Acute Subdural Hematoma
—Prediction of Outcome with a Linear Discriminant Function—

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Abstract

We devised a linear discriminant function to predict the outcome for patients with acute subdural hematoma (ASDH) based on a consecutive series of 170 ASDH cases with mild to severe head injury [Glasgow Coma Scale (GCS) 3-15]. Functional recovery was achieved in 50.0% of patients and the mortality was 36.5%. The relationship between initial clinical and radiological signs and the outcome 3 months after admission was studied retrospectively by Mann-Whitney’s U-test and Pearson’s chi-squared test. Fourteen factors (GCS, pupillary response, motor paresis, age, hematoma volume and thickness, midline shift, association with cerebral contusion and subarachnoid hemorrhage, obliteration of the basal, ambient, or quadrigeminal cistern on computed tomography, fibrin-fibrinogen degradation product level, and intracranial pressure) were found to correlate significantly (p < 0.01) with outcome. Linear discriminant functions were formulated by multivariate analysis to investigate the relationship between these factors and recovery or poor prognosis. The following formula was obtained:

\[ Z = -0.110 + 0.013 \text{(Age)} - 0.108 \text{(GCS)} + 0.397 \text{(Eye)} + 0.003 \text{(Shift)} + 0.268 \text{(Ambient)}. \]

Functional recovery could be predicted by a negative Z value, with an accuracy of 90.59%. This simple discriminant function is useful for predicting the outcome of ASDH.

Key words: acute subdural hematoma, discriminant analysis, prognosis, outcome

Introduction

Traumatic acute subdural hematoma (ASDH) remains one of the most lethal of all head injuries, causing a higher mortality than any other traumatic intracranial lesion, ranging from 40 to 90% in most large series.6,10,19,21,22,24,27-29) The quality of life for ASDH patients also concerns neurosurgeons as modern management increases the survival rate. Extensive prognostic analyses on head injuries in many centers have provided treatment and prognostic advice on the basis of previous clinical experience. However, although death or survival can be predicted with a more than 0.97 probability at day 3 after injury, early prediction of outcome is necessary to select the optimum management method.14)

Several prognostic factors, such as age and the level of consciousness,5,11,12,18,22,30,32,35,36) have been identified, but their comparative value in predicting the clinical outcome has not been evaluated. These factors must necessarily interact with each other. Here, we report prognostic discriminant functions based on multivariate analysis37) to determine the comparative predictive value of various factors, and a formula to predict the outcome for ASDH pa-
Clinical Materials and Methods

I. Criteria for patient selection

5562 patients with mild to severe head injuries [Glasgow Coma Scale (GCS) scores 3–15] were admitted to the University of Tsukuba Hospital and four local emergency hospitals between 1985 and 1992. In 224 cases, the predominant intracranial pathology was traumatic ASDH. Any patient satisfying the criteria for brain death on admission or died from causes other than ASDH was excluded from study. Patients with ASDH of the posterior fossa, interhemispheric fissure, or bilateral supratentorial were also excluded. Any patient whose initial management strategy was changed more than 4 hours after injury was also excluded. For example, a patient undergoing surgery because of deteriorating consciousness or marked enlargement of hematoma after initial conservative management was excluded. 170 patients satisfied the criteria for this study.

II. Patient management

Preadmission management included manual ventilation with a face mask. After initial emergency-room resuscitation, all patients underwent a standardized treatment protocol including intubation with assisted ventilation and administration of mannitol or glycerol. The diagnosis was based on computed tomography (CT). Patients with ASDH causing more than 5 mm of midline shift on CT scans were transferred directly from the CT scanning room to the operating room. No steroids were given to any patient.

Once surgical management was selected, rapid craniotomy and/or decompressive craniectomy with complete clot evacuation and resection of necrotic brain parenchyma, or hematoma irrigation with trephination therapy2 were performed. Decompressive hemicraniectomy with duroplasty was used for patients showing acute intraoperative brain swelling. Patients showing associated massive cerebral contusion also received decompressive hemicraniectomy. Postoperatively, they received prophylactic antibiotics such as piperacillin or cefazolin.

Conservative management was used initially if the midline shift was less than 5 mm on CT scans. Osmotherapy using mannitol or glycerol was carried out. Barbiturate coma therapy was given to 35 patients. Follow-up CT was carried out routinely at 24 and 76 hours.

All conservatively and surgically treated patients received loading doses of anticonvulsants such as phenytoin or phenobarbital. Nutrition was started early, with most severely head-injured patients receiving intravenous hyperalimentation by 3–4 days after injury.

All 108 surviving patients were followed for at least 3 months with serial CT scans and neurological examinations. Evaluation of the neurological outcome was standardized using the Glasgow Outcome Scale,31 and the outcome was recorded at death or 3 months after admission.

III. Statistical analysis

Each conservatively and surgically treated patient was evaluated retrospectively to provide data for a statistical analysis of prognostic factors. Items recorded included 1) patient profiles: age, sex, mechanism of injury, associated injuries of other organs, and level of fibrin-fibrinogen degradation products (FDP) and intracranial pressure (ICP); 2) neurological findings on admission: GCS, pupillary responses, and motor responses; and 3) radiological findings: hematoma volume measured by Sacks’ method,25 the greatest hematoma thickness on CT scans, associated intracranial lesions such as cerebral contusion, epidural hematoma, subarachnoid hemorrhage, skull fracture, and intracerebral hematoma, midline shift at the level of the caudate nucleus on CT scans, and obliteration of the basal, ambient, or quadrigeminal cistern. Management procedures were classified as 1) conservative management, 2) craniotomy, 3) decompressive hemicraniectomy, and 4) hematoma irrigation through trephination.

Mann-Whitney’s U-test was used for univariate analysis of continuous variables such as age, GCS, hematoma volume and thickness, midline shift, ICP, and FDP. Pearson’s chi-squared test was used for analysis of discrete variables such as sex, pupillary responses, and motor responses. A statistically significant difference was defined as a p-value of less than 0.01.

After identification of factors affecting the outcome, linear discriminant functions were formulated by multivariate analysis using the same prognostic factors. Other prognostic discriminant functions were also formulated based on the GCS score. Five factors that were simple to assess were selected from the significant factors.

Results

Eighty-five patients (50.0%) showed functional recovery, including 67 (39.4%) with a good recovery
and 18 (10.6%) with a moderate disability. The other 85 patients (50.0%) had a poor outcome, including 13 (7.6%) with severe disability, 10 (5.9%) in a persistent vegetative state, and 62 (36.5%) who died. The overall mortality was 36.5% with a 50.0% functional recovery rate.

I. Patient profile
The most common cause of injury was traffic accident (109 patients, 64.1%), with fall and assault in 34 (20.0%) and 19 patients (11.2%), respectively. The mean age was 48.1 years for all patients, and there were three times as many male as female patients (M:F = 130:40). Combined injury of other organs was found in 45 patients (26.5%). The mean FDP level was 26.0 µg/ml for all patients. The mean age and mean FDP level showed a significant difference in outcome, and combined injury of other organs tended to be correlated with outcome (Table 1).

II. Neurological presentation
The mean GCS score for all patients on admission was 9.3. Figure 1 shows the GCS distribution. Seventy of 85 patients with a high GCS score (9-15) and 15 of 85 patients showing a low GCS score (3-8) achieved functional recovery. There was a significant relationship between mean GCS score and outcome (Table 2).

Pupillary abnormalities occurred in 88 patients (51.8%): 60 anisocoria and 28 bilateral fully dilated pupils. Ninety-one patients (53.5%) showed abnormal motor responses such as flaccid paralysis or decerebrate posture on admission. These two factors were both significantly related to outcome (Table 2).

III. Radiological presentation
The mean ASDH volume was 67.7 cm³, mean ASDH thickness 11.0 mm, and mean midline shift 7.8 mm. These values were all significantly related to outcome (Table 3).

CT showed that 95 patients (55.9%) had obliterated basal cistern, 88 (51.8%) obliterated ambient cistern, and 73 (42.9%) obliterated quadrigeminal cistern. Bilateral obliteration occurred of the basal cistern in 67 patients (39.4%), the ambient cistern in 54 (31.8%), and the quadrigeminal cistern in 46 (27.1%). Obliteration of any cistern was statistically correlated with the outcome (Table 3).

The most common associated intracranial pathology was cerebral contusion (118 patients, 69.4%). Epidural hematoma, intracerebral hematoma, subarachnoid hemorrhage, and skull fracture occurred in 20, 34, 86, and 70 patients, respectively. Associated cerebral contusion and subarachnoid hemorrhage were significantly related to outcome, but others were not (Table 3).

IV. ICP
Intraventricular ICP was monitored in 23 patients. The mean ICP was 31.74 mmHg, and showed a significant difference in outcome (Table 1).
Table 3 Summary of radiological presentation

<table>
<thead>
<tr>
<th>Factor</th>
<th>Functional recovery</th>
<th>Poor outcome</th>
<th>Statistical significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean hematoma volume (ml)</td>
<td>31.0</td>
<td>104.4</td>
<td>p&lt;0.01</td>
</tr>
<tr>
<td>Mean hematoma thickness (mm)</td>
<td>7.8</td>
<td>14.1</td>
<td>p&lt;0.01</td>
</tr>
<tr>
<td>Mean midline shift (mm)</td>
<td>2.9</td>
<td>12.8</td>
<td>p&lt;0.01</td>
</tr>
<tr>
<td>Associated lesions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cerebral contusion</td>
<td>46</td>
<td>72</td>
<td>p&lt;0.01</td>
</tr>
<tr>
<td>intracerebral hematoma</td>
<td>15</td>
<td>19</td>
<td>NS</td>
</tr>
<tr>
<td>skull fracture</td>
<td>30</td>
<td>40</td>
<td>NS</td>
</tr>
<tr>
<td>subarachnoid hemorrhage</td>
<td>30</td>
<td>56</td>
<td>p&lt;0.01</td>
</tr>
<tr>
<td>epidural hematoma</td>
<td>11</td>
<td>9</td>
<td>NS</td>
</tr>
</tbody>
</table>

Table 4 Summary of management procedure

<table>
<thead>
<tr>
<th>Factor</th>
<th>Functional recovery</th>
<th>Poor outcome</th>
<th>Statistical significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conservative</td>
<td>48</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>Surgical</td>
<td>37</td>
<td>40</td>
<td>NS</td>
</tr>
<tr>
<td>craniotomy</td>
<td>20</td>
<td>6</td>
<td>NS</td>
</tr>
<tr>
<td>decompression</td>
<td>15</td>
<td>31</td>
<td>NS</td>
</tr>
<tr>
<td>HIT</td>
<td>2</td>
<td>3</td>
<td>NS</td>
</tr>
</tbody>
</table>

HIT: hematoma irrigation through trephination.

V. Management procedures

Conservative treatment was carried out in 93 patients (54.7%) and surgical treatment in 77 (45.3%). The management method was not changed during the entire course in any patient, and surgery was always carried out within 4 hours of injury. Craniotomy with hematoma removal was used in 26 patients, decompressive hemicraniectomy with duroplasty in 46, and hematoma irrigation with trephination therapy in five. Although there was no significant difference between management and outcome, this may have been affected by differences in the patient population (Table 4).

VI. Discriminant analysis

Fourteen initial features (GCS, pupillary response, motor paresis, age, hematoma volume and thickness, midline shift, associated cerebral contusion and subarachnoid hemorrhage, obliteration of the basal, ambient, or quadrigeminal cistern on CT scans, FDP level, and ICP) were identified as significantly correlated with outcome. Five factors selected were: age selected as an important factor reflecting the general condition, the GCS and the pupillary responses as representing neurological status, and midline shift and obliteration of the ambient cistern on CT scans as showing the mass effect. More complex indicators of outcome such as ICP, evoked potential studies, and cerebral blood flow were omitted to make the function simpler and more universally applicable.

The following formula achieved with the highest discrimination ratio (90.59%):

\[ Z = -0.110 + 0.013 \times \text{(Age)} - 0.108 \times \text{(GCS)} + 0.397 \times \text{Eye} + 0.003 \times \text{Shift} + 0.268 \times \text{Ambient}. \]

Where “Eye” indicates pupillary abnormalities, “Shift” indicates midline shift, and “Ambient” indicates obliteration of the ambient cistern. Pupillary abnormalities were scored as: normal, 0; anisocoria, 1; and bilateral full dilation, 2. Obliteration of the ambient cistern was scored as: normal, 0; unilateral, 1; and bilateral, 2.

Functional recovery is predicted by a negative Z value. In our series, eight patients were indicated as false positive in the poor outcome group and eight false negative in the functional recovery group. The correct predictions by single factors were 62.94 (Age), 17.06 (GCS), 84.71 (Eye), 70.59 (Shift), and 80.00% (Ambient), respectively.

Other discriminant functions were also derived using the GCS score. The following formula predicted outcome in 85 patients showing high GCS score (9-15) with 68.24% accuracy:

\[ Z = 2.060 + 0.030 \times \text{(Age)} - 0.270 \times \text{(GCS)} - 0.158 \times \text{Eye} - 0.045 \times \text{Shift} + 0.302 \times \text{Ambient}. \]

A second discriminant function predicted outcome in 85 patients showing low GCS score (3-8) with 67.06% accuracy:

\[ Z = -1.273 + 0.013 \times \text{(Age)} - 0.184 \times \text{(GCS)} + 1.011 \times \text{Eye} + 0.012 \times \text{Shift} + 0.194 \times \text{Ambient}. \]

Other statistically significant prognostic factors were identified, but did not appreciably improve the accuracy of our discriminant function in predicting the outcome.

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Discussion

The most reliable early prognostic factors for ASDH are age, severity of injury, and timing of surgery.\(^4,11,22,28,30,31,33-36,38\) Although its value is limited, the GCS is accepted as a method of acute classification of the severity of injury, and is widely used for determining the likelihood of survival and disability following severe head injury (GCS 3–8). However, the outcome after minor to moderate head injuries (GCS 9–15), including patients with ASDH, is less clear.\(^1,16,26\)

Although ASDH is recognized as one of the severest head injuries, many ASDH patients demonstrate a high GCS score (>8). In Japan, a patient with a head injury is transferred directly to the nearest hospital providing a neurosurgical service. Since these are found everywhere, patients generally receive good neurosurgical treatment immediately regardless of level of consciousness, and delays associated with transfer are negligible. Therefore, in this study the timing of operation or delay associated with selection of management showed negligible variation. Furthermore, patients with minor to moderate head injuries were also included in this study to determine the prognosis for all ASDH patients.

Many factors significantly correlate either positively or negatively with outcome in patients with severe head injury.\(^15,17,20\) We identified 14 factors that were useful for predicting outcome in this study: GCS, pupillary response, motor paresis, age, hematoma volume and thickness, midline shift, associated cerebral contusion and subarachnoid hemorrhage, obliteration of the basal, ambient, or quadrigeminal cistern on CT scans, FDP level, and ICP. Previous studies have not used multivariate analysis to predict the outcome, so the comparative value of these factors has not been clarified.

Surgeons often attach a subjective weight to clinical measurements to reflect the relative importance to the diagnosis. The weighted sum of the clinical score then indicates the prognosis for the patient. Discriminant analysis is similar to this subjective weighted-score method. Surgeons learn from experience which factors are useful for predicting the outcome. Similarly, stepwise discriminant analysis statistically selects the factors that are most important for predicting the prognosis for an individual.

We employed five of the 14 prognostic factors identified to predict the outcome of ASDH. It is important to select factors that contribute separate effects without associated interactions. Analysis of the covariance of each factor showed that most factors had interactions. Therefore, the five factors selected for discriminant analysis were chosen for simplicity and accuracy of data acquisition.

The discriminant ratios for each factor indicate comparative prognostic effectiveness when used alone. These five factors arranged in order of discriminant ratios are as follows: pupillary responses, obliteration of the ambient cistern, midline shift, age, and GCS. Pupillary response was the most important factor affecting outcome in ASDH. Although GCS score has been reported as the most important prognostic factor, neurosurgeons should not rely upon initial GCS score because the discriminant ratio using GCS alone was only 17.06%. Discriminant functions for the severe head injury (GCS 3–8) and minor to moderate head injury groups (GCS 9–15) could predict outcome correctly in only two-thirds of patients. The low discriminant ratio indicates that age and GCS may not have much significance.

Discriminant analysis was not carried out for separate managements in this study, because our patients were treated with the strict protocol described, which is consistent with current management methods. Further, management had no significant relationship with outcome, although this might be due to the different patient conditions. Our discriminant function is appropriate to predict outcome for patients when management is selected based on the patient condition using a strict protocol for management selection like ours. (The authors will discuss discriminant functions for all managements in another paper).

ASDH remains a difficult challenge for neurosurgeons because of the high mortality and limited prospects for functional recovery. Our simple discriminant function provides a method for rapidly predicting the prognosis for ASDH patients, and should provide a better basis for selecting the therapeutic approach and family counseling.

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