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Combined Strategy of Burr Hole Surgery and Elective Craniotomy under Intracranial Pressure Monitoring for Severe Acute Subdural Hematoma

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Abstract

Burr hole surgery in the emergency room can be lifesaving for patients with acute subdural hematoma (ASDH). In the first part of this study, a strategy of combined burr hole surgery, a period of intracranial pressure (ICP) monitoring, and then craniotomy was examined for safe and effective treatment of ASDH. Since 2012, 16 patients with severe ASDH with indications for burr hole surgery were admitted to Kenwakai Otemachi Hospital. From 2012 to 2016, craniotomy was performed immediately after burr hole surgery (emergency [EM] group, n = 10). From 2017, an ICP sensor was placed before burr hole surgery. After a period for correction of traumatic coagulopathy, craniotomy was performed when ICP increased (elective [EL] group, n = 6). Patient background, bleeding tendency, intraoperative blood transfusion, and outcomes were compared between the groups. In the second part of the study, ICP was measured before and after burr hole surgery in seven patients (including two of the six in the EL group) to assess the effect of this surgery. Activated partial thromboplastin time (APTT) and prothrombin time-international normalized ratio (PT-INR) were significantly prolonged after craniotomy in the EM group, but not in the EL group, and the EM group tended to require a higher intraoperative transfusion volume. The rate of good outcomes was significantly higher in the EL group, and ICP was significantly decreased after burr hole surgery. These results suggest the value of burr hole surgery followed by ICP monitoring in patients with severe ASDH. Craniotomy can be performed safely using this method, and this may contribute to improved outcomes.

Keywords: severe acute subdural hematoma, burr hole surgery, large craniotomy, intercranial pressure, posttraumatic coagulopathy

Introduction

The incidence of acute subdural hematoma (ASDH) is 10–20% in patients with traumatic brain injury (TBI), and as high as 60% in those with severe TBI.[1] Many surgical strategies for ASDH have been reported,[2–4] and the relationship between timing of craniotomy and outcomes may be important.[5] Seelig et al.[6] found mortalities of 30% and 90% in patients with ASDH operated on ≤4 and >4 hours after injury, respectively. Haselberger et al.[7] also found a relationship of outcome with time from onset of coma to craniotomy, with patients operated on at ≤2 hours after clinical deterioration having significantly better outcomes than those operated on at >2 hours.[7]

Based on these reports, guidelines suggest that treatment for ASDH should include craniotomy as soon as possible.[8] However, traumatic coagulopathy

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is a problem in the pathophysiology of severe TBI,[9,10] and we found that TBI releases factors from brain tissue that trigger the extrinsic coagulation cascade to induce traumatic coagulopathy.[11] This causes an abrupt decrease in fibrinogen, and traumatic coagulopathy occurs from immediately to 3 hours after injury.[12] In severe ASDH, this period overlaps with the timing of craniotomy required to improve outcomes. If craniotomy is performed at this time, hemostasis is difficult and hemorrhage may increase, leading to hemorrhagic shock and acute brain swelling, and resulting in a poor outcome.

We adopted burr hole surgery for ASDH to solve this conflicting condition. ICP management by ventricular drainage is another treatment strategy, but this procedure has a risk of failure of ventricular drainage puncture in patients with ASDH and spread of hematoma and cerebral hernia due to decreased ICP. Burr hole surgery for ASDH is a minimally invasive surgery[13] that we use for early decompression followed by correction traumatic coagulopathy. ICP monitoring is performed during the period of correction of coagulopathy, and craniotomy is added if necessary and can be performed safely using this method. Empirically, we have found this treatment strategy to be useful. In this study, we examined the utility of the strategy more formally by evaluating the ICP before and after burr hole surgery, the amount of bleeding during craniotomy, and the clinical outcome.

Materials and Methods

A retrospective observational cohort study was performed using a protocol approved by the Institutional Review Board of Kenwakai Otemachi Hospital, Japan. All procedures on human subjects were conducted in accordance with "Ethical Guidelines for Medical and Health Research Involving Human Subjects (Provisional Translation as of March 2015)." Informed consent was not obtained from individual patients because this is a retrospective study of the outcomes of routine treatment. Instead, information on the study was displayed in the hospital as a form of opt out.

All patients with TBI at Kenwakai Otemachi Hospital were treated based on guidelines for management of severe TBI set forth by the Japan Society of Neurotraumatology.[8] Indications of surgical intervention for ASDH are hematoma >1 cm in thickness, hematoma with edema and disappearance of the basilar or perimesencephalic cisterns, and rapidly progressing neurological deficits. For a case with pupil abnormality or rapid progression, burr hole surgery is performed in the emergency room before craniotomy.

Examination of the optimal time for craniotomy

In all, 16 adult patients with severe (Glasgow Coma Scale (GCS) score ≤8) ASDH with indications for burr hole surgery were admitted to Kenwakai Otemachi Hospital between January 2012 and December 2018. Patients were classified into two groups according to timing of craniotomy. From 2012 to 2016, craniotomy was performed immediately after burr hole surgery (emergency [EM] group). From 2017, the protocol was changed to placement of an intracranial pressure (ICP) sensor before burr hole surgery, after which respiratory and circulation conditions were stabilized without craniotomy, and traumatic coagulopathy was improved by blood transfusion, if required. Craniotomy was performed upon occurrence of ICP >30 mmHg or CPP <60 mmHg, despite drug treatment (elective [EL] group).

Age, sex, GCS score on admission, pupil findings, type of injury, head computed tomography (CT) findings, blood test results (activated partial thromboplastin time [APTT], prothrombin time-international normalized ratio [PT-INR]) on admission and after craniotomy, time from admission to surgery, intraoperative bleeding and transfusion volumes, and outcome at discharge were compared between the two groups. The outcome was judged to be good when the Glasgow Outcome Scale (GOS) indicated good recovery (GR), moderate disabilities (MD) and severely disabled (SD) at the time of discharge. Vegetative state (VS) and death (DD) were defined as bad outcomes.

Examination of the effects of burr hole surgery

Seven adult patients with moderate to severe ASDH (GCS score 3–12) with indications for burr hole surgery who were admitted to Kenwakai Otemachi Hospital between January 2017 and December 2018 were included in this part of the study. Two of these patients were also in group EL above. After confirming ASDH on head CT, an ICP sensor was placed on the side opposite to the hematoma, after which burr hole surgery was performed to drain the hematoma. All these procedures were performed in the emergency room. ICP was measured throughout the surgical procedure, and ICP immediately before and after burr hole surgery was compared.

Statistical analysis

Data are presented as the mean ± standard deviation (SD). Statistical analysis was performed by unpaired t-test or Mann–Whitney U test in the first part of the study because the sample size was small in each group. Samples of more than six were analyzed by non-parametric measures.[14] A Fisher's exact test was used to evaluate covariates for binary categorical dependent variables. Normal data

Table 1 Characteristics of patients in the study of optimal timing for craniotomy

Item	EM group (n = 10)	EL group (n = 6)	p value
Age (years)	61.5 ± 17.7	69.7 ± 20.0	0.46
Sex (male)	6 (60%)	3 (50%)	0.71
GCS score on admission	4.0 ± 1.2	4.3 ± 1.8	0.48
Pupil examination			
Bilaterally dilatation	3 (30%)	0 (0%)	0.24
Unilaterally dilatation	5 (50%)	3 (50%)	
Normal	2 (20%)	3 (50%)	
Type of injury			
Traffic accident	3 (30%)	2 (33.3%)	0.73
Fall	6 (60%)	4 (66.7%)	
Unknown	1 (10%)	0 (0%)	
Head CT findings on admission			
Thickness of hematoma (mm)	21.4 ± 12.0	16.3 ± 7.1	0.37
Midline shift (mm)	16.7 ± 5.7	12.8 ± 4.7	0.31
Δ Thickness of hematoma (mm)	7.2 ± 4.5	4.9 ± 2.7	0.39
Δ Midline shift (mm)	4.3 ± 4.1	4.2 ± 3.5	0.81
Time from admission to burr hole surgery (min)	62.0 ± 34.2	100.0 ± 55.5	0.17
Time from admission to craniotomy (min)	160.1 ± 32.9	706.3 ± 373.1	<0.01*
Outcome at discharge			
Good outcome	1 (10%)	6 (100%)	<0.01*
Bad outcome	9 (90%)	0 (0%)	

Values are presented as mean ± standard deviation. *Significant difference between the two groups at p <0.05. CT: computed tomography, EL: elective, EM: emergency, GCS: Glasgow Coma Scale.

distribution was confirmed by Kolmogorov–Smirnov test in the first part, and by Shapiro–Wilk test in the second part of the study. ICPs measured before and after burr hole surgery were compared by paired t-test. P <0.05 was considered to be significant in all tests. All analyses were performed using JMP 13.1 Pro (SAS Institute Inc., Cary, NC, USA).

Results

Comparison of the EM and EL groups

The characteristics of the patients in the EM (n = 10) and EL (n = 6) groups are shown in Table 1. There was no significant difference in age, sex, GCS on admission, pupil findings, type of injury, and head CT findings between the two groups. The time from admission to burr hole surgery also did not differ significantly (EM 62.0 ± 34.2 vs. EL 100.0 ± 55.5 min). The time from admission to craniotomy was significantly longer in the EL group (160.1 ± 32.9 vs. 706.3 ± 373.1 min).

APTT and PT-INR at admission and after craniotomy were 31.1 ± 8.0 s and 1.0 ± 0.1 and 35.8 ± 11.4 s and 1.2 ± 0.2, respectively, in the EM group, with significant increases after craniotomy; and 35.3 ± 12.2 s and 1.1 ± 0.1 and 29.4 ± 2.4 s and 1.1 ± 0.1, respectively, in the EL group, with no significant changes after craniotomy (Fig. 1). Intraoperatively, the EL group had a lower total bleeding volume (1112.4 ± 1402.6 vs. 636.7 ± 946.6 ml), and lower transfusion volumes of red cell concentrate (1064 ± 1063 vs. 280 ± 354 ml) and fresh frozen plasma (656 ± 790 vs. 313 ± 195 ml) compared to the EM group, but these differences were not significant (Fig. 2). The rate of good outcomes was significantly higher in the EL group (10% vs. 100%) (Table 1).

Comparison of ICP before and after burr hole surgery

The characteristics of the seven patients (six males and one female) in the study of the effects of burr hole surgery on ICP are shown in Table 2. The mean age of these patients was 66.7 ± 12.7 years (range 47–85 years), and the mean GCS score on admission was 5.6 ± 4.1. Head CT findings on admission mainly indicated ASDH. The types of injury were two traffic accidents and five falls. GOS at discharge

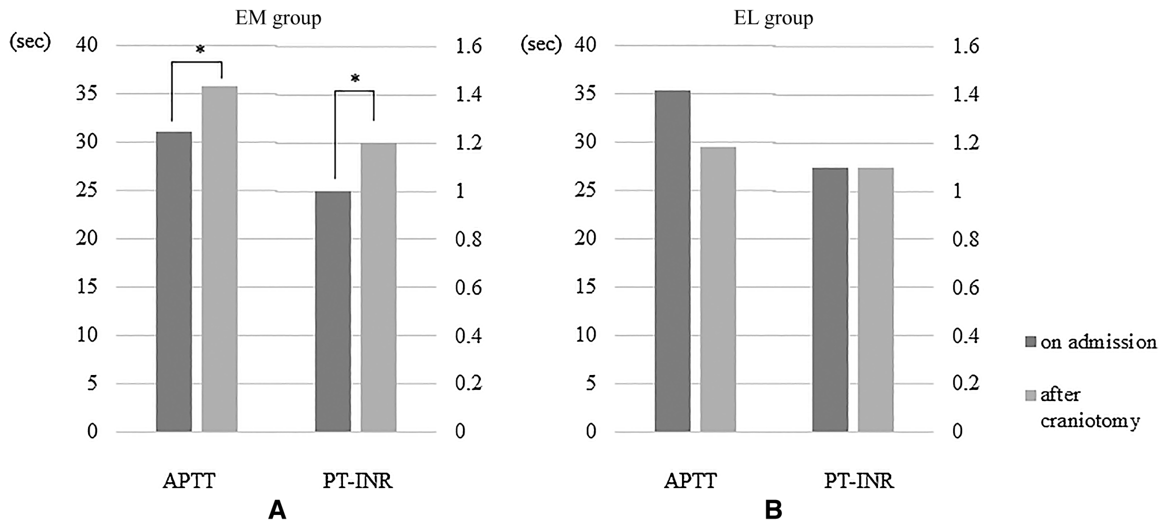

Fig. 1 Comparison of APTT and PT-INR at admission and after craniotomy in the EM (a) and EL (b) groups. *p <0.01. APTT: activated partial thromboplastin time, EL: elective, EM: emergency, PT-INR: prothrombin time-international normalized ratio.

was GR in one case, MD in three cases, SD in one case, VS in one case, and DD in one case. ICP was significantly lower after burr hole surgery (36.2 ± 21.5 vs 9.8 ± 6.6 mmHg) (Fig. 3).

Discussion

In this study, we examined outcomes of patients with ASDH treated by decompression with burr hole surgery, which is minimally invasive, and large craniotomy performed after improvement of traumatic coagulopathy. This method reduced the amount of bleeding and blood transfusion during craniotomy and improved outcomes, compared to burr hole surgery followed by immediate craniotomy. In addition, an ICP sensor was inserted before burr hole surgery, and ICP was measured before and after this surgery. This is the first report showing the decompression effect of burr hole surgery based on ICP values.

The time from admission to burr hole surgery was >60 minutes on average. In this period of initial treatment of severe trauma, the first priority is to secure the airway and stabilize respiratory and circulatory conditions. After stabilization, head CT can be used for definite diagnosis of ASDH, and then preparations for burr hole surgery can begin. Decompression at an early stage is important in treatment of ASDH.[5] Therefore, to obtain as good an outcome as possible, it would be helpful to predict ASDH based on injury type and clinical symptoms, and to perform burr hole surgery as early as possible. Thus, establishment of a method for prediction of ASDH is an important future task.

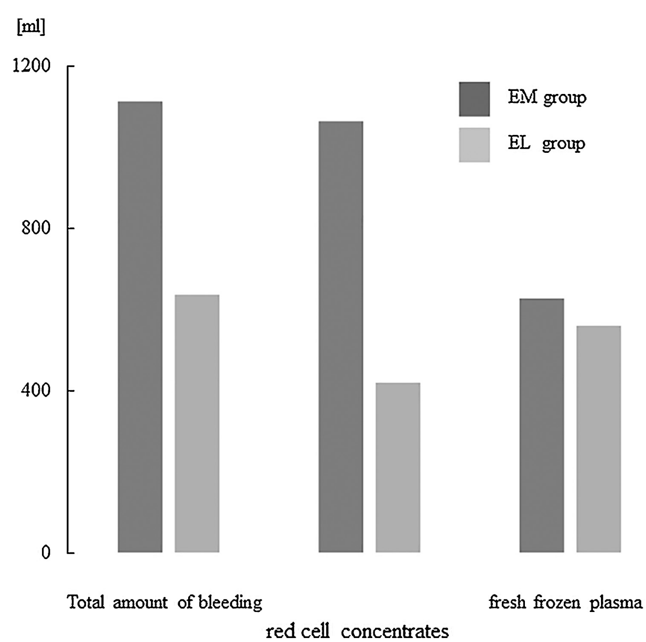

Fig. 2 Comparison of intraoperative total bleeding and transfusion volumes in the EM and EL groups. The EM group showed a tendency to require a higher intraoperative transfusion volume. EL: elective, EM: emergency.

The average time from admission to craniotomy in the EL group was 706 min. There were differences among cases, but it typically took several hours for ICP lowered by burr hole surgery to return to a state of intracranial hypertension. Traumatic coagulopathy is thought to begin immediately after injury and to peak at 3 hours after injury.[12] After this time

Table 2 Characteristics of patients in the study of the effects of burr hole surgery on ICP

Case	Age (years)	Sex	GCS on admission	Type of injury	CT findings	ICP before burr hole surgery (mmHg)	ICP after burr hole surgery (mmHg)	GOS
1	58	Male	3	Fall	ASDH	14	5	GR
2	85	Female	3	Fall	ASDH	26	2	SD
3	72	Male	3	Traffic accident	ASDH	64	15	DD
4	77	Male	3	Fall	ASDH	25	14	MD
5	67	Male	4	Traffic accident	ASDH	60	9	VS
6	61	Male	12	Fall	ASDH, CC	6	5	MD
7	47	Male	11	Fall	ASDH	46	8	MD

ASDH: acute subdural hematoma, CC: cerebral contusion, CT: computed tomography, DD: dead, GCS: Glasgow Coma Scale, GOS: Glasgow Outcome Scale, GR: Good recovery, ICP: intracranial pressure, MD: moderate disability, SD: severe disability, VS: vegetative state.

period, craniotomy can be safely performed because bleeding tendency gradually shifts to a state of significant coagulation. Therefore, an important observation in this study is that performance of craniotomy during the period of traumatic coagulopathy can be avoided by using burr hole surgery as a minimally invasive procedure. In addition, the pathophysiology of ASDH involves secondary brain injury caused by ischemia–reperfusion injury at the time of craniotomy.[15] It may be possible to reduce brain damage due to ischemia–reperfusion by performing two-stage decompression with burr hole surgery and delayed craniotomy.

The usefulness of burr hole surgery and craniotomy for severe ASDH has been reported[16,17] and this approach has improved outcomes as a salvage procedure for patients with cerebral hernia.[18] However, it was not clear how burr hole surgery contributed to these improved outcomes. In the current study, we first showed quantitatively that ICP is lowered by burr hole surgery. This decrease in ICP releases cerebral hernia and contributes to resumption of cerebral perfusion. Second, lowering of ICP is involved in correction of traumatic coagulopathy. Intraoperative bleeding was high in the EM group, resulting in an increased requirement for transfusion of red cell concentrate. This occurred because craniotomy was started without correction of traumatic coagulopathy, with a large amount of bleeding than caused by difficulty with hemostasis. Blood tests at the time of admission and after craniotomy also showed postoperative PT-INR and APTT increases in the EM group. Thus, traumatic coagulopathy seems to have been exacerbated due to massive bleeding and surgical invasion due to consecutive craniotomy after burr hole surgery, and

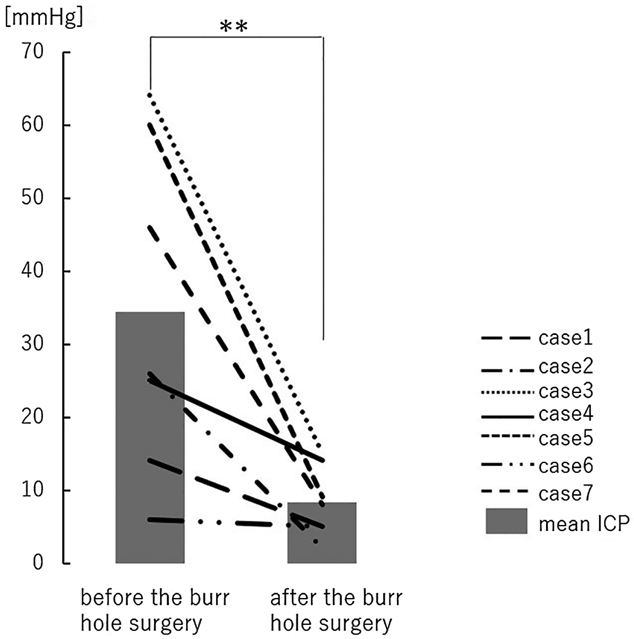

Fig. 3 Values of ICP before and after burr hole surgery. ICP was significantly decreased just after burr hole surgery in the emergency department. **p = 0.005. ICP: intracranial pressure.

this has a negative effect on outcomes.[10,19] Increased blood transfusion may also adversely affect outcomes.[9,20,21] In contrast, in the EL group, ICP was lowered and traumatic coagulopathy was corrected in the period between burr hole surgery and craniotomy, resulting in less intraoperative blood loss and blood transfusion, no changes in postoperative blood tests, and no worsening of bleeding. Thus, craniotomy can be performed more safely after a period of ICP monitoring after burr hole surgery, even for patients with severe ASDH.

In this study, we introduced a new strategy of lowering of ICP by burr hole surgery, with craniotomy then safely performed after stabilizing the general condition of patients with ASDH. However, the number of cases was small and further examinations of the details of this method are required. Better outcomes may be obtained by extending the indication to ASDH cases without cerebral hernia, rather than using burr hole surgery for rescue. Alternatively, ICP >30 mmHg or CPP <60 mmHg was used as the standard for the timing of craniotomy, but this threshold may not be necessary. Regardless, the results of this study suggest that burr hole surgery in the emergency room may be performed as aggressive initial treatment for severe ASDH.

In conclusion, this study shows the efficacy of a combined approach of burr hole surgery in the emergency room and elective craniotomy for patients with severe ASDH. ICP can be continuously measured by placing an ICP sensor during burr hole surgery, and the timing of craniotomy can be determined based on the ICP. Respiratory and circulatory stabilization and correction of traumatic coagulopathy prior to craniotomy allow craniotomy to be performed safely and may contribute to improved outcomes for patients with severe ASDH.

Conflicts of Interest Disclosure

None of the authors report a conflict of interest.

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