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Minimally invasive fibrinolytic treatment and drainage in patients with acute subdural hemorrhage and underlying comorbidities

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Abstract

The incidence of acute subdural hemorrhage (ASDH), which is often caused by head trauma, is steadily increasing due to an increase in the elderly population and the use of anticoagulants. Urgent surgical treatment is recommended if the patient has impaired consciousness, worsening neurological symptoms, or brain midline shift (MLS) due to large hematomas on brain computed tomography (CT). Although large craniotomy is traditionally recommended for ASDH removal, old age, comorbidities, and antiplatelet drugs are considered risk factors for surgical complications, many neurosurgeons hesitate to perform aggressive surgical procedures in these patients. In this study, we introduced a method that can quickly and effectively remove ASDH without general anesthesia. We retrospectively reviewed 11 cases of patients with ASDH who underwent hematoma drainage between June 2019 and December 2020. We measured the maximum subdural hematoma thickness and MLS on brain CT of patients and recorded the Glasgow Coma Scale scores before and after the surgical procedure. All patients had multiple comorbidities, and seven patients received anticoagulant or antiplatelet therapy. On initial brain CT, the median subdural hemorrhage thickness was 21.36 mm, median MLS was 10.09 mm, and mean volume of the subdural hematoma was 163.64 mL. The mean evacuation rate of the subdural hematoma after drainage was 83.57%. There was no rebleeding or operation-related infection during the aspiration procedure, and the median MLS correction after the procedure was 7.0 mm. Our treatment strategies can be a reliable, less invasive, and alternative treatment option for patients at high risk of complications due to general anesthesia or patients who are reluctant to undergo a large craniotomy due to a high bleeding tendency.

Abbreviations: ASDH = acute subdural hematoma, CT = computed tomography, EVD = external ventricular drainage, GCS = Glasgow coma scale, MLS = midline shifting, mRS = modified Rankin Scale, rtPA = recombinant tissue plasminogen activator.

Keywords: acute subdural hematoma, elderly patient, head trauma, hematoma aspiration, minimal invasive surgery, tissue plasminogen activator

1. Introduction

Acute subdural hematoma (ASDH) is a significant part of traumatic brain injury, and is observed in one-third of patients with severe traumatic brain injury.[1] ASDH has a 52% to 57% mortality rate and accounts for up to 30% of severe head injuries. Due to the growing aging population, the incidence of ASDH has been continuously rising with increased comorbidities, disease severity, and anticoagulant use.[2–6]

Early reduction in brain shifting and decompression of increased intracranial pressure are essential to reduce the duration of ischemic brain injury, and urgent surgical treatment through large craniotomy is recommended if the patient has consciousness impairment, worsening neurological symptoms, or cerebral midline shift (MLS) caused by a large amount of hematoma as detected on brain computed tomography (CT).[5,7–12]

A large craniotomy is traditionally recommended as the first-line treatment for ASDH. However, older age, underlying medical conditions, and use of antiplatelet drugs are considered risk factors for surgery. If craniotomy is performed under general anesthesia in patients with these comorbidities, general anesthesia and surgery-related complications may occur. Therefore, many neurosurgeons hesitate to aggressively treat these patients. As a result, minimally invasive surgery has become an essential topic of discussion, as revealed in a recently published study of minimally invasive surgical techniques such as endoscopic surgery in patients with ASDH at a high risk of complications associated with a large craniotomy.[13–17]

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This retrospective study does not require informed consent.

The authors have no conflicts of interest to disclose.

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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In this study, we report an alternative strategy for primary treatment and rescue that involves reducing the mass effect of a subdural hematoma through minimally invasive surgery without general anesthesia.

2. Materials and methods

2.1. Patients' data and surgical indication

We retrospectively reviewed the cases of patients with ASDH who underwent our drainage procedure at a single center at Chonnam National University Hospital. Eleven patients with ASDH were enrolled in this study between January 2019 and May 2021. This study was conducted in accordance with the tenets of the Declaration of Helsinki (6th Amendment, 2008) and satisfied all the requirements for patient anonymity. Informed oral consent was obtained from each patient and guardian for submission to this research paper. All patients were admitted to the emergency room, and ASDH was diagnosed using non-contrast brain CT. Maximal subdural hematoma thickness and MLS were measured on brain CT scans, and the neurosurgeons recorded the patients' Glasgow Coma Scale (GCS) scores. Based on the reviewed literature, decisions on the surgical management of ASDH have been suggested based on whether the hematoma thickness is 10 mm or more or MLS is 5 mm or more, regardless of the GCS score.[18] Indications for our treatment include a high risk of general anesthesia due to old age or underlying diseases, high bleeding tendency due to anticoagulant or antithrombotic drugs, no swirl signs in the hematoma on brain CT, and no intraparenchymal bleeding.

Before explaining our treatment, a detailed explanation of traditional craniotomy was given, and if the guardian's intention to refuse was specific, our method was explained as salvage treatment, and consent was obtained.

2.2. Measurement of the amount of hematoma

We measured the hematoma volume (mL) before and after the procedure using the ABC/2 volume formula and confirmed the evacuation rate.[19] The maximum extended length from the anterior to the posterior edge of the ASDH was designated as A (cm), and the maximal thickness of the hematoma as a straight line perpendicular to A in the same slice in which A was measured was designated as the maximum width B (cm). The maximum height of the hematoma was calculated by multiplying the number of CT slides where the hematoma was visible by the thickness of the CT scan (e.g., 5 mm) and was designated as C (cm).

2.3. Operative procedure

The operative procedure was performed under local anesthesia. All patients were administered 2 g cefazolin 30 to 60 minutes prior to the incision as antibiotic prophylaxis. Regarding pain management for burr hole surgery, we prepared a 0.1 mg/2 mL remifentanil (ultra-short-acting opioid) for intraoperative intravenous administration.[20] The patient was in the supine position, and the head was rotated to the opposite side of the ASDH.

According to the brain CT scan, at the maximal thickness of the hematoma, a target point was set at the site by avoiding the main branch of the superficial temporal artery and the middle meningeal artery. After infiltration of local anesthesia with 2% lidocaine, a 3-cm linear skin incision was made, and a 1-cm-diameter burr hole was made using a high-speed electrical drill. After the bone edges were waxed, the dura was coagulated and incised in a cruciate form. After the subdural hematoma was exposed, a 10.5-Fr external ventricular drainage (EVD) catheter (Yu-Shin Medical, Seoul, Republic of Korea) was inserted 3 to 5 cm into the hematoma before it was subcutaneously tunneled and fixed to the scalp. To prevent rebleeding due to sudden negative pressure applied to the subdural space, the amount of subdural hematoma discharged during surgery was minimized by reducing the dural incision, and a closed-system EVD catheter was inserted.

2.4. Drainage procedure

After aspiration tip insertion, free drainage was performed for 12 to 24 hours after the trauma. Brain CT should be performed to investigate active bleeding in the hematoma if neurological symptoms worsen after surgery or if fresh blood is drained during free drainage. However, there were no such cases in our study.

For fibrinolytic treatment, 1.0 cc saline mixed with 1 mg recombinant tissue plasminogen activator (rtPA) was then injected through the catheter. The EVD catheter has a diameter of 2 mm and a length of 360 mm; therefore, the total volume is 1.13 cc. Therefore, to inject rtPA into the hematoma without leaving it in the catheter, it was washed with 1.2 cc saline (Fig. 1).

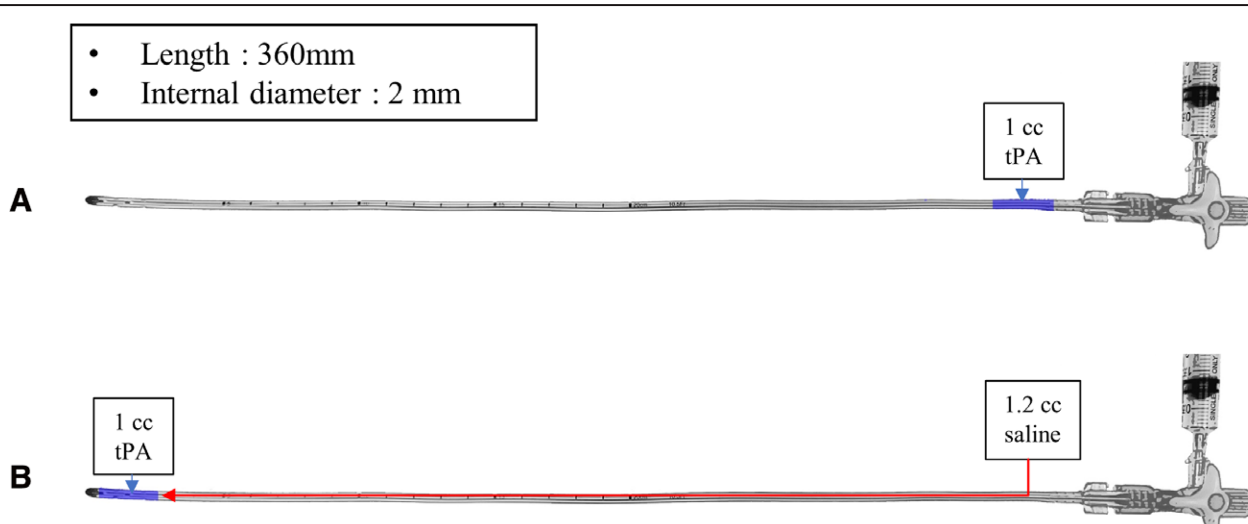

Figure 1. rtPA infusion through EVD catheter. (A) 1.0 cc rtPA is injected through the EVD catheter (2-mm internal diameter, 360-mm length). (B) Since the volume of the catheter is 1.13 cc, saline flushing (1.2 cc) is performed to release the 1.0 cc rtPA. EVD = external ventricular drainage, rtPA = recombinant tissue plasminogen activator.

After 30 minutes of rtPA injection, the free drain and liquefied hematoma were removed. Follow-up brain CT was performed after the repeat procedure for 2 days at 12-hour intervals. Follow-up brain CT was used to evaluate the residual hematoma and decide whether to proceed further. The aspiration tip maintenance period did not exceed 1 week. After the burr hole drainage procedure, the patient's GCS score and MLS on follow-up brain CT were measured and compared with those before surgery. The modified Rankin Scale (mRS) was used to evaluate patient prognosis.

2.5. Statistical analysis

Continuous variables are expressed as mean ± standard deviation. Paired *t* tests were used to compare the measures of patient status at different time points. Statistical analysis was performed using the SPSS program (version 25.0; IBM Corp., Armonk, NY). Statistical significance was set at $P < .05$.

2.6. Illustrative cases

Through the presentation of four cases, we introduce how we successfully treated elderly patients who received dual antiplatelet therapy or anticoagulant therapy and patients with low platelet count before surgery among patients requiring hematoma removal due to ASDH.

2.7. Case 1

A 77-year-old man (patient 5) visited the emergency center with decreased consciousness. The patient had been taking aspirin and clopidogrel and had a history of hypertension and progressive supranuclear palsy. He was also scheduled for coil embolization for an incidentally detected cerebral aneurysm. The patient was last seen conscious 1 hour before the visit, and the neurological examination performed at the emergency center revealed that he was in a semi-comatose mental state (GCS E1V2M4). He showed left-sided dilated (8 mm) anisocoria, and both corneal reflexes were present.

On brain CT performed in the emergency room, ASDH was detected without any cerebral parenchymal injury (Fig. 2A-1). Considering that the patient was elderly and was taking dual antiplatelet agents, we decided to insert a hematoma aspiration tip through burr holes under local anesthesia rather than performing a traditional large craniotomy.

Immediately after surgery, the MLS decreased to 10 mm with an improvement in mental status (GCS E3V4M6) (Fig. 2A-2). After the aspiration procedure, the midline correction was confirmed on a follow-up brain CT scan (Fig. 2A-3). The evacuation rate was 77.08% after the drainage procedure. The patient was discharged after recovery from a drowsy mental state (GCS E4V4M6).

2.8. Case 2

A 73-year-old man (patient 8) with a headache was admitted to the hospital's emergency center. The patient was on medication for hypertension, diabetes, and previous cerebral infarction. Aspirin and clopidogrel were among his maintenance medications. At the emergency room, the neurological examination revealed an alert mental state with left hemiparesis. He was classified as grade III due to the sequelae of a previous cerebral infarction.

On brain CT scan performed at the emergency center, ASDH was detected without any cerebral parenchymal injury (Fig. 2B-1). Because he was an elderly patient taking dual antiplatelet agents, we decided to perform hematoma removal through hematoma aspiration tip insertion under local anesthesia.

Immediately after surgery, the MLS decreased to 5 mm (Fig. 2B-2), and 92.68% of the hematoma was evacuated after the procedure (Fig. 2B-3).

2.9. Case 3

A 48-year-old man (patient 11) was transported to the emergency center due to altered consciousness. The patient had a history of surgery for laryngeal cancer and was undergoing medical treatment for alcoholic liver cirrhosis.

Where the patient was last seen conscious was not determined, but he was found unconscious 2 hour prior and was transferred to an emergency center. The neurological examination performed at the emergency center revealed that the patient was in a semi-comatose mental state (GCS E1V1M3). He showed left-sided dilated (6 mm) anisocoria, and both corneal reflexes were present.

On preoperative brain CT, ASDH was observed (Fig. 2C-1). In the laboratory study performed during admission, the platelet count was 30,000/μL, and no major operation was indicated. We decided to insert a hematoma aspiration tip through a burr hole under local anesthesia after transfusing 8 units of platelet concentrate.

Immediately after surgery, the MLS decreased (Fig. 2C-2), and midline correction with 98.94% of the hematoma evacuation was confirmed on follow-up brain CT after the procedure (Fig. 2C-3). The patient was discharged after recovering from a drowsy mental state (GCS E4V3M6).

2.10. Case 4

A 75-year-old man (patient 7) was admitted to the hospital's emergency center with headache and loss of consciousness after he slipped while hiking. The patient was under medication for hypertension, diabetes, previous cerebral infarction, and atrial fibrillation and was taking warfarin after a mitral valve replacement 2 years before the visit.

The neurological examination performed at the emergency center revealed that the patient was in a drowsy mental state (GCS E3V5M6). On brain CT scan in the emergency room, ASDH was observed as a right frontotemporoparietal lesion with MLS to the left (Fig. 2D-1). Because the guardians were skeptical about the operation, we admitted the patient to the intensive care unit and followed up the patient after vitamin K administration (antidote of warfarin).

After 4 hours of hospitalization, the patient was in a stuporous mental state. On follow-up brain CT, an increase in the amount of subdural hemorrhage and worsening of MLS (13 mm deviation to the left) were observed (Fig. 2D-2).

We discussed with the patient's caregivers that surgical treatment was necessary as the hematoma continued to increase. However, the caregivers were still skeptical about surgery with general anesthesia, as a large craniotomy would be required, due to the patient's old age and comorbidities.

As an alternative method, we proposed hematoma removal through aspiration tip insertion under local anesthesia, which was performed with the guardians' consent.

Immediately after surgery, the MLS decreased to 8 mm, and midline correction was confirmed on a brain CT scan after the procedure with an evacuation rate of 87% (Fig. 2D-3). The patient was discharged after recovery from a drowsy mental state (GCS E4V4M6).

3. Results

During the study period, 11 patients with ASDH underwent burr hole drainage. Patient demographics and characteristics are summarized in Tables 1 and 2, respectively.

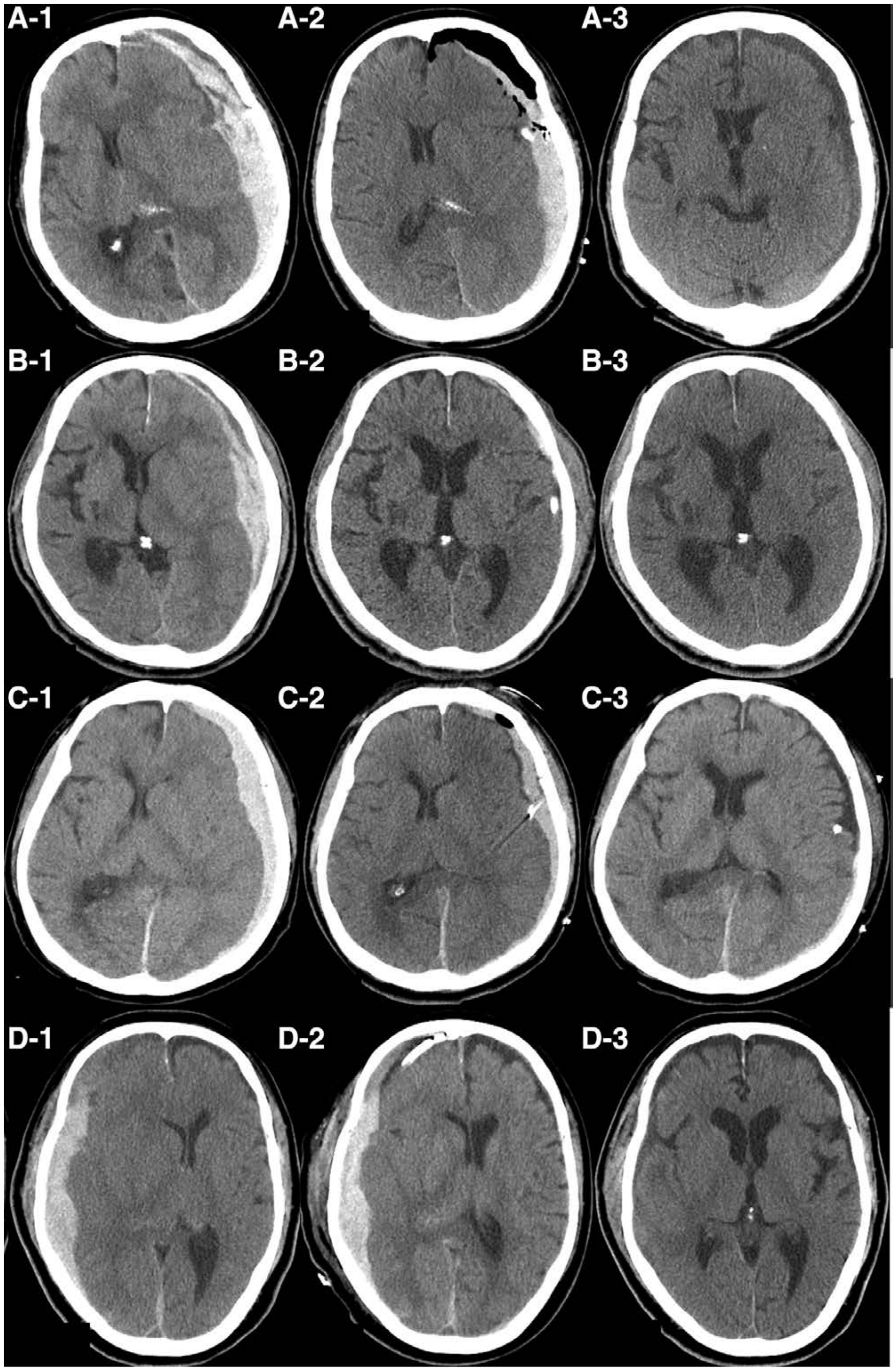

Figure 2. Serial non-contrast brain CT images of illustrative cases. Preoperative brain CT for the 1st case shows an ASDH in the left frontotemporoparietal convexity with 17 mm of MLS to the right (A-1). Postoperative brain CT shows that the aspiration catheter is settled inside the hematoma immediately after burr hole surgery (A-2). Follow-up brain CT shows improvement in the MLS after the aspiration procedure (A-3). Preoperative brain CT for the 2nd case shows an ASDH in the left frontotemporoparietal convexity with 10 mm of MLS to the right (B-1). Immediately after the drainage procedure, brain CT shows nearly total hematoma removal and correction of MLS (B-2). Follow-up brain CT shows nearly total hematoma removal with no re-bleeding at discharge (B-3). Preoperative brain CT for the 3rd case shows an ASDH in the left frontotemporoparietal convexity with 11 mm of MLS to the right (C-1). Brain CT immediately after surgery shows sufficient hematoma removal, and the aspiration catheter is placed in the subdural space (C-2). Follow-up brain CT shows removal of most of the hematoma and correction of MLS after the aspiration procedure (C-3). Preoperative brain CT for the 4th case shows an ASDH in the right frontotemporoparietal convexity with 10 mm of MLS to the left (D-1). Postoperative brain CT shows MLS correction, and the aspiration catheter is placed inside the hematoma immediately after burr hole surgery (D-2). Follow-up brain CT shows nearly total hematoma removal and MLS correction after an aspiration procedure (D-3). ASDH = acute subdural hemorrhage, CT = computed tomography, MLS = midline shifting.

Table 1

Clinical and radiologic characteristics.

No.	Age	Sex	Operation time (min)	Underlying Ds.	Antiplatelet or anti coagulation Tx.	GCS at Adm.	Max. hematoma thickness (mm)	MLS (mm) at Adm.	Hematoma Vol (ml) at Adm.	GCS after procedure	MLS (mm) after procedure	Hematoma evacuation (%)	Death	Cause of death	mRS at discharge
1	77	F	35	A-fib, s/p MVR	Warfarin	11	25	6	140.25	13	3	91.82	-		3
2	90	F	40	HTN, A-fib	Unknown	13	23	12	144.90	14	5	74.21	-		2
3	80	M	45	Old CVA	Clopidogrel	14	28	6	171.15	15	0	74.84	-		2
4	74	M	48	HTN, DM, ESRD, Old CVA, BPH, Glottic ca.	Aspirin, Clopidogrel	7+T	30	15	239.40	13	5	70.71	+	Sepsis d/t pneumonia	6
5	77	M	35	HTN, PSP, Unruptured Rt. ICA an.	Aspirin, Clopidogrel	5+T	22	17	216.32	13	6	77.08	-		3
6	90	F	50	HTN, DL, UAP, Old CVA	Aspirin, Clopidogrel	11	24	3	177.84	15	0	97.90	-		2
7	75	M	48	HTN, DM, A-fib, s/p MVR, ARF, Old CVA	Warfarin	13	20	10	175.95	14	5	87.00	-		2
8	73	M	30	HTN, DM, DL, BPH, Old CVA	Aspirin, Clopidogrel	14	17	10	117.09	15	0	92.68	-		2
9	80	M	40	A-fib, DL, Old CVA	Pradaxa	14	20	12	191.10	15	0	92.42	-		2
10	81	M	25	HTN, DM, Parkison's Ds., Dementia	Unknown	12	13	9	116.61	13	4	61.65	-		3
11	48	M	43	Esophageal Ca., LC	Unknown	5	13	11	109.40	13	6	98.94	-		3

Adm. = admission, A-fib = atrial fibrillation, ARF = acute renal failure, BPH = benign prostatic hyperplasia, Ca. = cancer, CVA = cerebrovascular accident, DL = dyslipidemia, DM = diabetes mellitus, Ds. = disease, ESRD = end stage renal disease, GCS = Glasgow coma scale, HTN = hypertension, ICA an. = internal carotid artery aneurysm, LC = liver cirrhosis, MLS = midline shifting, mRS = modified Rankin Scale, MVR = mitral valve replacement, PSP = progressive supranuclear palsy, Tx. = treatment, Vol. = volume.

Table 2

Distribution of patients' clinical and radiological characteristics.

Number of patients	11
Clinical summary	
Age, mean (range)	76.82 (48–90)
<80	5 (45.5%)
≥80	6 (54.5%)
Sex	
Male	3 (27.3%)
Female	8 (72.7%)
Cause of trauma	
Unknown	4 (36.4%)
Fall at ground level	5 (45.5%)
Fall from a height	2 (18.1%)
GCS at Adm., mean (range)	10.82 (5–14)
Anticoagulant therapy	3 (27.3%)
Antiplatelet therapy	5 (45.5%)
Initial radiographical findings, mean (range)	
SDH thickness (mm)	21.36 (13–30)
MLS (mm)	10.09 (3–17)
Clinical outcomes	
Survival	10 (90.9%)
Re-bleeding	0
MLS correction (mm), mean (range)	7.0 (3–12)
GCS improvement, mean (range)	3.09 (1–8)
mRS at discharge	
2	6 (54.5%)
3	4 (36.4%)
6	1 (9.1%)

GCS = Glasgow coma scale, MLS = midline shifting, mRS = = modified Rankin Scale, SDH = subdural hematoma.

The median age of the patients was 76.82 years, and all the patients had comorbidities, such as cardiac arrhythmia, previous cerebral infarction, liver cirrhosis, renal disease, and cancer.

Seven patients had a clear history of trauma, and in the remaining four patients, the exact injury mechanism was unknown, as they were found unconscious.

Eight of the 11 patients received anticoagulant or antiplatelet therapy. Six patients (54.6%) had a GCS score less than 13 at the time of admission. On the initial brain CT, the median SDH thickness was 21.36 mm, median MLS was 10.09 mm, and mean volume of the subdural hematoma was 163.64 mL. The mean evacuation rate of the subdural hematoma after drainage was 83.57%.

The clinical outcomes after the burr hole aspiration procedure are summarized in Table 2. One of the 11 patients died, and the cause of death was worsening aspiration pneumonia unrelated to the hematoma. There were no cases of rebleeding or operation-related infection during the aspiration procedure, and the median MLS correction after the procedure was 7.0 mm. The GCS score improvement averaged 3 points or more, and some patients improved by up to 8 points. When evaluating the patients' condition at discharge, six patients had an mRS score of 2 points, and four patients had an mRS score of 3 points. The percentage of favorable outcomes (mRS ≤ 2) at discharge was 54.5%. Ten patients were discharged without severe neurological symptoms. One patient showed improvement in radiological and neurological symptoms after the procedure but probably died from sepsis due to worsening pneumonia.

After the drainage procedure, neurological and radiological improvements were observed in all patients. GCS levels (mean ± SD) increased from 10.82 ± 3.52 preoperatively to 13.91 ± 0.94 points after the procedure. In addition, radiological findings (subdural hematoma volume and MLS) showed a decrease from 163.64 ± 42.31 mL and 10.09 ± 4.06 mm preoperatively to 16.58 ± 12.28 mL and 3.09 ± 2.59 mm, respectively, after the procedure. The final follow-up value using the data of ten patients, excluding the patient who died, was calculated using neurological and radiological findings 3 months after discharge. At the last follow-up, the neurological symptoms and radiological findings of ten patients showed improvement compared to the immediate postoperative values. None of the patients who survived reported worsening neurologic symptoms after surgery, and there was no surgery-related bleeding or rebleeding on radiology examinations (Table 3).

4. Discussion

Most ASDHs result from damage to the venous blood vessels on the surface of the brain. In this type of injury, direct brain injury is usually minor, and symptoms are primarily caused by local ischemia due to the mass effects of hematoma or local venous outflow impairment. It is widely known that the rapid resolution of cerebral ischemia by removing these hematomas can improve the prognosis of patients with ASDH.[5,8–10,12,21,22] For this reason, hematoma removal through a large craniotomy is recommended as the first-line treatment for patients who meet the guidelines for surgical treatment of ASDH (a hematoma of ≥10 mm in width or a MLS of ≥5 mm)[18,23]; this method has been traditionally performed in our hospital as well.

The burden of performing a large craniotomy under general anesthesia in patients with various underlying diseases or in patients receiving antithrombotic or anticoagulant treatment is perceived not only by the surgeon, but also by the patients' guardians.

The use of antithrombotic drugs, such as antiplatelet drugs or anticoagulants, is on the rise as the prevalence of ischemic stroke, usually seen in the elderly, is gradually increasing.[24] Antiplatelet agents and anticoagulants predispose patients to the development of acute SDH, and the elderly taking antithrombotic agents often visit the emergency center due to an acute subdural hematoma. The mortality rates in elderly patients with ASDH aged 60 years and older were 88% and 74%, respectively.[25,26] In the most recent papers published, the mortality rates of ASDH patients aged 80 years and older have been reported to be 28% and 33%, respectively.[27,28] Except for the 48-year-old patient (patient 11), the average age of the remaining ten patients was 79.7 years; of these patients, only one patient died (patient 4). In a study of the patient group treated with our procedure, the mortality rate of elderly patients with ASDH over 70 years of age was 10%. This is the lowest mortality rate among the papers published to date.

The "Trial of Decompressive Craniectomy for Traumatic Intracranial Hypertension" showed a more significant decrease in mortality in the group who underwent decompression craniectomy than in the group without decompression craniectomy. However, the prognosis of the surgical group was poor.[29] Therefore, while an early large decompressive craniectomy can reduce intracranial pressure and effectively reduce mortality, it cannot guarantee a good prognosis for patients after surgery. A large craniectomy is also associated with risk factors, such as postoperative hematoma due to a sizable surgical flap and infection due to a large surgical wound. In addition, even after the patient's survival, there is a disadvantage in that it requires cranioplasty under general anesthesia owing to the prevention of trephined syndrome or cosmetic problems. Patients with many underlying diseases or elderly patients have to endure surgery through general anesthesia again, and the complication rate increases when cranioplasty surgery is performed in patients with several underlying diseases.[30] In addition, a large craniotomy or craniectomy is a variation of the pterional approach and often shows temporal hollowing after surgery. According to the literature, this complication was observed in 87% to 100% of patients who underwent the pterional approach, which profoundly affects the patient's quality of life.[31–34] In clinical practice, decompression craniectomy has been performed in patients with severe brain edema or brain herniation.

Our method yields a good post-surgery prognosis and does not require additional surgery, such as cranioplasty; since the surgical site is also small, it does not result in any cosmetic problems after surgery.

Regarding functional outcome, three of the 11 survivors showed functional recovery among patients with ASDH aged 65 years and older in Howard et al's study,[26] and according to Younsi et al's study,[28] six out of 27 elderly patients showed favorable outcomes at discharge. According to our results, six out of 11 patients showed favorable outcomes (mRS ≤ 2) when they were discharged; the other four patients also had an mRS score of 3. Our procedure could improve the patients' quality of life in the future through excellent functional outcomes after treatment.

With the increasing number of elderly patients or comorbidities, minimally invasive surgical methods are being devised to prevent high mortality and morbidity, rather than resorting to aggressive surgical treatments, such as a large craniotomy. Recently, ASDH removal through minimally invasive surgery, such as endoscopic surgery, has been reported.[15,35–39] Miki et al[15] performed endoscopic surgery under general anesthesia in 26 patients with ASDH over 65 years of age, achieving a mean hematoma reduction rate of 90% and a favorable outcome of 69.2%. Huang et al[17] reported that seven patients over 65 years of age with ASDH achieved more than 70% of hematoma evacuation using twist drill craniotomy under local anesthesia. In patients with ASDH, the delay from injury to surgery is an essential factor influencing a patient's mortality rate.[5] Our surgical method was performed under local anesthesia. The average operation time was 39.9 minutes; thus, rapid surgical treatment was possible if there was no delay from patient onset to lesion diagnosis. In addition, since there is no need for preoperative examination for general anesthesia, staff preparation for anesthesia, and special mechanical instruments preparation such as endoscopes, the time from patient visit to operation can be minimized. Despite the fast and straightforward method, it shows excellent postoperative results with an efficient hematoma removal rate of 83.57%; therefore, it is expected to be an alternative or salvage treatment strategy.

The use of thrombolytics, such as rtPA, for the evacuation of hemorrhage, has been controversial because of the possibility of additional hemorrhage promotion or drug-induced side effects, such as neurotoxicity or inflammatory effects.

In a "Minimally-Invasive Surgery Plus rtPA for Intracerebral Hemorrhage Evacuation" II trial published by Mold et al,[40] it was reported that the use of rtPA in patients with intracranial hemorrhage affects hematoma removal and the consequent reduction of perihematomal edema. In patients with ASDH who manifest with MLS due to edema of the parenchyma adjacent

Table 3

Mean values of clinical and radiological improvement through the aspiration procedure.

Parameters	Preoperatively	After procedure	Last follow-up	*P*-value‡
GCS level	10.82 ± 3.52	13.91 ± 0.94	14.5 ± 0.7	.002* .005†
MLS	10.09 ± 4.06	3.09 ± 2.59	0	.000* .000†
Hematoma (mL)	163.64 ± 42.31	16.58 ± 12.28	5.10 ± 8.25	.000* .000†

Values are expressed as means ± standard deviation.
GCS = Glasgow coma scale, MLS = midline shifting.
*A comparison of mean values between the preoperative period and after procedure.
†A comparison of mean values between the after procedure and the last follow-up.
‡Paired *t* test was used for analysis.

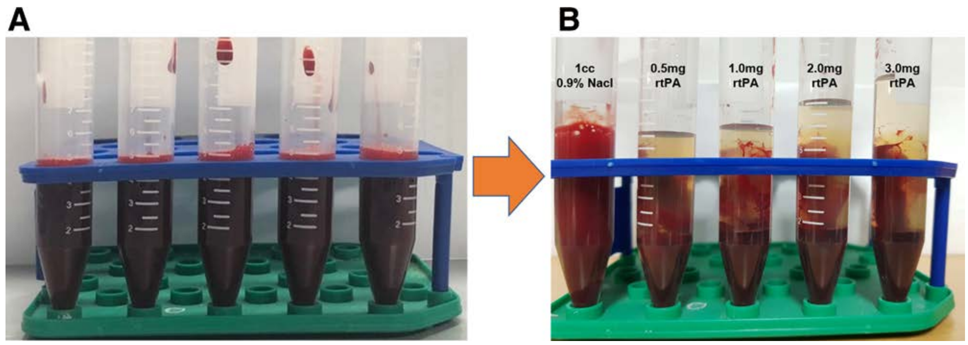

Figure 3. Experiment of the hematoma lysis with rtPA. (A) Five 5-cc pure human blood clot models in test tubes. (B) After mixing of different volumes of rtPA in 5 tubes; 1 h later, the degree of hematoma lysis is confirmed in each tube. rtPA = recombinant tissue plasminogen activator.

to the hematoma and the amount of hematoma, the use of rtPA is expected to lead to faster improvement if the use of rtPA can reduce hematoma lysis and edema around the hematoma. In patients with parenchymal bleeding, the loss of the mass effect may increase bleeding. Therefore, patients with ASDH with parenchymal hemorrhage will be excluded from our treatment strategy.

Various factors, such as the dose and timing of rtPA injection, and the timing of maximal hematoma lysis remain unknown. Keric et al[41] used an in vitro model to optimize the amount of rtPA used by comparing the amount of hematoma removal following the use of various doses of rtPA. Based on these studies, we planned an in vitro test to obtain an appropriate dose of rtPA for use in our hematoma aspiration procedure. We prepared five blood clot models with the same amount (5 cc) of human blood (Fig. 3A). Hematoma lysis was visually compared 1 hour after adding 1 cc of 0.9% normal saline and 0.5, 1.0, 2.0, and 3.0 mg of rtPA to each test tube (Fig. 3B). More hematoma lysis was observed in the test tube to which rtPA (1.0 mg) was added than the test tube with 0.5 mg rtPA and no more hematoma lysis was observed in the other test tube to which rtPA was added at a dose higher than 1.0 mg (Fig. 3B). Based on these experimental results and papers, we determined that 1.0 mg of rtPA was the optimal dose for hematoma-lysis.

Finally, our treatment plan is challenging to apply to all patients with ASDH. In particular, if a "Swirl sign" and hypodensity in extra-axial hemorrhages are observed on the patient's brain CT, our method should not be used because it is difficult to rule out active bleeding. If a simple decompression is performed without proper direct hemostasis for patients with acute active bleeding, promotion of bleeding occurs. Since this can lead to the patient's death, the indications for treatment should be carefully considered. Therefore, patients with ASDH with a swirl sign are the absolute exclusion criteria for our treatment.

All 11 patients presented with indications for hematoma evacuation surgery, and we explained traditional craniotomy requiring general anesthesia to all caregivers in detail; however, the carers refused this treatment method. Our treatment has not yet been established, there is a risk of increased hemorrhage, and the bleeding focus cannot be visualized directly. Therefore, our method was presented as an alternative treatment only when a detailed explanation of the traditional large craniotomy was provided and the guardian's intention to refuse it was present.

There were several limitations to our study:

1. We performed a retrospective study that was potentially subject to bias.
2. Our study had a small sample size; therefore, it is impossible to establish a clear indication of which patients will undergo the procedure with better results than with traditional treatments. Additionally, it is difficult to generalize that rtPA is safe for bleeding complications in all patients with ASDH.
3. The evaluation of prognosis after discharge was limited owing to the lack of follow-up data after the patients' discharge.
4. Since this study was conducted in a single institution, external validation is required by collecting data from other centers.

Further, a prospective clinical trial with a group of patients using our technology and a group who underwent twist drill/burr hole craniotomy or large craniotomy is needed. In the future, we hope the following prospective study will enable us to establish more accurate indications for our technique and evaluate the procedure's prognosis.

5. Conclusion

Owing to the aging of the population, the number of elderly patients with head trauma has increased, and among these patients, patients with ASDH who require emergency surgery are also growing in number. In keeping pace with the changing times, surgeons cannot insist on treatment with traditional surgical methods.

We cannot ensure that our treatment strategies guarantee superior treatment outcomes to standard craniotomy and hematoma removal. However, it can be a reliable and less invasive treatment and an alternative treatment option for patients at high risk of complications due to general anesthesia or patients who are reluctant to undergo a large craniotomy due to a high bleeding tendency.

Author contributions

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