rather, we show that noting the presence of SDH may provide a more informative assessment of injury severity and prognosis when used in conjunction with established predictors, specifically older age and low GCS score (3–8).

The SDH Evaluation Augments Age Assessment

Of all factors that influence outcome after TBI, age has been shown to be one of the most important. Hukkelhoven et al.13 found that increasing age is consistently associated with worse outcome after TBI. In that study analyzing more than 5600 patients, Hukkelhoven et al. reported that the odds of poor outcome increased by 40%–50% per 10 years of age. Mosenthal et al.27 studied isolated subtypes of TBI and found that the mortality rate of patients ≥65 years old was twice that of younger patients, even for those with mild to moderate injury according to GCS scores (9–15).

Our results similarly show that increasing age was associated with worse outcome in all TBI patients; however, we also demonstrate that isolated SDH was most closely associated with worse short-term outcomes compared with other TBI subtypes, even among patients with similar (i.e., older) ages. Although patients with isolated SDH in our population had the highest mean age (67.6 years) of all isolated TBI subtypes, when we analyzed only patients ≥60 years old, the isolated SDH group still had a significantly higher proportion of patients who died (16.6%) compared with isolated tSAH (6.2%) and isolated IPH (2.1%), and a significantly lower proportion of patients who were discharged to home (42.4%) compared with isolated tSAH (53.7%). These results suggest that the higher rates of mortality seen in isolated SDH versus in other isolated subtypes were not fully due to older age. Although our statistical analyses for isolated EDH did not reach significance, we note there were only 31 patients ≥60 years old with isolated EDH, and all 31 of these patients were discharged home; thus our statistical analyses were limited by the small number of patients.

The SDH Evaluation Augments GCS Score Assessment

The GCS score has been shown to be a strong predictor of outcome after TBI.16,23 King et al.16 reported a strong correlation between admission GCS score and 3-month Glasgow Outcome Scale score, which they found to be a powerful predictor of long-term outcome (12 months) for patients with severe TBI. Likewise, Marmarou et al.23 found a strong association between GCS score and 6-month Glasgow Outcome Scale score. Recent studies, however, have argued that the GCS score by itself is inadequate to classify the severity of TBI17,23 or to predict functionality at discharge after TBI.23 Salottolo et al.27 reported that elderly patients have higher GCS scores than younger patients with similar TBI severity, and Chieregato et al.26 argued that CT findings should be incorporated into TBI severity definitions. Saatman et al.36 point out that the GCS score does not provide specific information about the pathophysiological mechanisms responsible for neurological deficits.

In the present study, we confirm that a lower GCS score is associated with worse short-term outcomes in patients with TBI; however, we also argue that the presence of SDH augments the ability of the GCS score to predict short-term outcome, much more so than the presence of the other simple radiographic findings we studied. First, we showed that isolated SDH was most closely associated with worse short-term outcomes compared with other isolated TBI subtypes, even among all patients with low GCS scores (3–8); the isolated SDH group had a significantly lower proportion of patients discharged to home compared with the isolated tSAH and isolated EDH groups, and a significantly higher proportion of patients who died, compared with those with isolated tSAH and isolated IPH. Although SDH had the highest proportion of patients with low GCS scores of any TBI subtype, the demonstration that patients with SDH still do worse, even among those with low GCS scores, indicates that the worse outcomes seen with SDH are not fully captured by the GCS score alone.

Second, we found that the presence of SDH is a more sensitive (86.5%), albeit less specific, indicator of poor short-term outcome than the presence of a low GCS score (3–8) (45.9%), especially for older patients. We found that the presence of other traumatic hemorrhage subtypes had much lower sensitivity for poor outcome compared with the presence of SDH.

Last, we found that, even in the smaller patient population who had a GCS score of 3–8 and who were ≥60 years of age, the presence of SDH was still significantly associated with mortality (OR 3.93); the presence of other TBI subtypes either had a negative or insignificant association with mortality. Importantly, this finding may discount the argument that the association of SDH with mortality seen across all ages (in the GCS 3–8 population) was due simply to the relatively older ages of patients with SDH. We found that those with a GCS score of 3–8 had a mortality OR of 15.96 (95% CI 10.93–23.29), confirming the value of GCS score assessment in predicting short-term outcome.

Limitations of Current CT Classification Systems

Refining the methodology by which radiographic findings are incorporated into the assessment of TBI severity and prognosis, as was done here and elsewhere,30 is important to better understand the specific influence of particular forms of TBI and to improve upon prognostic models.

Although the Marshall score (first introduced in 1991) has been influential in past years, Maas et al.32 argued that it is limited by its inability to distinguish different types of intracranial lesions and its use of “evacuated” and “non-evacuated” mass lesions. Maas and colleagues proposed a new classification scheme in 2005, the Rotterdam score. However, the predictive models used by Maas et al. were derived from a selected patient population that was not
optimal for the comprehensive study of TBI outcomes alone. Among many other concerns, the population included patients who often sustained more than one intracranial lesion (i.e., nonisolated injuries), and who may have had major extracranial injuries. We argue that the goal of incorporating specific CT features into classification scores to improve prognosis may benefit from an analysis of TBI patients without these extracranial injuries. Moreover, the studies that Maas et al. referenced to justify the Rotterdam score’s inclusion of specific CT features are not derived from patients with isolated head injuries.

Surprisingly, the Rotterdam score does not include SDH as a separate CT feature; only the differentiation between epidural and intradural lesions was highly relevant after multivariable analysis, and this led to the decision to evaluate only for the presence or absence of an epidural mass lesion. The decision to not incorporate SDH in the Rotterdam score was in large part due to 2 reasons: first, the difference in mortality between patients with and without SDH was not found to be significant; and second, the similar mortality rates seen in patients with SDH and intracerebral lesions resulted in only a minor improvement in discriminative ability in logistic regression analysis.

However, after comparing TBI subtypes in our more controlled patient population, we found that the presence of SDH was significantly associated with mortality in the TBI population in patients both < 60 and ≥ 60 years old (OR 8.01 and 3.34, respectively). Given the rarity of mortality in patients with and without SDH in the TBI population (< 60 years old: 4.9% and 0.63%, respectively; ≥ 60 years old: 17.7% and 6.1%, respectively) relative to other major systemic diseases referenced in epidemiology research, it is not unreasonable to interpret the odds ratios as approximate relative risks. Furthermore, the difference in the mortality rate between isolated SDH (13.7%) and isolated IPH (including IVH) (0.6%) was also significant in our study. In contrast to the findings of the Rotterdam study, our study, which analyzed the effect of isolated and all-inclusive SDH in a more optimal patient population, suggests that SDH assessment should be included in future classification models.

Limitations of the Study

Our study uses data from a single center; thus there is a need for our results to be validated across other institutions. Furthermore, some of our statistical analyses were limited by small numbers of patients in certain subgroups (e.g., isolated EDH patients). Due to our conservative inclusion and exclusion criteria (e.g., agreement of both ICD-9 and AIS codes, no extracranial injuries, and so on), many patients were excluded from our study; future research looking into national TBI databases may be more revealing. Although we were conservative in the inclusion criteria for each TBI subtype by use of both ICD-9 and AIS codes, we did not directly review CT data to confirm the presence or absence of such lesions for all of our patients. In addition, we did not use CT data to further characterize TBI subtypes, such as size and location of SDHs. It is likely that short-term outcome was influenced also by particular radiographic features not captured by AIS and ICD-9 classification, such as the presence of midline shift or certain locations of the injuries, in addition to the category of the TBI subtype itself. Despite these limitations, we found consistent, significant associations of short-term outcomes with the presence of SDH.

Conclusions

We conclude that SDH is the most important TBI subtype associated with poor outcome in patients with TBI. Patients with isolated SDH generally had worse outcomes compared with those who had other intracranial hemorrhage subtypes. Most of these findings persisted when we restricted the analyses to certain age groups or GCS ranges. The evaluation of SDH, more so than any other radiographic finding in our study, augments the assessment of TBI severity and prognosis beyond what can be found through assessment of GCS score and age, and could improve the predictive ability of future CT-based prognostic models.

Acknowledgments

We thank the Department of Neurosurgery, the Alpert Medical School of Brown University, and Rhode Island Hospital for their support.

References


Disclosures
The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

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Conception and design: Asaad, J Lee, Segar, Morrison, Mangham. Acquisition of data: Asaad, J Lee, Segar, Morrison, Mangham. Analysis and interpretation of data: Asaad, J Lee, Segar, Morrison. Drafting the article: Asaad, J Lee, Morrison. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Asaad. Statistical analysis: Asaad, J Lee, Segar, Morrison, S Lee. Administrative/technical/material support: Asaad. Study supervision: Asaad, Morrison, S Lee.

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