Comparison of Outcomes Following Neuronavigation-Assisted Aspiration and Thrombolysis Using Single and Multiple Catheter Insertion for Moderate-Volume Supratentorial Spontaneous Intracerebral Hemorrhage: A Single-Center Retrospective Study of 102 Patients

In-Hyoung Lee
Jong-II Choi

Background: This retrospective study from a single center aimed to investigate 102 patients with isolated moderate-volume (30-60 mL) supratentorial spontaneous intracerebral hemorrhage (sICH) treated with neuronavigation-assisted aspiration and thrombolysis to compare outcomes using single and multiple catheter insertion.

Material/Methods: We retrospectively enrolled 102 patients (58 single-catheter insertion recipients and 44 multi-catheter insertion recipients) diagnosed with isolated moderate-volume supratentorial sICH who underwent neuronavigation-assisted aspiration and thrombolysis surgery in a single center between March 2017 and December 2019. The impact of multi-catheter insertion on the radiologic and clinical outcomes and complications were compared with those of single-catheter insertion.

Results: The baseline characteristics, clinical status, and outcomes of both groups were not significantly different, except for the number of inserted catheters and surgical time. The single-catheter group had a significantly shorter surgical time than the multi-catheter group (39.52±8.76 min vs 61.39±16.6 min; \(P<0.001\)). The surgery-related complication catheter tract hemorrhage (CTH) occurred significantly more frequently in the multi-catheter group than in the single-catheter group (8.6% vs 27.3%; \(P=0.019\)). In the regression analysis, international normalized ratio prolongation and multi-catheter insertion were independent risk factors for CTH.

Conclusions: Single-catheter insertion is not inferior to multi-catheter insertion for isolated moderate-volume (30-60 mL) supratentorial sICH in terms of radiologic and clinical outcomes and significantly shortened the surgical time and reduced the incidence of CTH.

Keywords: Catheters • Cerebral Hemorrhage • Neuronavigation • Tissue Plasminogen Activator • Treatment Outcome

Full-text PDF: https://www.medscimonit.com/abstract/index/idArt/934935

Authors' Contribution:
- Study Design A
- Data Collection B
- Statistical Analysis C
- Data Interpretation D
- Manuscript Preparation E
- Literature Search F
- Funds Collection G

Corresponding Author: Jong-II Choi, e-mail: thlhhd@korea.ac.kr

Financial support: This study was supported in part by the Hallym University Research Fund and the Korea University Research Fund

Conflict of interest: None declared
Background

Spontaneous intracerebral hemorrhage (sICH) accounts for approximately 10-15% of all cases of stroke, with a high mortality rate of approximately 40%, and can cause serious neurologic deficits [1,2]. Currently, sICH management mainly consists of conservative medical treatment and surgical intervention [3]. In general, conservative care is usually performed in patients with small hematomas and absence of neurologic deficits, while surgical evacuation tends to be used in those with large-volume hemorrhage and progressive neurological deterioration [4].

Conventional open craniotomy is generally preferred in treating large hematomas because it allows a wide surgical field, resulting in a dramatic reduction of mass effects [5,6]. However, a recent well-performed trial of craniotomy for supratentorial sICH failed to prove significant benefits in functional outcomes [7].

In recent years, new surgical techniques, collectively referred to as minimally-invasive surgery (MIS), such as computed tomography (CT)-guided stereotactic aspiration, neuronavigation-assisted aspiration, and endoscopic hematoma evacuation, have emerged as an alternative approach for treating sICH by sparing the brain parenchyma from secondary damage induced by surgical procedures; they have shown satisfactory outcomes, unlike open craniotomy [8-10].

In detail, these techniques showed great potential for the treatment of sICH and replacement of craniotomy for patients with moderate hematoma volume (30-50 mL) and mildly impaired consciousness [11,12]. Among them, MIS plus recombinant tissue plasminogen activator (tPA) for intracerebral hemorrhage (ICH) evacuation (MISTIE) was recently completed in a phase III trial, and its safety was verified [13]. Furthermore, it was shown to have benefits in mortality, with no significant increase in severe disability. The amount of hematoma to be removed that could have functional benefits was specified and presented in a recent clinical trial [14].

However, there has been no study on the classification according to the number of inserted catheters required in relation to the hematoma burden. When performing neuronavigation-assisted aspiration and thrombolysis surgery for sICH, neurosurgeons may be unconsciously inclined to use multiple catheters to evacuate more hematoma or be concerned regarding catheter obstruction. The present study was conducted on the basis of the assumption that multi-catheter insertion may not be necessary for isolated moderate-volume (30-60 mL) hematomas. By assessing and comparing the surgical impact of single and multiple catheter insertions on hematoma evacuation, functional outcomes, and associated complications, we attempted to determine the proper number of catheters inserted for isolated moderate-volume supratentorial sICH. Therefore, this retrospective study from a single center investigated 102 patients with isolated moderate-volume supratentorial sICH treated with neuronavigation-assisted aspiration and thrombolysis to compare outcomes using single and multiple catheter insertion.

Material and Methods

Study Design and Patient Enrollment

After obtaining approval from our Institutional Review Board (IRB No. HKS 2020-04-023), we conducted this prospective study based on electronic medical records and imaging data of 160 patients who underwent neuronavigation-assisted aspiration with thrombolysis surgery in the Department of Neurosurgery at our institution after being diagnosed with moderate-volume ICH (30-60 mL) on CT scans from March 2017 to December 2019.

The exclusion criteria were as follows: (1) hemorrhage induced by clear pre-existing causes, such as arteriovenous malformation, intracranial tumor bleeding, moyamoya disease, ruptured intracranial aneurysm, hemorrhagic transformation of cerebral infarction, or trauma; (2) hemorrhage originating from the infratentorial region or brainstem; (3) hematoma extension into the ventricles on CT scans derived from ventricular rupture, especially thalamic ICH; (4) loss to follow-up; and (5) brain CT follow-up not meeting the required criteria.

The patient selection process is depicted schematically in Figure 1.

Data Collection and Clinical Outcome Assessment

The following clinical information of the patients was collected: age and sex; initial systolic blood pressure measured at the emergency room; coagulation time in the blood test; presence of pre-existing diseases, such as history of hypertension, diabetes mellitus, chronic kidney disease, cardiovascular disease, liver disease, and stroke; history of antiplatelet or anticoagulant use; preoperative consciousness level (Glasgow Coma Scale); surgical time; number of inserted catheters; and catheter duration.

The clinical outcomes included the Intensive Care Unit stay duration, in-hospital mortality, and modified Rankin scale (mRS) score at discharge and after 3 and 6 months. An mRS score at 6 months of 0-3 was considered to indicate a favorable outcome. Pneumonia, urinary tract infection, and venous thromboembolism during the postoperative period were defined as non-surgical complications.
Neuroradiologic Assessment

The following radiologic data of the patients were obtained using INFINITT PACS M6 (INFINITT Healthcare, Seoul, Korea): ICH location, preoperative ICH volume, immediate postoperative ICH volume, postoperative day 2 ICH volume, and ICH volume at the endpoint of treatment (EOT) defined as the time of catheter removal. The proportion of patients who achieved the target values was identified on the basis of ICH removal to ≤15 mL (or of ≥70%) at the EOT. In addition, surgery-related complications, such as postoperative re-bleeding, catheter tract hemorrhage (CTH), and intracranial infection, were also evaluated.

All examinations included in this study were performed as part of standard clinical care using a dual-source 64-slice CT scanner (SOMATOM Definition Flash; Siemens Healthcare Sector, Forchheim, Germany), including non-contrast CT (120 kV, 380 mA, and contiguous 5-mm axial slices) and CT angiography to evaluate vascular pathologies.

The ABC/2 formula was used to estimate the hematoma volume on CT scans, where A is the maximal transverse diameter on the maximal hematoma slice, B is the largest diameter perpendicular to A, and C is the number of CT slices in which hematoma is visibly multiplied by the slice thickness in centimeters [15].
Postoperative re-bleeding was defined as a hematoma volume of any CT scan after aspiration that is larger than that of the preoperative CT scan or any previous CT scan after aspiration or a <5-mL difference between the preoperative and immediate postoperative CT hematoma volume measurements [16].

CTH was defined as newly identified bleeding that was visually observed, which is usually easily recognized in the catheterized tract on the CT scan taken after surgery (Figure 2). All imaging data were analyzed and evaluated independently by 2 neurosurgeons and 1 neuro-radiologist blinded to clinical information.

**Surgical Planning**

All surgeries were performed using the StealthStation® S7 AxiEM™ navigation system (Medtronic, Minneapolis, MN, USA).

Preoperative 1-mm slice high-resolution CT was performed to determine the entry point, optimal trajectory, and most efficient target point. After tracer registration (surface matching), the entry point, usually Kocher's point or that above the subcortical hematoma, was set up, and 1 or multiple target points were established. The number of the catheters to be inserted was determined by preference, based on the clinical experience of each of the 3 attending neurosurgeons at our institution.

The entry point and catheter trajectory were set in consideration of the shortest path that can minimize secondary injury to the eloquent brain cortex and blood vessels.

In the case of single-catheter insertion, the target points were located in the dependent portion and center of the hematoma to maximize the area exposed to the catheter and thrombolytic
agent. In the case of 2-catheter insertion, the long axis of the hematoma in the axial CT plane was evenly divided, and the target points were set at each middle point. With this method, the target points were located in the lower 2 quadrants when the longest transverse axis and perpendicular line to it were drawn in the sagittal CT plane. In the case of 3-catheter insertion, the target point was additionally set between the target points of the 2 catheters described above. Additionally, to prevent brain tissue injury due to invasion of the lower boundary of the hematoma caused by navigation error, we set the target point at approximately 5 mm superficial from the lower margin of the hematoma (Figure 3).

### Intraoperative Procedures and Postoperative Strategies

The subsequent surgical procedure followed a generally accepted method. External ventricular drainage (EVD) tubes of 10.5 French (Yushin Medical, Seoul, Korea) were inserted into the target point, with assistance from the navigation stylet. The liquefied hematoma was manually aspirated with low tension using a 10-mL syringe to target confirmation and diminish the mass effect, until resistance was observed.

Postoperative CT was performed to confirm that the catheters were properly located in the hematoma and to measure the amount of residual hematoma. When the catheter location required adjustment, appropriate withdrawal was performed. Thereafter, intra-clot administration of tPA (Actilyse®, Boehringer Ingelheim, Seoul, Korea) was performed. The dose regimen for tPA was based on the MISTIE clinical trial [17]. However, tPA was not used when the amount of hematoma volume immediately after surgery was less than 10 mL or when catheter malposition or re-bleeding occurred.

When the residual hematoma volume was less than 10 mL or significant re-bleeding occurred on the follow-up CT scans obtained 2 days after surgery, tPA administration was stopped and the hematoma naturally drained. When the ICH volume did not increase, and the amount of drainage significantly decreased, the catheters were removed. We termed these 2 prerequisites for catheter removal as hematoma stability. The postoperative strategies are outlined in Figure 4. Figure 5 shows an example of the treatment process for patients in our cohort following this postoperative strategy.

The medical management of these patients followed the American Heart Recommendations for the treatment of sICH [18], including correction of coagulopathy, control of blood pressure and glucose, and prevention of medical complications. Additionally, in accordance with our institutional routine practice, patients received prophylactic antibiotics until 2 days after the surgical procedure, and no prophylactic antiepileptic drugs were administered.

### Statistical Analysis

The data collected in this study were analyzed using the SPSS 27.0 software (SPSS, Inc., Chicago, IL, USA). Continuous variables

---

**Figure 4. Postoperative strategies and thrombolysis algorithm for moderate-volume (30-60 mL) supratentorial spontaneous intracerebral hemorrhage (sICH) in our institution.** ICH – intracerebral hemorrhage; CT – computed tomography; tPA – tissue plasminogen activator. The figure was created using Microsoft PowerPoint 2010 (Microsoft, Redmond, WA, USA).
Figure 5. Brain computed tomography (CT) scans of a successful case of hematoma removal using single-catheter insertion in neuronavigation-assisted stereotactic aspiration and thrombolysis surgery. (A) Spontaneous intracerebral hemorrhage of 15 mL in the right basal ganglia with the spot sign on the initial CT angiography scan. (B) Marked volume enlargement on the follow-up CT scan (57 mL). (C) Remarkable decrease in the hematoma volume after single-catheter insertion on the postoperative CT scan. (D) Approximately 80% of the hematoma had been removed as a result of tissue plasminogen activator administration on the follow-up CT scan 2 days after surgery. The figure was created by the author from the PACS database of our institution using FastStone capture 9.0 (FastStone Soft).
were expressed as means±standard deviations (ranges) and categorical variables as numbers of patients (percentages). The t test and Pearson’s chi-squared test were used to compare the baseline characteristics and outcomes between the 2 groups. Multivariate logistic regression analysis was used to evaluate the risk factors for CTH. Adjusted odds ratios (ORs) and 95% confidence intervals (CIs) were also calculated. For all analyses, a P value of <0.05 was considered statistically significant.

Results

Patient Characteristics

A total of 58 patients were excluded from the study. Thus, a total of 102 patients with isolated moderate-volume (30-60 mL) supratentorial sICH who underwent neuronavigation-assisted aspiration with thrombolysis surgery were enrolled in this study: 58 patients who underwent single-catheter insertion and 44 patients who underwent multi-catheter insertion.

There were no significant differences in demographics, severity, and clinical features between the 2 groups, except for the number of inserted catheters and surgical time. The average number of catheters inserted in the multi-catheter group was 2.27. The single-catheter group had significantly shorter surgical time than the multi-catheter group (39.52±8.76 min vs 61.39±16.6 min; P<0.001) (Table 1).

Clinical Outcomes and Complications

Table 2 shows the differences in the clinical outcomes and complications between the single-catheter and multi-catheter groups. Irrespective of the group, the clinical status improved in terms of the mRS score from the time of discharge and up to the 6-month postoperative period, with no significant differences in the clinical outcomes between the 2 groups.

Table 1. Patient characteristics.

|                      | Single-catheter group (n=58) | Multi-catheter group (n=44) | p-value |
|----------------------|-----------------------------|-----------------------------|---------|
| Male sex             | 36 (62.1)                   | 27 (61.4)                   | 0.942   |
| Age (y)              | 64.3±11.3                   | 62.6±10.9                   | 0.433   |
| Initial SBP (mmHg)   | 168.6±25.1                  | 171.7±29.4                  | 0.566   |
| PT (INR)             | 1.17±0.3                    | 1.1±0.2                     | 0.207   |
| Hypertension         | 12 (20.7)                   | 10 (22.7)                   | 0.813   |
| Diabetes mellitus    | 11 (18.9)                   | 8 (18.2)                    | 0.921   |
| Chronic kidney disease | 8 (13.8)                  | 7 (12.1)                    | 0.876   |
| Liver disease        | 7 (12.1)                    | 4 (9.1)                     | 0.635   |
| History of stroke    | 6 (10.3)                    | 6 (13.6)                    | 0.614   |
| Antiplatelet use     | 18 (31)                     | 12 (27)                     | 0.680   |
| Anticoagulant use    | 7 (12.1)                    | 4 (9.1)                     | 0.631   |
| Preoperative GCS score | 9.5±1.6                    | 9.4±1.1                     | 0.757   |
| Preoperative ICH volume (mL) | 46.1±9.6                   | 48.7±9.5                    | 0.166   |
| ICH location         |                             |                             |         |
| Deep                 | 43 (74.1)                   | 34 (77.3)                   | 0.852   |
| Lobar                | 15 (25.9)                   | 10 (22.7)                   |         |
| No. of inserted catheters (ea) | 1                        | 2.27±0.45                   | <0.001* |
| Surgical time (min)  | 39.52±8.76                  | 61.39±16.6                  | <0.001* |
| Catheter duration (d) | 5.09±1.01                  | 5.11±1.26                   | 0.906   |

Data are presented as means±standard deviations (ranges) or numbers (%). * Statistical significance. SBP – systolic blood pressure; PT – prothrombin time; INR – international normalized ratio; GCS – Glasgow Coma Scale; ICH – intracerebral hemorrhage; No – number.
The incidence of CTH was significantly higher in the multi-catheter group than in the single-catheter group (8.6% vs 27.3%; \(P=0.019\)). Multivariate analyses revealed that prothrombin time (PT) (international normalized ratio [INR]) prolongation and multi-catheter insertion were the independent risk factors associated with CTH (OR=4.386, 95% CI=1.202-16.01, \(P=0.025\); OR=5.115, 95% CI=1.467-17.836, \(P=0.01\), respectively) (Table 3).

Radiologic Outcomes

The mean preoperative and immediate postoperative ICH volumes were 47.2±9.5 mL and 28.3±8.9 mL, respectively. As a result, the mean immediate postoperative ICH clearance rate was approximately 40%. The differences between the 2 groups, including the values on postoperative day 2 and at the EOT, are summarized in Table 4 and Figure 6.

| Factors                        | Odds ratio (95% confidence interval) | \(p\)-value |
|--------------------------------|--------------------------------------|-------------|
| Antiplatelets                  | 1.069 (0.278-4.114)                  | 0.923       |
| Anticoagulants                 | 1.926 (0.369-10.061)                 | 0.437       |
| PT (INR) prolongation (>1.3)   | 4.386 (1.202-16.01)                  | 0.025*      |
| Multi-catheter insertion       | 5.115 (1.467-17.836)                 | 0.01*       |

* Statistical significance. PT – prothrombin time; INR – international normalized ratio.

Discussion

Based on our study findings, it was concluded that the superiority of multi-catheter insertion to single-catheter insertion was not significant in all aspects: hematoma removal,
prognosis, and in-hospital mortality. Meanwhile, there was significant inferiority of multi-catheter insertion to single-catheter insertion in terms of the incidence of CTH and surgical time. Although the difference in the absolute value of the surgical time was approximately 20 min, when calculated as a percentage, it corresponds to more than 50%. Thus, if single-catheter insertion is selected, it is possible to shorten the surgical time and consequently start the postoperative management at an earlier time.

Many reports reaffirmed the widely held belief that with greater hematoma size and volume, less functional and favorable outcomes are obtained [19-21]. In the MISTIE III trial, hematoma aspiration with thrombolysis achieving approximately 70% evacuation of the initial hematoma and clot size reduction to ≤15 mL was related to decreased mortality and no significant increase in severe disability 1 year later (mRS score of 5) [13]. Further, a surgical trial reported that specific thresholds for reduction of ICH volume were correlated with improved mortality and functional outcomes [14].

In that study, the threshold achievement rate was approximately 60%, and in our study it was 72.5%, both of which were satisfactory results. The threshold achievement rate of the single-catheter group was comparable to that of the multi-catheter group (70.7% vs 75%; P=0.633). In the MISTIE II trial,

| Table 4. Comparison of the radiologic outcomes. |
|-----------------------------------------------|
| Radiologic outcomes | Single-catheter group | Multi-catheter group | p-value |
| Preoperative ICH volume (mL) | 46.1±9.6 | 48.7±9.5 | 0.166 |
| Immediate postoperative ICH volume (mL) | 28.1±8.1 | 28.6±9.9 | 0.752 |
| Immediate postoperative ICH CR (%) | 38.9±12.8 | 40.4±19.3 | 0.649 |
| Postoperative day 2 ICH volume (mL) | 18.6±7.8 | 18.2±7.8 | 0.815 |
| Postoperative day 2 ICH CR (%) | 60±12.9 | 62.3±15.8 | 0.424 |
| EOT ICH volume (mL) | 12.7±5.7 | 12.7±5.6 | 0.978 |
| EOT ICH CR (%) | 72.7±10.1 | 73.7±11.5 | 0.630 |
| Daily average ICH removal volume (mL) | 6.9±2.6 | 7.5±2.9 | 0.290 |
| ICH removal to ≤15 mL (or of ≥70%) | 41 (70.7%) | 33 (75%) | 0.633 |

Data are presented as means±standard deviations (ranges) or numbers (%). ICH – intracerebral hemorrhage; CR – clearance rate; EOT – endpoint of treatment.

Figure 6. Hematoma volume (A) and chronological change in the hematoma clearance rate (B) at various time points in the single and multiple catheter groups. (A) There were no significant differences between the single (light blue bar) and multiple catheter groups (deep blue bar) in hematoma volume (mL) through all chronologies. (B) There were no significant differences between the single (light blue line) and multiple catheter groups (deep blue line) in hematoma clearance rate (%) through all chronologies. T0 – the time at which preoperative computed tomography (CT) scan was carried out; T1 – the time at which immediate postoperative CT scan was taken; T2 – postoperative 2 days; EOT – endpoint of treatment (the time of catheter removal); CR – clearance rate; ns – no significant difference between the 2 values. The figure was created with GraphPad Prism 9.3.0 (GraphPad Software, Inc., San Diego, CA, USA).
in which the ICH volume was somewhat similar to that in our study (48.2±19.6 mL), the rate of achievement of the favorable outcome (mRS score of <4) at 6 months was approximately 33%; in our study, the rate was higher (49%) [22]. Similar to the threshold achievement rate, single-catheter insertion was not inferior to multi-catheter insertion in terms of the achievement of the favorable outcome (50% vs 47.7%; $P=0.822$).

Regarding the mortality rate in the above-mentioned study, the mortality benefit was achieved at ≤30 mL EOT ICH volume or >53% volume reduction. Several recent studies reported that the in-hospital mortality rate of sICH is approximately 20% [23,24]. In our study, the in-hospital mortality rate was 10.8%, which was lower than that in the above-mentioned studies; this is because our study only focused on moderate-volume sICH. In our study, the amount of residual hematoma and volume reduction rate on postoperative day 2 in both groups already exceeded the mortality benefit threshold, with no significant difference (18.6 mL vs 18.2 mL, $P=0.815$; 60% vs 62.3%, $P=0.424$).

In summary, the surgical goal of obtaining favorable outcomes and mortality benefits suggested by the serial MISTIE-based trial in this study wherein neuronavigation-assisted aspiration with thrombolysis surgery was performed was sufficiently achieved in both groups, with no significant differences; it was especially meaningful that the surgical goal achievement rate exceeded the threshold value even with only single-catheter insertion.

Postoperative re-bleeding is one of the most fatal complications of sICH, occurring in approximately 5% of patients who underwent stereotactic aspiration [25,26]. In our cohort series of 102 consecutive patients, re-bleeding occurred in 5 patients (4.9%), which is comparable to that in other studies. Unfortunately, there have been no reports comparing the incidence of re-bleeding according to the number of inserted catheters in stereotactic aspiration for sICH.

CTH is a relatively common post-surgical complication, and to the best of our knowledge, most studies were conducted only on CTH that occurred after EVD. A previous study has reported a rate of hemorrhagic complications after EVD tube placement of 8.4% [27]. Similarly, an overall bleeding risk rate of 9.4% was associated with ventricular catheterization [28]. Another study reported a higher rate of 19.7% [29]. In this study, the overall incidence of CTH was 16.7%, and 12 patients received three-catheter insertion in the multi-catheter group; thus, the total number of inserted catheters was 100. Therefore, when recalculated, the CTH occurrence rate per catheter was 10.7%, which is not different from that in other studies.

Several studies have analyzed the risk factors of CTH in EVD. CTH appears to be associated with several potentially modifiable risk factors, including prior use of an antiplatelet agent, the accuracy of catheter placement [30], high PT, and prolonged INR [31]. Similarly, the known independent risk factors of CTH were also well reflected in our study: PT (INR) prolongation and multi-catheter insertion. A low accuracy of catheter placement implies an increased number of catheter positioning attempts, which can be interpreted similarly with the multi-catheter insertion in this study. In other words, the significantly higher occurrence of CTH in the multi-catheter group than in the single-catheter group originated from an increase in the number of catheters passed through the brain tissue during the surgical procedures.

There have been many studies conducted on the accuracy of neuronavigation that tested the differences in the stereotactic accuracy of various types of equipment and found similarly excellent accuracy among them [32]. When the standardized registration method was used, neuronavigation inaccuracies between 1.8 and 5 mm have been achieved, and when the ongoing loss of accuracy was investigated, the initial error was found to be 2.9 mm on average [33]. In another study, the mean errors after the imaging phase were reported to be approximately 1.11±0.42 mm [34].

In our study, there were a total of 6 cases (5.9%) where the catheter was located at the border of the hematoma on the postoperative CT scan owing to intraoperative hematoma aspiration. In these cases, catheter position adjustment was performed without any particular problems before the administration of tPA. One study reported a catheter malposition rate of 3.2% when neuronavigation was used [35]; however, strictly, no catheter malposition occurred in our study (the catheter was inserted far from the hematoma), although we did not specifically measure the navigation accuracy. This is because the neuronavigation system can identify the location of the navigation stylet and hematoma in real time.

With use of neuronavigation in stereotactic hematoma aspiration it is thought that there may be cases where multi-catheter insertions are performed owing to concerns on catheter malposition; however, because of the above-mentioned high accuracy and real-time monitoring capability, we thought that hematoma removal with single-catheter insertion would be sufficient if the neurosurgeon is proficient enough.

Although there are no comparable reports according to the number of inserted catheters in surgery for sICH that were similar to our study, several reports related to EVD were found. In cases of intraventricular hemorrhage (IVH), there have been several studies comparing the efficacy of single catheters and dual catheters [36,37]. Dual catheters may be useful in the management of very large-volume IVH. Since the cerebrospinal fluid (CSF) is continuously generated, they can be considered useful in terms of reducing the overall volume burden. In IVH treatment, more rapid removal of more blood clots may have
clinical benefits because the risk of hydrocephalus is increased if the duration of exposure to clotted bloody CSF is prolonged. However, in moderate-volume supratentorial sICH, except for some cases of thalamic sICH that extends to the lateral ventricle, a similar principle cannot be applied, since the hematoma cavity is usually isolated and volume-limited. In other words, the results of the present study cannot be applied equally to patients with hematoma extended into the ventricle.

In terms of radiologic outcomes, there was no significant difference in the daily average hematoma removal amount regardless of the number of inserted catheter (6.9±2.6 mL vs 7.5±2.9 mL; P=0.290). In cases where multi-catheter insertion was performed for isolated moderate-volume supratentorial sICH, unless the shape of the hematoma was bizarre, a spherical shape was generally observed; thus, the distance between the 2 inserted catheters was relatively close. Therefore, it is considered that a single catheter can sufficiently cover the hematoma burden, under the assumption that single-catheter insertion is performed at the exact location as planned.

Limitations

This study had several limitations. First, this was a retrospective, single-center study with a small number of enrolled patients.

References:

1. Gokhale S, Caplan LR, James ML. Sex differences in incidence, pathophysiology, and outcome of primary intracerebral hemorrhage. Stroke. 2015;46(3):886-92
2. van Asch CJ, Luitse MJ, Rinkel GJ, et al. Incidence, case fatality, and functional outcome of intracerebral haemorrhage over time, according to age, sex, and ethnic origin: A systematic review and meta-analysis. Lancet Neurol. 2010;9(2):167-76
3. Morgenstern LB, Hemphill JC 3rd, Anderson C, et al. Guidelines for the management of spontaneous intracerebral hemorrhage: A guideline for healthcare professionals from the American Heart Association/American Stroke Association. Stroke. 2010;41(9):2108-29
4. Kelly ML, Sulmasy DP, Weil RJ. Spontaneous intracerebral hemorrhage and the challenge of surgical decision making: A review. Neurosurg Focus. 2013;34(5):E1
5. Zhou H, Zhang Y, Liu L, et al. A prospective controlled study: Minimally invasive stereotactic puncture therapy versus conventional craniotomy in the treatment of acute intracerebral hemorrhage. BMC Neurol. 2011;11:76
6. Shi J, Cai Z, Han W, et al. Stereotactic catheter drainage versus conventional craniotomy for severe spontaneous intracerebral hemorrhage in the basal ganglia. Cell Transplant. 2019;28(8):1025-32
7. Mendelow AD, Gregson BA, Rowan EN, et al. Early surgery versus initial conservative treatment in patients with spontaneous supratentorial lobar intracerebral haematomas (STICH II): A randomised trial. Lancet. 2013;382(9890):397-408
8. Nam TM, Kim YZ. A meta-analysis for evaluating efficacy of neuroendoscopic surgery versus craniotomy for supratentorial hypertensive intracerebral hemorrhage. J Cerebrovasc Endovasc Neurosurg. 2019;21(1):11-17
9. Tang Y, Yin F, Fu D, et al. Efficacy and safety of minimal invasive surgery treatment in hypertensive intracerebral hemorrhage: A systematic review and meta-analysis. BMC Neurol. 2018;18(1):136
10. Zhou X, Chen J, Li Q, et al. Minimally invasive surgery for spontaneous supratentorial intracerebral hemorrhage: A meta-analysis of randomized controlled trials. Stroke. 2012;43(1):2923-30
11. Ramanan M, Shankar A. Minimally invasive surgery for primary supratentorial intracerebral haemorrhage. J Clin Neurosci. 2013;20(12):1650-58
12. Wang WZ, Jiang B, Liu HM, et al. Minimally invasive craniopuncture therapy vs. conservative treatment for spontaneous intracerebral hemorrhage: Results from a randomized clinical trial in China. Int J Stroke. 2009;4(1):11-16
13. Hanley DF, Thompson RE, Rosenblum M, et al. Efficacy and safety of minimally invasive surgery with thrombolyis in intracerebral haemorrhage evacuation (MISTIE III): A randomised, controlled, open-label, blinded endpoint phase 3 trial. Lancet. 2019;393(10175):1021-32
14. Awad IA, Polster SP, Carrion-Penagos J, et al. Surgical performance determines functional outcome benefit in the minimally-invasive surgery plus recombinant tissue plasminogen activator for intracerebral hemorrhage evacuation (MISTIE) procedure. Neurosurgery. 2019;84(6):1157-68
15. Kothari RU, Brott T, Broderick JP, et al. The ABCs of measuring intracerebral hemorrhage volumes. Stroke. 1996;27(8):1304-5
16. Morgenstern L, Demchuk A, Kim D, Frankowski R, Grotta J. Rebleeding leads to poor outcome in ultra-early craniotomy for intracerebral hemorrhage. Neurology. 2001;56(10):1294-99
17. Morgan T, Zuccarello M, Narayan R, et al. Preliminary findings of the minimally invasive surgery plus rtPA for intracerebral hemorrhage evacuation (MISTIE) clinical trial. Acta Neurochir Suppl. 2008;105:147-51
18. Hemphill JC 3rd, Greenberg SM, Anderson CS, et al. Guidelines for the management of spontaneous intracerebral hemorrhage: A guideline for healthcare professionals from the American Heart Association/American Stroke Association. Stroke. 2015;46(7):2032-60
19. Broderick JP, Brott TG, Duldner JE, et al. Volume of intracerebral hemorrhage. A powerful and easy-to-use predictor of 30-day mortality. Stroke. 1993;24(7):987-93
20. Lo Presti MA, Bruce SS, Camacho E, et al. Hematoma volume as the major determinant of outcomes after intracerebral hemorrhage. J Neurol Sci. 2014;345(1-2):3-7

Conclusions

In conclusion, the comprehensive comparison of radiologic and clinical outcomes showed that single-catheter insertion was not inferior to multi-catheter insertion. Instead, single-catheter insertion was advantageous in complications, especially CTH, and could significantly shorten the surgical time. Therefore, we recommend single-catheter insertion in neuronavigation-assisted stereotactic aspiration and thrombolysis surgery for isolated moderate-volume (30-60 mL) supratentorial sICH.

Declaration of Figures’ Authenticity

All figures submitted have been created by the authors, who confirm that the images are original with no duplication and have not been previously published in whole or in part.
21. Hall AN, Weaver B, Liotta E, et al. Identifying modifiable predictors of patient outcomes after intracerebral hemorrhage with machine learning. Neurocrit Care. 2021;34(1):73-84

22. Hanley DF, Thompson RE, Muschelli J, et al. Safety and efficacy of minimally-invasive surgery plus alteplase in intracerebral haemorrhage evacuation (MISTIE): A randomised, controlled, open-label, phase 2 trial. Lancet Neurol. 2016;15(12):1228-37

23. Bernardo F, Rebordão L, Machado S, Salgado V, Pinto AN. In-hospital and long-term prognosis after spontaneous intracerebral hemorrhage among young adults aged 18-65 years. J Stroke Cerebrovasc Dis. 2019;28(11):104350

24. Al-Khaled M, Awwad S, Brüning T. Nontraumatic spontaneous intracerebral hemorrhage: Baseline characteristics and early outcomes. Brain Behav. 2020;10(1):e01512

25. Mendelow AD, Gregson BA, Fernandes HM, et al. Early surgery versus initial conservative treatment in patients with spontaneous supratentorial intracerebral haematomas in the International Surgical Trial in Intracerebral Haemorrhage (STICH): A randomised trial. Lancet. 2005;365(9457):387-97

26. Umebayashi D, Mandai A, Osaka Y, et al. Effects and complications of stereotactic aspiration for spontaneous intracerebral hemorrhage. Neurol Med Chir (Tokyo). 2010;50(7):538-44

27. Dey M, Stadnik A, Riad F, et al. Bleeding and infection with external ventricular drainage: A systematic review in comparison with adjudicated adverse events in the ongoing Clot Lysis Evaluating Accelerated Resolution of Intraventricular Hemorrhage Phase III (CLEAR-III IHV) trial. Neurosurgery. 2015;76(3):291-301

28. Wiesmann M, Mayer TE. Intracranial bleeding rates associated with two methods of external ventricular drainage. J Clin Neurosci. 2001;8(2):126-28

29. Gardner PA, Engh J, Atteberry D, Moossey J. Hemorrhage rates after external ventricular drain placement. J Neurosurg. 2009;110(5):1021-25

30. Müller A, Mould WA, Freeman WD, et al. The incidence of catheter tract hemorrhage and catheter placement accuracy in the CLEAR III trial. Neurocrit Care. 2018;29(1):23-32

31. Mun JH, Cho KY, Lim BC, Lim JS, Lee RS. Factors related to catheter-induced hemorrhage after brain parenchymal catheterization. Chonnam Med J. 2013;49(3):113-17

32. Koivukangas T, Katisko JP, Koivukangas JP. Technical accuracy of optical and the electromagnetic tracking systems. Springerplus. 2013;2(1):90

33. Stieglitz LH, Fichtner J, Andres R, et al. The silent loss of neuronavigation accuracy: A systematic retrospective analysis of factors influencing the mismatch of frameless stereotactic systems in cranial neurosurgery. Neurosurgery. 2013;72(5):796-807

34. Batista PO, Machado IP, Roios P, et al. Position and orientation errors in a neuronavigation procedure: A stepwise protocol using a cranial phantom. World Neurosurg. 2019;126:e342-50

35. Chang YH, Hwang SK. Frameless stereotactic aspiration for spontaneous intracerebral hemorrhage and subsequent fibrinolysis using urokinase. J Cerebrovasc Endovasc Neurosurg. 2014;16(1):5-10

36. Hinson HE, Melnychuk E, Muschelli J, et al. Drainage efficiency with dual versus single catheters in severe intraventricular hemorrhage. Neurocrit Care. 2012;16(3):399-405

37. Hussain SS, Raza A, Shahid S, Asif HH, et al. Postoperative reduction of intraventricular hemorrhage volume: Single-versus dual-catheter drainage. J Neurol Surg A Cent Eur Neurosurg. 2018;79(4):279-84