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Risk Stratification in Patients with Severe Traumatic Acute Subdural Hematoma

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Objective: The aim of this study was to investigate risk grouping for surgical outcome in patients with severe traumatic acute subdural hematoma (ASDH). **Methods:** Seventy-five patients showing low Glasgow Coma Scale (GCS) 3 to 8 were enrolled in this retrospective study. Clinico-radiologic findings were retrieved from electronic medical record and computed tomography. Prognostic factors from univariate and multivariate statistical methodology were included in a recursive partitioning analysis for risk stratification. **Results:** One month after surgery, 54 patients (72%) had poor Glasgow Outcome Scale (GOS) 1 to 2 (unfavorable outcome). The surgical outcomes were stratified into three homogenous risk groups according to preoperative GCS and presence of basal cistern obliteration. The rate of favorable outcome and mortality significantly differ between the groups: 4.9% and 68.3% in patients with GCS 3 to 5, 23.1% and 53.8% in patients with GCS 6 to 8 and basal cistern obliteration, and 76.2% and 0% in patients with GCS 6 to 8 and without basal cistern obliteration. **Conclusion:** The surgical outcomes of severe traumatic ASDH patients could be stratified preoperative GCS score and the presence of basal cistern obliteration. It is expected that this model will not only provide objective information when we make decisions about treatment, but it can also be a useful tool when discussing the patient's prognosis with the patient's caregivers.

Key Words: Craniotomy; Decompressive craniectomy; Hematoma; Subdural; Acute; Prognosis

INTRODUCTION

Acute subdural hematoma (ASDH) is a major clinical entity in traumatic brain injury (TBI) and is diagnosed by computed tomography (CT) as a hyperdense, extra-axial, crescent lesion between the dura and brain parenchyma[1]. The acceleration-deceleration force applied during traumatic insults can result in stretching and tearing of the cross-linking blood vessels and cortical arteries, which is the source of hematoma formation[2-5]. The pressure imposed on the cerebral tissue by a hematoma is not the only factor that affects neurological outcomes, because ASDH is commonly associated with brain edema, contusions, and diffuse axonal injury (DAI)[1,6,7]. This can increase midline shift (MLS) and make hematoma removal inappropriate for satisfactory patient outcomes[8,9].

Studies have shown that the mortality rate of ASDH is up to 60%, and most patients with ASDH have no consciousness from the time of admission, and thus their prognosis is poor, regardless of whether or not surgery is performed[10]. The main dilemma is deciding whether or not to perform maximal care, or to refrain from aggressive treatment and perform palliative care instead[11]. Predicting the prognosis of patients diagnosed with ASDH is often difficult and leads to controversial surgical decisions. Various prognostic factors are implicated in the outcome of ASDH, including patient age, admission Glasgow Coma Scale (GCS), and associated injuries[10,12-14]. In addition, radiological findings on the brain CT scans play an important role in management planning[15].

The thickness of the ASDH is considered to be an important determinant of surgical decisions[16,17]. Recently, it has been reported that the outcome can be predicted by the ratio between hematoma thickness and MLS[2,11]. Although there are many models of prediction tools, there is no way to describe the prognosis objectively. We retrospectively investigated preoperative clinical status and imaging findings in ASDH patients who underwent hematoma evacuation in our institution. Based on this, we conducted the study to provide a communication tool for rationally reporting the patient's prognosis to the caregivers.

MATERIALS AND METHODS

1. Study Design

A retrospective study was performed on 142 adult patients who received surgical decompression and hematoma evacuation after a diagnosis of traumatic ASDH at the Konkuk University Medical Center between August 2005 and March 2017. Data from all patients who met the study criteria were extracted from the database, including the patient's sex and age, history, medications given, neurological examinations (including preoperative GCS and pupil abnormalities), thickness of the hematoma and MLS, presence of basal cistern obliteration, presence of subarachnoid hemorrhage (SAH) or contusional hemorrhage, and 1-month follow-up Glasgow Outcome Scale (GOS). Data were extracted, based on the inclusion criteria, from patients aged 18 years or older diagnosed with traumatic ASDH with a hematoma of thickness 5 mm or more, who underwent unilateral craniotomy or craniectomy, among patients with a GCS of 8 or less at the time of admission. Patients younger than 18 years of age (n=1), having a GCS of 9 or greater at the time of admission (n=31), with a previous history of cranial surgery (n=7), with uncontrolled primary malignancy and a hematologic disorder (n=1) or with the Karnofsky Performance Score (KPS) score below 60 before the trauma (n=4) were excluded. Patients with a reason for choosing surgery for other hematomas with a mass effect rather than subdural hematoma (SDH) (n=5), spontaneous SDH (n=4), or patients with SDH due to other intracranial pathologies (n=2) were also excluded. Patients who underwent craniotomy on both sides or at the posterior fossa (n=9) were excluded, and patients with unavailable preoperative CT images (n=1) were also excluded. Patients who were lost to follow-up during treatment were also excluded (n=2). Finally, 75 patients were included in this study (Fig. 1). The age of the patients ranged from 22 to 83 years with a median age of 61 years (range, 22-83 years), and the male to female ratio was 53:22. The median preoperative GCS was 5. Falls (n=48) were the most common mechanism of ASDH, followed by pedestrian traffic accidents (n=13) and motorcycle traffic accidents (n=10). There were also some assault injuries (n=2).

The preoperative imaging findings were defined as follows. Measurements of the thickness of the hematoma and MLS were obtained at the level of the frontal horns. MLS was defined as the distance measured from the midline to the displaced septum pellucidum. The difference between the thickness of the hematoma and the MLS was expressed in millimeters. The state of the basal cistern was classified as follows: 'patent' if at least one side is open, 'obliterated' if neither is visible. Because the presence of SAH or contusional hemorrhage could be a predictive value for parenchymal damage, we checked for SAH or contusional hemorrhage on preoperative CT.

The surgical technique used to remove the ASDH was decided by the neurosurgeon during surgery. All patients who satisfied our inclusion criteria received decompressive craniectomy or craniotomy, which were determined based on their preoperative clinical status, CT findings, and operative findings. After surgical intervention, all patients were transferred to the intensive care unit for postoperative management and monitoring. Their intracranial pressure (ICP) was monitored in patients who had an ICP monitoring catheter. Only after extubation and vital functions were stabilized was the patient transferred to the ward for further management.

The GOS evaluates the patient's functional outcome on a 5-point scale, from 1 (death) to 5 (good recovery). Patients were categorized in the poor functional outcome group if their 1-month follow-up GOS ranged from 1 (death) to 2 (vegetative state). One month after surgery, the patients were classified into the

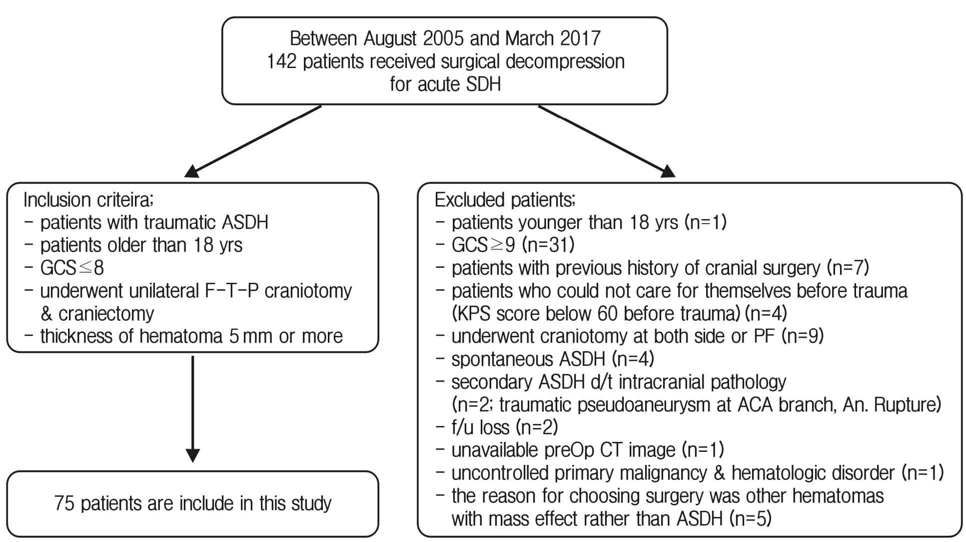

Fig. 1. The flow of patient selection process using our inclusion criteria and exclusion criteria during the period from August 1, 2005 to March 31, 2017. SDH: subdural hematoma; ASDH: acute SDH; GCS: Glasgow Coma Scale; F-T-P: fronto-temporoparietal; KPS: Karnofsky Performance Score; PF: posterior fossa; ACA: anterior cerebral artery; f/u: follow up; pre OP: preoperative; CT: computed tomography.

'Unfavorable' group, which was measured by the GOS from 1 to 2, or the 'Favorable' group, which was measured by the GOS from 3 to 5.

2. Statistical Analysis

Associations between clinic-radiologic variables and prognosis were evaluated with the χ^2 test. A multivariate logistic regression model was used to adjust for covariates which showed $p<0.2$ on the univariate tests. Variables with $p<0.05$ were defined as significantly relevant. These analyses were performed using the Statistical Package for the Social Sciences version 17.0 (SPSS Inc., Chicago, IL, USA). For the variables showing significance in multivariate analysis, recursive partitioning analysis (RPA) was done with free software (R version 3.3.3; The R Foundation for Statistical Computing, Vienna, Austria) to create the recursive decision tree with the split criteria of $p<0.05$. The final nodes were grouped according to their 1-month mortality and favorable/unfavorable prognosis rate.

RESULTS

1. Prognostic Factors in Severe Traumatic Acute SDH

One month after surgery, 54 patients (72%) had poor GOS 1 to 2 (unfavorable outcome) and 21 patients (28%) had GOS 3 to 5 (favorable outcome). Patients with a low preoperative GCS (3-5) showed a statistically high incidence of an unfavorable outcome with a low GOS (1-2) a month after surgery ($p<0.001$). Pupillary abnormalities (bilateral fixed dilated pupils) on admission was associated with unfavorable outcomes ($p=0.006$). A statistically significant unfavorable outcome was also observed in patients with loss of self-respiration during admission ($p=0.001$). The time from the onset of the injury to the start of surgery varied from a minimum of 1.2 hr to a maximum of 46 hr, and an unfavorable prognosis was observed in patients who underwent surgery within 6 hr ($p=0.042$).

The imaging findings that were associated with the prognosis of the patients were also observed in this study. An unfavorable outcome could be predicted if the thickness of the hematoma was 13 mm or more ($p=0.025$), there was basal cistern obliteration ($p<0.001$), or SAH or contusional hemorrhage ($p=0.030$) was observed on preoperative CT scan images.

A multivariate analysis was performed with significant univariate predictors entered into multivariate regression models. Lower admission GCS ($p=0.030$; 95% confidence interval [CI]=1.24-68.33), presence of SAH or contusional hemorrhage ($p=0.050$; 95% CI=1.00-56.97), observed basal cistern obliteration ($p=0.018$; 95% CI=1.40-37.19), and a greater thickness of hematoma ($p=0.037$; 95% CI=1.12-35.66) were associated with unfavorable outcomes of ASDH patients. The observed data during the hospital period are shown in Table 1.

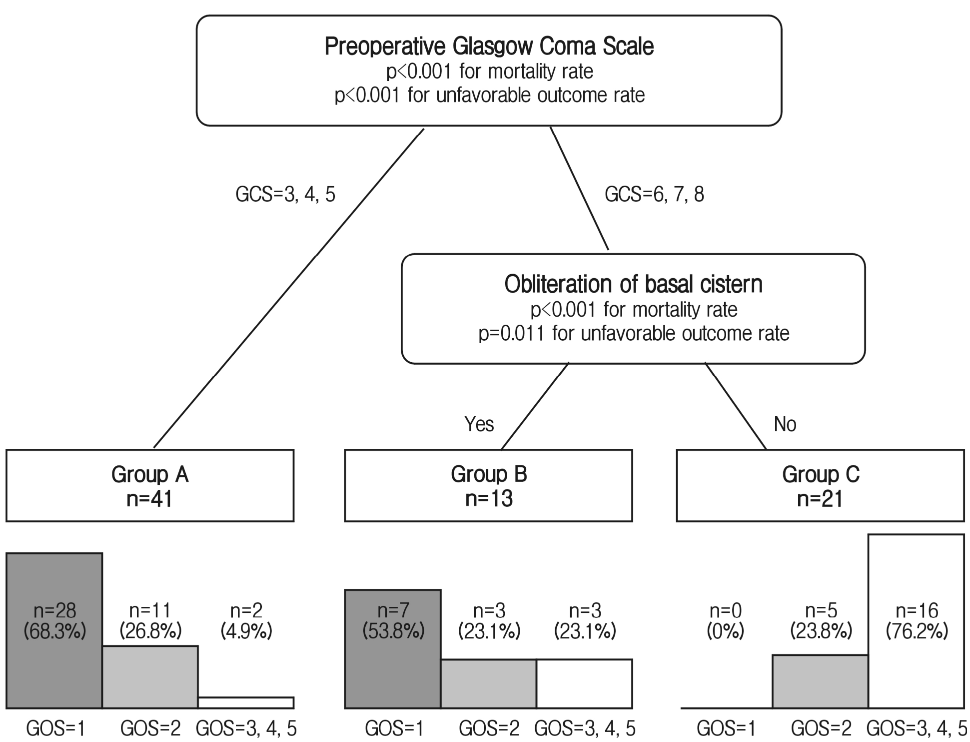

Fig. 2. The decision tree which is constructed by applying the significant factors in the ultivariate analysis to the recursive partitioning model. GCS: Glasgow Coma Scale. GOS: Glasgow Outcome Score.

Table 1. Variables related to outcome in patients who underwent surgery for traumatic acute subdural hematoma

	No. of unfavorable outcome	No. of patients	Univariate	Multivariate		
				p-value	HR	95% CI
Sex			0.928			
Male	38	53				
Female	16	22				
Age			0.399			
<60 years	25	37				
≥60 years	29	38				
Comorbidities			0.343			
No	35	51				
Yes	19	24				
Antiplatelet or anticoagulation			0.680			
No	50	70				
Yes	4	5				
Accompanying injuries			0.544			
No	43	61				
Yes	11	14				
Lucid interval			0.958			
No	10	14				
Yes	44	61				
GCS			<0.001	0.030	9.203	1.239-68.333
3-5	15	34				
6-8	39	41				
Pupil change			0.006	0.911	0.908	0.169-4.884
None or ipsilateral	9	19				
Bilateral	45	56				
Loss of self respiration			0.001	0.512	2.460	0.167-36.271
No	30	50				
Yes	24	25				
Time interval from onset of complaint to surgery			0.042	0.431	2.151	0.319-14.491
>6 hours	7	14				
≤6 hours	47	61				
Spot sign in CT angiography			0.891			
No	51	71				
Yes	3	4				
SAH or contusional hemorrhage			0.030	0.050	7.557	1.003-56.968
No	10	19				
Yes	44	56				
Basal cistern obliteration			<0.001	0.018	7.215	1.400-37.188
No	17	34				
Yes	37	41				
Thickness of hematoma			0.025	0.037	6.314	1.118-35.659
<13 mm	23	38				
≥13 mm	31	37				
Midline shift			0.536			
<14 mm	24	35				
≥14 mm	30	40				
Midline shift/Thickness of hematoma ratio			0.445			
<1	31	41				
≥1	23	34				
Skull fracture			0.440			
No	18	27				
Yes	36	48				
Serum albumin level			0.665			
<3.5 g/dL	6	7				
≥3.5 g/dL	48	68				

HR: hazard ratio; CI: confidence intervals; GCS: Glasgow Coma Scale; CT: computed tomography; SAH: subarachnoid hemorrhage.

2. Decision Tree for the Prognosis of Acute SDH

Using the above-mentioned significant prognostic factors (GCS 3-5, basal cistern obliteration, hematoma thickness ≥ 13 mm, presence of SAH or contusional hemorrhage) for ASDH, a recursive decision tree comprising 75 patients was created. Figure 2 shows 3 terminal nodes based on the preoperative KPS scores and the status of the basal cistern. Based on the terminal nodes, we categorized them into three groups. Independent of the radiologic findings, patients with a GCS of 3 to 5 can expect the worst outcomes (Group A). Among the patients with a GCS of 6 to 8, the patients without obliteration of the basal cistern (Group C) had a better 1 month clinical prognosis than those with obliteration of the basal cistern (Group B). The 1-month favorable outcome rates for each group were 4.9% in group A, 23.1% in group B, and 76.2% in group C. The same decision tree was drawn when applying the 1-month mortality rates. The 1-month mortality rates in groups A, B, and C were 68.3%, 53.8%, and 0%, respectively.

3. Illustrative Cases

The patient had a relatively high GCS of 8 and basal cistern obliteration was observed (Fig. 3A). In this case, the patient was categorized as Group B and we predicted an unfavorable outcome. As predicted in the decision tree, this patient died 19 days after admission. The second patient had a low GCS of 5 on admission, and a basal cistern obliteration was observed in the CT scan image (Fig. 3B). According to the decision tree, the patient was in Group A and an unfavorable outcome was predicted. However, the patient had a favorable outcome with a GOS of 4 months after the operation. The third patient had

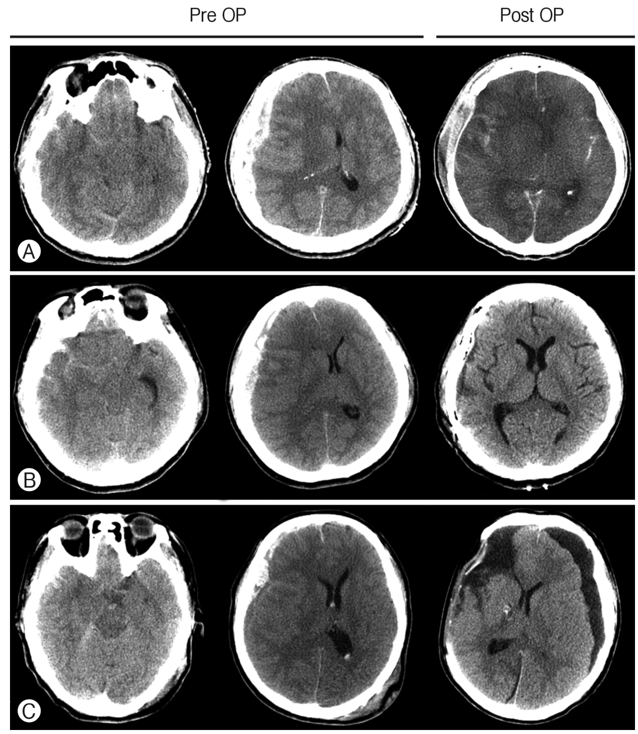

Fig. 3. Preoperative (Pre OP) and postoperative (Post OP) computed tomography (CT) of acute subdural hematoma patients who underwent surgery. (A) Axial CT images of patient with preoperative Glasgow Coma Scale (GCS) 8 and basal cistern obliteration. (B) Axial CT images of patient with preoperative GCS 5 and basal cistern obliteration. (C) Axial CT images of patient with preoperative GCS 5 and patent basal cistern.

Table 2. Prognostic factors of acute subdural hematoma known from previous literature

References	No. of patients	Overall mortality	Proposed prognostic factor
Toutant et al., 1984[21]	218	77.0%	Basal cistern absence
Dent et al., 1995[5]	211	52.0%	Admission GCS, midline shift, basal cistern absence, hematoma evacuated within 4 hours
Servadei et al., 2000[19]	206	46.0%	Thickness of hematoma, midline shift, basal cistern absence, presence of SAH
Ono et al., 2001[16]	272	N/A	Admission GCS, pupillary abnormalities, presence of SAH
Kim, 2009[11]	256	39.8%	Mechanism of injury, admission GCS, pupillary abnormalities, thickness of hematoma, volume of hematoma, midline shift
Leitgeb et al., 2012[13]	863	47.6%	Age, admission GCS, pupillary abnormalities
Bartels et al., 2015[2]	59	50.8%	Midline shift in relation to thickness of hematoma
Yu et al., 2015[24]	1,780	N/A	Admission GCS, serum albumin level
Alagoz et al., 2017[1]	99	64.1%	Admission GCS, thickness of hematoma
Han et al., 2017[6]	318	22.0%	Admission GCS, use of antithrombotics, history of diabetes mellitus, presence of SAH
Moussa et al., 2017[15]	67	23.9%	Midline shift/Thickness of hematoma ratio

GCS: Glasgow Coma Scale; SAH: subarachnoid hemorrhage.

a low GCS of 3 and was classified as Group A, suggesting an unfavorable outcome. However, a month after surgery, his GOS of 3 was checked and the patient had a favorable outcome. Basal cistern obliteration was not observed on a CT scan of this patient (Fig. 3C). Therefore, it is important to be aware that an exceptional situation may arise when determining the required type of surgery based on this diagram or when explaining it to the patient's caregiver.

DISCUSSION

The RPA classification not only provides simple and intuitive information on risk grouping, but also allows grouping of patients with the same risk and allows the clinician to predict the clinical prognosis of a particular patient population. However, it is clear that the ability to identify prognostic factors is low when the variables are large compared with the multivariate regression model[18]. Thus, we first identified four prognostic factors by analyzing prognostic factors using chi-square tests and multiple logistic regression models and applied them to the RPA model.

Preoperative GCS was the most powerful splitting criteria in our model. It is well-known that GCS not only directly reflects brain damage and clinical status, but also provides information about survival during follow-up[10,19,20]. In previous studies, preoperative GCS has been reported to be associated with the outcome of patients with TBI (Table 2)[10,14,17,20-23]. A low GCS on admission is known to be an important prognostic factor[10,23]. It is known that mortality is high in patients with GCS 3 to 5 at admission[22]. Previously published data have shown mortality rates of 60% to 84% in patients with a preoperative GCS of 3 to 5[12,13]. Because the results were statistically significant, the preoperative GCS was used as a factor in the derivation of the RPA model and as a result it was found to be an important axis in our RPA decision tree. In our RPA decision tree, patients with preoperative GCS 3 to 5 were assigned to group A, and 95.1% of the 41 patients in group A showed an unfavorable outcome indicating GOS 1 to 2 a month after surgery.

Our RPA model provides two nodes separated by the status of the basal cistern in patients with a GCS of 6 to 8. Studies have shown that the presence or absence of basal cistern obliteration on the CT scan image is strongly associated with the prognosis of the patient[14,16,24]. Toutant et al.[21] reported that a 77% mortality rate was observed when basal cistern obliteration existed. In our study, 90.2% (37/41) of patients showed unfavorable outcomes with basal cistern obliteration, consistent with previous findings. Among the patients with GCS 6 to 8, patients with basal cistern obliteration were placed in group B and those without basal cistern obliteration were placed in group C. According to our RPA tree, the outcomes of these groups are clearly different. In Group B, 76.9% showed unfavorable outcomes with GOS 1 to 2 at 1 month postoperatively and 53.8% mortality. In group C, 76.2% showed a favorable outcome with GOS 3 to 5 and 0% mortality.

Among the preoperative imaging findings, results that could be regarded as prognostic factors were also derived. It has been reported that unfavorable outcomes are observed when SAH is present on CT scan images before surgery[16,21,22]. We noted the outcomes of patients with SAH or contusional hemorrhage on preoperative CT scans. A total of 79% of these patients showed unfavorable outcomes. We also examined data from our patients based on a previous study indicating that a greater thickness of hematoma could be used as a poor prognostic factor[16,17]. A mean hematoma thickness of 13 mm was detected in patients satisfying our inclusion criteria and an unfavorable outcome was observed when the thickness of hematoma was greater than 13 mm. However, despite the significant statistical results of the two factors mentioned above, the two factors failed to be a splitting criterion in RPA analysis because they did not have priority in executing the RPA.

In our study, an unfavorable outcome was observed in patients who underwent surgery within 6 hr of the injury ($p=0.042$), although a previous study showed a favorable outcome in patients who underwent surgery within 4 hr of admission[14]. This is probably due to the severe brain damage in patients who underwent surgery within 6 hours because of ASDH, contusional hemorrhage, and DAI. In addition, preoperative basal cistern obliteration or greater thickness of a hematoma was associated with a poor prognosis, which was associated with severe clinical symptoms, suggesting a poor prognosis.

Previous studies have reported that MLS and MLS/thickness of hematoma ratio are strongly associated with prognostic factors[2,11,14,16,17], but our study did not show any significant association. We compared the results of other studies with MLS or MLS/thickness of hematoma ratio as prognostic predictive factors. In our study, bilateral SAH or contusional hemorrhage were observed in most patients with severe brain injury. Because mass effect was observed on both sides, we presumed that MLS could be compensated by bilateral mass effect. In addition, the preoperative GCS of the patients in our study was lower (patients with a GCS of 3 to 5 accounted for 55% of all patients) than in other study groups, suggesting that the severity of brain damage was high. Therefore, it could be assumed that the influence of MLS or MLS/thickness of hematoma ratio is not observed in our study more often than in other studies. However, since the number of patients in our study is relatively small, further investigation is mandatory to reveal the effect of MLS/thickness of hematoma ratio to the outcome of ASDH patients. Some studies have shown that antithrombotics[21] and serum albumin levels[23] are associated with patient prognosis. However, there was no difference in outcomes according to the serum albumin level or the use of antiplatelet/anticoagulation medication in this study.

There are some limitations in our study. First, we applied strict inclusion criteria and therefore selection bias may have occurred. However, since ASDH is often accompanied by various injury mechanisms and involves large spectrum of heterogeneous disease entities. For the sake of homogenous study group, we excluded 47.2% of patients showing relatively good neurological status or unusual clinical status. Second, as shown in the illustrative cases, some cases do not match the diagram we have proposed. When performing CT scans in the emergency room, we did not perform thin-section CT scans such as CT angiograms in all patients. In most cases, a CT scan was done in a setting with an interval of 5 mm per section. Thus, even if basal cistern is observed, there is a possibility of over-estimation as if obliteration existed. Moreover, because the concept of basal cistern obliteration itself is vague, evaluating the degree of basal cistern obliteration is not easy. One of the two patients with a favorable outcome who belonged to Group A had no basal cistern obliteration observed on the preoperative CT scan. Third, the number of patients studied is small. Because of this, variables that were meaningful in multivariate analysis were not selected and failed to form a decision tree. Therefore, for further study of ASDH, it is necessary to increase the number of patients and perform more thorough imaging studies.

CONCLUSION

There have been studies on the prognostic predictors of ASDH and some prognostic factors have been identified in this study. We were able to establish a model for predicting prognosis in patients with ASDH through preoperative GCS and basal cistern obliteration on CT scan images. It is expected that this model will not only provide objective information when we make decisions about treatment, but it can also be a useful tool when discussing the patient's prognosis with the patient's caregivers.

CONFLICTS OF INTEREST

No potential conflict of interest relevant to this article was reported.

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