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Original Article

Application of A New Combined Surgical Strategy in Spontaneous Supratentorial Intracerebral Hemorrhage: A Retrospective Cohort Study

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Abstract

Background and objectives: The optimal surgical management for spontaneous supratentorial intracerebral hemorrhage (SSICH) remains controversial because conventional approaches often fail to balance rapid decompression with effective hematoma evacuation. This study aimed to evaluate the efficacy and safety of new combined surgical strategies ("two-in-one" and "three-in-one") versus conventional methods for SSICH.

Methods: This retrospective cohort study included 451 SSICH patients treated between January 2019 and December 2023. Based on clinical severity, patients were stratified into Group I (non-herniation, n = 374) and Group II (herniation, n = 77). Within each subgroup, patients were further categorized by treatment period: a historical control cohort (2019–2020) receiving conventional surgery, and an intervention cohort (2021–2023) receiving combined strategies ("two-in-one" for Group I; "three-in-one" for Group II). Outcomes included decompression time, hematoma evacuation rate, complications, and six-month functional recovery (Glasgow Outcome Scale/modified Rankin Scale), were compared.

Results: In Group I, the "two-in-one" strategy achieved faster decompression (4.65 min) and a high evacuation rate (92.15%), which was comparable to neuroendoscopy alone (90.58%) and significantly higher than stereotactic aspiration alone (44.55%). This was associated with improved six-month outcomes (poor outcome rates were 39.39%, 54.35%, and 42.86% in Groups I-A, I-B, and I-C, respectively, overall $P = 0.034$). In Group II, the "three-in-one" strategy demonstrated shorter decompression time (4.73 vs. 37.85 min, $P < 0.001$) and higher evacuation rates (80.51% vs. 63.50%, $P < 0.001$) than decompressive craniectomy alone. Logistic regression further supported the prognostic advantage of the "two-in-one" strategy in Group I.

Conclusions: These combined strategies may integrate the advantages of multiple techniques to enable rapid decompression and effective hematoma clearance in SSICH. Prospective studies are warranted.

Keywords: Spontaneous supratentorial intracerebral hemorrhage; Neuroendoscopic evacuation; Stereotactic aspiration; Decompressive craniectomy; Cerebral herniation; Combined surgical strategy; Intracranial hypertension; Hematoma evacuation.

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Introduction

Spontaneous intracerebral hemorrhage (SICH) is a fatal type of stroke, accounting for approximately 6.5% to 19.6% of all strokes worldwide.[1–3] The mortality rate within one year of onset exceeds 50%, and only 12% to 39% of survivors achieve functional independence.[4–7] In China, the incidence of SICH is significantly higher than in other countries, constituting approximately 23.8% of all strokes. The 28-day mortality rate can reach 47%, which is substantially higher than the 3% mortality rate of ischemic stroke.[8] Most patients with SICH, particularly those undergoing surgical intervention, are at risk of elevated intracranial pressure (ICP).[9–11] In patients with large or massive hematomas, ICP can increase

markedly, and uncontrollable intracranial hypertension may lead to cerebral herniation, which is a primary cause of death.[12]

Therefore, one of the most critical objectives in the surgical treatment of spontaneous supratentorial intracerebral hemorrhage (SSICH) is to reduce ICP, especially in patients presenting with cerebral herniation. Rapid and sufficient reduction of ICP is often a prerequisite for both surgical success and patient survival. In clinical practice, we have explored a combined surgical strategy, termed "two-in-one" (stereotactic aspiration plus neuroendoscopic evacuation) and "three-in-one" (stereotactic aspiration plus neuroendoscopic evacuation plus decompressive craniectomy), for the treatment of different types of SSICH. This study aimed to evaluate the efficacy and safety of new combined surgical strategies ("two-in-one" and "three-in-one") versus conventional methods for SSICH.

Materials and methods

Study design and ethical approval

This was a single-center, retrospective cohort study conducted at Renmin Hospital of Wuhan University, China. The study protocol was reviewed and approved by the Ethics Committee of Renmin Hospital of Wuhan University (Approval No. WDRM2022-KS002). The requirement for obtaining informed consent from patients was waived due to the retrospective nature of the study, which utilized anonymized data collected as part of routine clinical care. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 2013 Helsinki Declaration and its later amendments or comparable ethical standards.

Patient selection and study population

We retrospectively reviewed the clinical data of all patients diagnosed with SSICH who underwent neurosurgery at our center between January 2019 and December 2023. Inclusion criteria: (1) First-ever spontaneous hypertensive intracerebral hemorrhage; (2) Age ≥18 years with sudden onset of symptoms (e.g., headache, hemiplegia, aphasia, coma); (3) SICH confirmed by head computed tomography (CT) scan; (4) Hospitalization and surgical intervention within 24 h of symptom onset; (5) Hematoma volume >25 mL, necessitating surgical evacuation. Exclusion criteria: (1) Primary intraventricular hemorrhage; (2) Secondary hemorrhage due to coagulopathy, cerebral infarction transformation, moyamoya disease, aneurysm, arteriovenous malformation, or tumor; (3) Coexistence of severe, life-limiting systemic diseases; (4) Patient or family refusal of surgery; (5) Incomplete clinical or follow-up records. A total of 451 patients met the criteria and were included in the final analysis. The patient selection process is detailed in a flowchart (Fig. 1).

Patient stratification and grouping

A two-step stratification process was employed: Time-based cohort assignment: Patients were primarily assigned to one of two cohorts based on the chronology of surgical protocol implementation at our center. The Control Cohort consisted of 221 patients who received traditional surgical strategies (stereotactic aspiration, neuroendoscopic evacuation, or craniotomy with decompressive craniectomy) between January 2019 and December 2020. The Intervention Cohort consisted of 230 patients who underwent the new combined surgical strategies ("two-in-one" or "three-in-one") between January 2021 and December 2023.

Clinical severity-based subgrouping: Based on preoperative imaging and clinical indicators (Table 1), the entire cohort was further stratified into two distinct clinical subgroups for subsequent analysis: Group I (non-herniation group, n = 374): patients without radiological signs of cerebral herniation (smaller hematoma volume, minimal midline shift, preserved basal cisterns, higher Glasgow Coma Scale (GCS) score). Group II (herniation group, n = 77): patients with signs of cerebral herniation (large hematoma volume, significant midline shift, basal cistern effacement, lower GCS score). This stratification established the framework for comparing surgical outcomes within clinically relevant subgroups (Table 2). Baseline characteristics of all patients and subgroups are presented in Table 1.

Data collection

Data were systematically extracted from the hospital information system, including: (1) demographics (sex, age); (2) comorbidities (diabetes, preoperative systolic blood pressure); (3) imaging features (hemorrhage location, midline shift, basal cistern effacement, intraventricular hemorrhage, acute hydrocephalus); (4) preoperative GCS score; (5) surgical parameters, including decompression time (defined as the interval from skin incision to the first observed reduction of ICP on the ICP monitor); (6) preoperative and postoperative (within 24 h) hematoma volumes, with clearance rate calculated as [(preoperative − postoperative volume) / preoperative volume] × 100% using 3D Slicer software; (7) postoperative complications (rebleeding, infection, epilepsy, cerebrospinal fluid leak, hydrocephalus); and (8) functional outcomes (Glasgow Outcome Scale (GOS) at discharge and modified Rankin Scale (mRS) at six-month follow-up).

Surgical procedures

Control cohort (traditional strategies)

Stereotactic aspiration: Following preoperative CT-based stereotactic planning and registration, a safe surgical trajectory to the hematoma core was determined. A burr hole was then created at the planned entry point, through which a flexible aspiration catheter was advanced into the hematoma cavity. Partial evacuation of the clot was achieved via gentle manual syringe aspiration, with the primary objective of achieving rapid ICP reduction. Upon completion, the aspiration catheter could be secured in situ for postoperative drainage prior to standard wound closure.

Neuroendoscopic evacuation: A small linear scalp incision and a limited craniotomy (approximately 2.5 cm in diameter) were performed based on preoperative trajectory planning. After dural opening, a transparent endoscopic sheath was inserted into the hematoma cavity under guidance. A rigid endoscope was then introduced, allowing for direct visualization and systematic evacuation of the clot using suction and micro-forceps under continuous irrigation. Hemostasis was achieved under endoscopic view using a bipolar coagulator. Following evacuation, the sheath was removed, a drainage catheter was optionally placed, and the wound was closed in layers.

Decompressive craniectomy: A generous question-mark scalp incision was made, and a musculocutaneous flap was elevated to expose the skull. A large bone flap (typically ≥12 cm in diameter) was then removed using a craniotome after placing multiple burr holes, ensuring adequate extension to the cranial base for temporal lobe decompression. The dura was opened in a stellate fashion to allow for brain expansion and ICP release. A dural graft was often

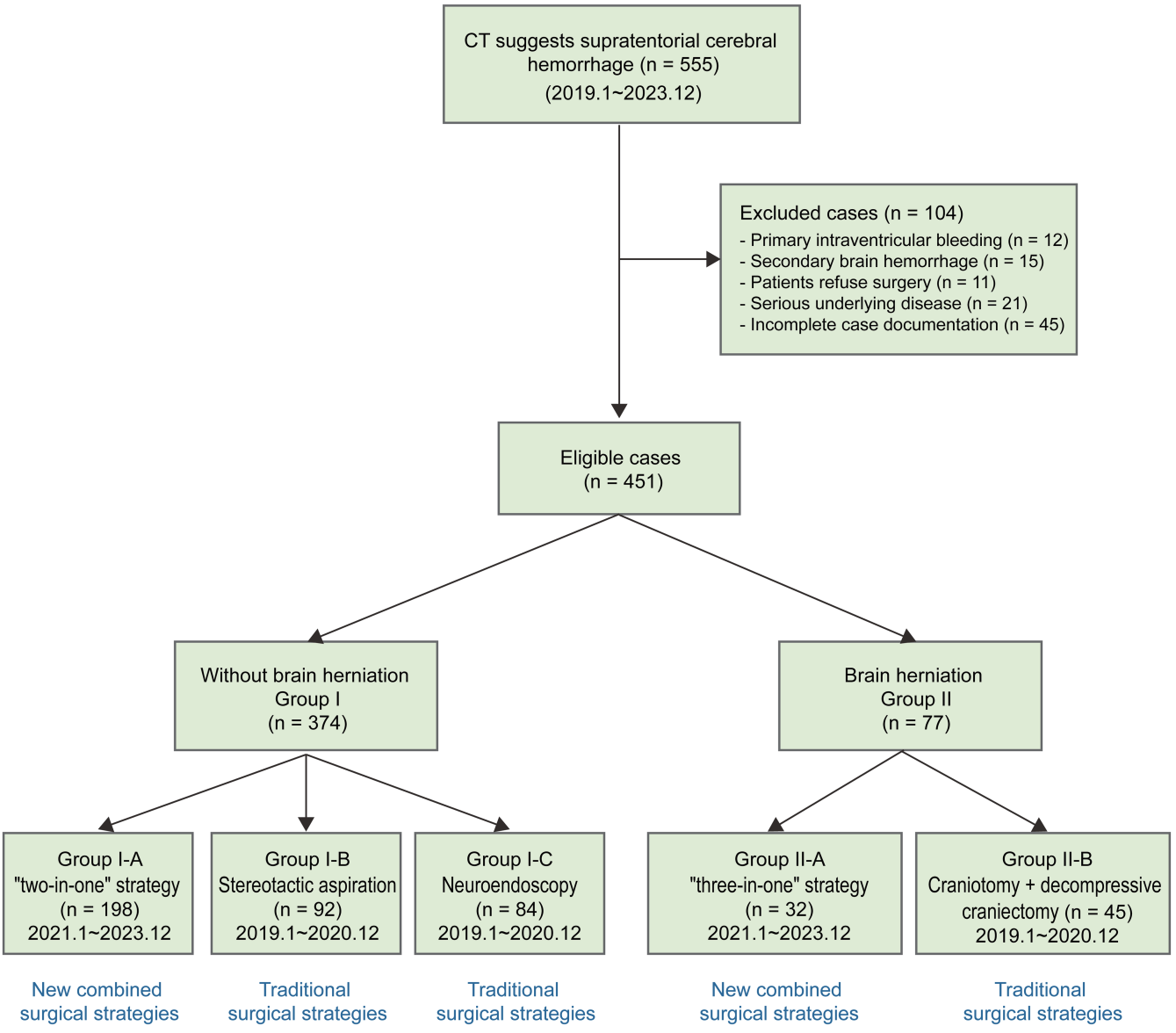


Fig. 1. Flow chart for patient selection. Information on 555 patients was collected, of which 104 patients were excluded for multiple reasons, and finally 451 patients were included for further analysis. CT, computed tomography.

applied for closure. Finally, the flap was repositioned and the scalp was closed in layers over a drain, with the bone flap preserved for future cranioplasty.

Intervention cohort (new combined strategies)

"Two-in-one" strategy: The operation included two parts: (1) Inserting a soft catheter into the hematoma and partially aspirating the clot to rapidly decrease ICP; and (2) Using a neuroendoscope to remove the residual hematoma and stop the bleeding. Specifically, a linear scalp incision (4–5 cm) was performed according to the hematoma location. A burr hole was made, and a soft catheter was inserted into the hematoma cavity. Then, approximately one-third of the clot was aspirated through the catheter using a syringe to decrease ICP quickly. Secondly, a small bone flap (~2.5 cm) was created and the dura mater opened, and a transparent plastic sheath was inserted into the hematoma cavity. Then, a 0° rigid endoscope (Karl Storz, Germany) was introduced to remove the residual hematoma. Obvious intraoperative bleeding was stopped using a bipolar coagulator. After removing the hematoma, a soft catheter was placed inside the cavity, the bone flap was replaced, and the skin incision was sutured (Fig. 2a–i).

"Three-in-one" strategy: This strategy was divided into three steps: (1) Inserting a soft catheter into the hematoma and partially aspirating the clot to rapidly decrease ICP; (2) Removing the residual hematoma and stopping the bleeding under a neuroendoscope; and (3) Decompressive craniectomy. The first and second steps were similar to the "two-in-one" strategy. The third step involved extending the skin incision to form an expanded pterional approach or an enlarged temporal approach. The bone flap, with a diameter of ≥10 cm, was removed, and the dura mater

Table 1. Descriptive statistics of all patients (N = 451)

Characteristics	Total (N = 451)	Group I (n = 374)	Group II (n = 77)
Gender, n (%)			
M	235 (52.11%)	188 (50.27%)	47 (61.04%)
F	216 (47.89%)	186 (49.73%)	30 (38.96%)
Age	54.56 ± 11.06	54.48 ± 10.93	55.01 ± 11.56
Diabetes, n (%)	130 (28.82%)	109 (29.14%)	21 (27.27%)
Preop. SBP	154.53 ± 18.79	151.29 ± 17.32	166.04 ± 20.19
Hemorrhage location, n (%)			
Superficial	123 (27.27%)	106 (28.34%)	17 (22.08%)
Deep	328 (72.73%)	268 (71.66%)	60 (77.92%)
Midline shift (mm)	3.51 ± 2.55	2.45 ± 0.44	7.97 ± 1.14
Basal cistern effacement, n (%)	78 (17.30%)	7 (1.87%)	71 (92.21%)
IVH, n (%)	151 (33.48%)	129 (34.49%)	22 (28.57%)
Preop. acute hydrocephalus, n (%)	78 (17.30%)	63 (16.84%)	15 (19.48%)
Preop. Volume (mL)	45.51 ± 22.58	36.42 ± 8.44	82.51 ± 12.96
Preop. GCS	7.49 ± 2.75	8.12 ± 2.58	5.07 ± 1.30

Data are presented as mean ± standard deviation or n (%). GCS, Glasgow Coma Scale; IVH, intraventricular hemorrhage; Preop., preoperative; SBP, systolic blood pressure.

was cut radially and sutured. After that, the scalp was sutured in layers (Fig. 3a–j).

Statistical analysis

Statistical analyses were performed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA). Categorical variables were expressed as numbers (percentages) and were compared using the chi-square test or Fisher's exact test. Continuous variables were assessed for normality using the Shapiro–Wilk test. Normally distributed data were presented as mean ± standard deviation and were compared using Student's t-test or analysis of variance (ANOVA); otherwise, they were expressed as median (interquartile range) and compared using the Mann–Whitney U test or Kruskal–Wallis test. For ANOVA followed by post hoc pairwise comparisons, the Bonferroni correction was applied to control for Type I error. Univariate logistic regression was first performed to identify factors associated with prognosis (defined by GOS/mRS). Variables with $P < 0.05$ in univariate analysis were entered into a multivariate logistic regression model to identify independent predictors, with results reported as odds ratios (ORs) and 95% confidence intervals. A two-tailed $P < 0.05$ was considered statistically significant for all analyses.

It is important to clarify that the treatment period (January 2019–December 2020 vs. January 2021–December 2023) was not included as an independent covariate in the multivariable regression model. This decision was made because the treatment period was inherently collinear with the surgical strategy groups: all patients in the control cohort (Groups I-B, I-C, and II-B) were treated exclusively during the earlier period, while all patients in the intervention cohort (Groups I-A and II-A) were treated exclusively during the later period. Including both variables would have introduced redundancy and violated the assumptions of regression modeling. Therefore, the grouping variable itself sufficiently captures the effect of the surgical approach, and the period effect is implicitly accounted for through the group comparisons. This approach ensures model stability while maintaining statistical transparency.

Results

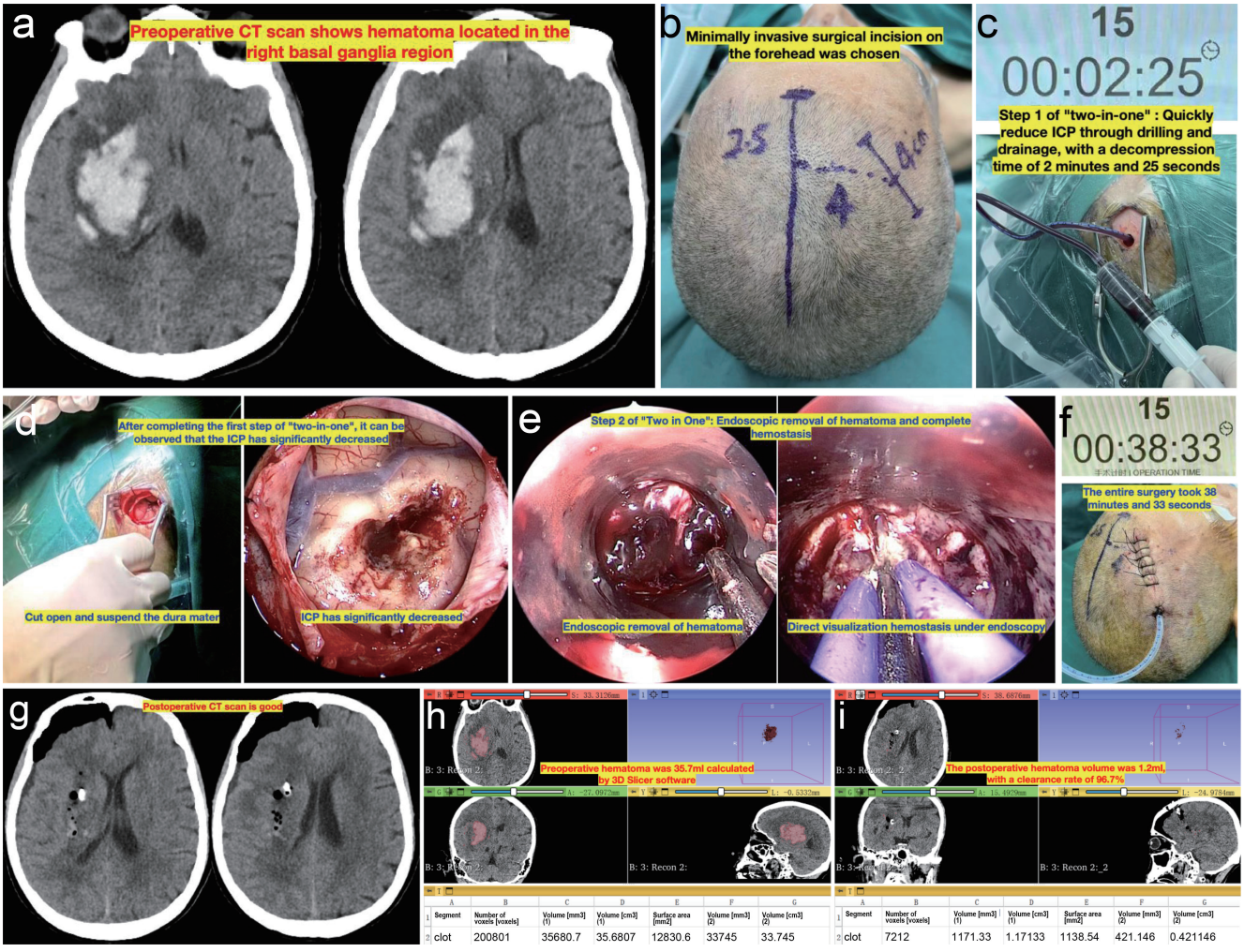
Comparison results of Group I

A total of 374 SICH patients were stratified into Group I-A (n = 198), I-B (n = 92), and I-C (n = 84). Baseline demographics, comorbidities, preoperative imaging features, and GCS did not differ significantly (all $P > 0.05$). Perioperative outcomes varied significantly: time to decrease ICP was prolonged in Group I-C (10.84 ± 2.50 min) versus I-A and I-B (4.65 ± 0.60 min and 4.51 ± 0.70 min). Postoperative hematoma volume was greatest in Group I-B (19.57 ± 4.60 mL), accompanied by the lowest evacuation rate

Table 2. Patient classification and surgical strategy

Strategy Group (n)	New combined strategy	Traditional surgical strategy	
Gruop I (374)	"two-in-one" strategy, Gruop I-A (n = 198)	Stereotactic aspiration, Gruop I-B (n = 92)	Neuroendoscopy, Gruop I-C (n = 84)
Gruop II (77)	"three-in-one" strategy, Gruop II-A (n = 32)	craniotomy + decompressive craniectomy, Gruop II-B (n = 45)	

Group I, patients without obvious brain herniation; Group II, patients with obvious brain herniation.



Segment	Number of voxels [voxels]	Volume [mm3] (1)	Volume [cm3] (1)	Surface area [mm2]	Volume [mm3] (2)	Volume [cm3] (2)
clot	200801	35680.7	35.6807	12830.6	33745	33.745

Segment	Number of voxels [voxels]	Volume [mm3] (1)	Volume [cm3] (1)	Surface area [mm2]	Volume [mm3] (2)	Volume [cm3] (2)
clot	7212	1171.33	1.17133	1138.54	421.146	0.421146

Fig. 2. The two-in-one surgical strategy for basal ganglia hemorrhage. (a) Preoperative non-contrast axial CT scan showing a hematoma located in the right basal ganglia, and the midline structure was shifted. (b) A 4-cm linear scalp incision was performed. (c) A burr hole was made, a soft catheter was inserted into the hematoma cavity, and approximately one-third of the hematoma was aspirated through the catheter using a syringe; the decompression time was 2 min 25 s (defined as the interval from skin incision to the first observed reduction of intracranial pressure on the ICP monitor). (d) After completing the first step of "two-in-one", it can be observed that the ICP has significantly decreased. (e) The residual hematoma was evacuated, and complete hemostasis was achieved under direct neuroendoscopic view. (f) The entire surgery took 38 min and 33 s. (g) Postoperative CT scan showing that the hematoma was removed satisfactorily. (h) Preoperative hematoma volume was 35.7 mL, calculated by 3D Slicer software. (i) The postoperative hematoma volume was 1.2 mL, with a clearance rate of 96.7%. CT, computed tomography; ICP, intracranial pressure.

(44.55 ± 8.53%), whereas I-A and I-C achieved >90% evacuation ($P < 0.001$). Rebleeding incidence was highest in I-B (11.96%, $P = 0.047$). Although discharge GOS did not differ ($P = 0.724$), six-month mRS outcomes were significantly worse in I-B (54.35% mRS 3–5) compared to I-A (39.39%) and I-C (42.86%, $P = 0.034$). In summary, Group I-B demonstrated inferior surgical efficacy, higher rebleeding risk, and poorer long-term functional recovery, while Group I-C was characterized by prolonged ICP control despite comparable evacuation success to I-A (Table 3).

Comparison results of Group II

A total of 77 patients were stratified into Group II-A (n = 32) and Group II-B (n = 45). The groups were comparable across baseline demographics, comorbidities, preoperative imaging characteristics, and GCS scores (all $P > 0.05$). Significant intergroup differences were observed in key procedural outcomes: Group II-A demonstrated markedly shorter time to ICP normalization (4.73 ± 0.77 vs. 37.85 ± 7.78 min, $P < 0.001$), lower postoperative hematoma volume (15.02 ± 11.73 vs. 31.15 ± 13.16 mL, $P < 0.001$), and higher evacuation rate (80.51 ± 15.76% vs. 63.50 ± 13.85%, $P < 0.001$). However, no significant differences were found in postoperative complication rates or discharge GOS scores ($P > 0.05$), indicating that the enhanced procedural efficiency in Group II-A did not confer a short-term prognostic advantage (Table 4).

Logistic regression analysis of prognostic factors in Group I

Patients were stratified into two prognostic categories based on the mRS: favorable outcome (mRS 0–2) and unfavorable outcome (mRS 3–6). We found no significant difference in GOS at discharge among Groups I-A, I-B, and I-C, whereas the six-month mRS differed significantly across these groups, suggesting that the "two-in-one" strategy may be associated with better long-term

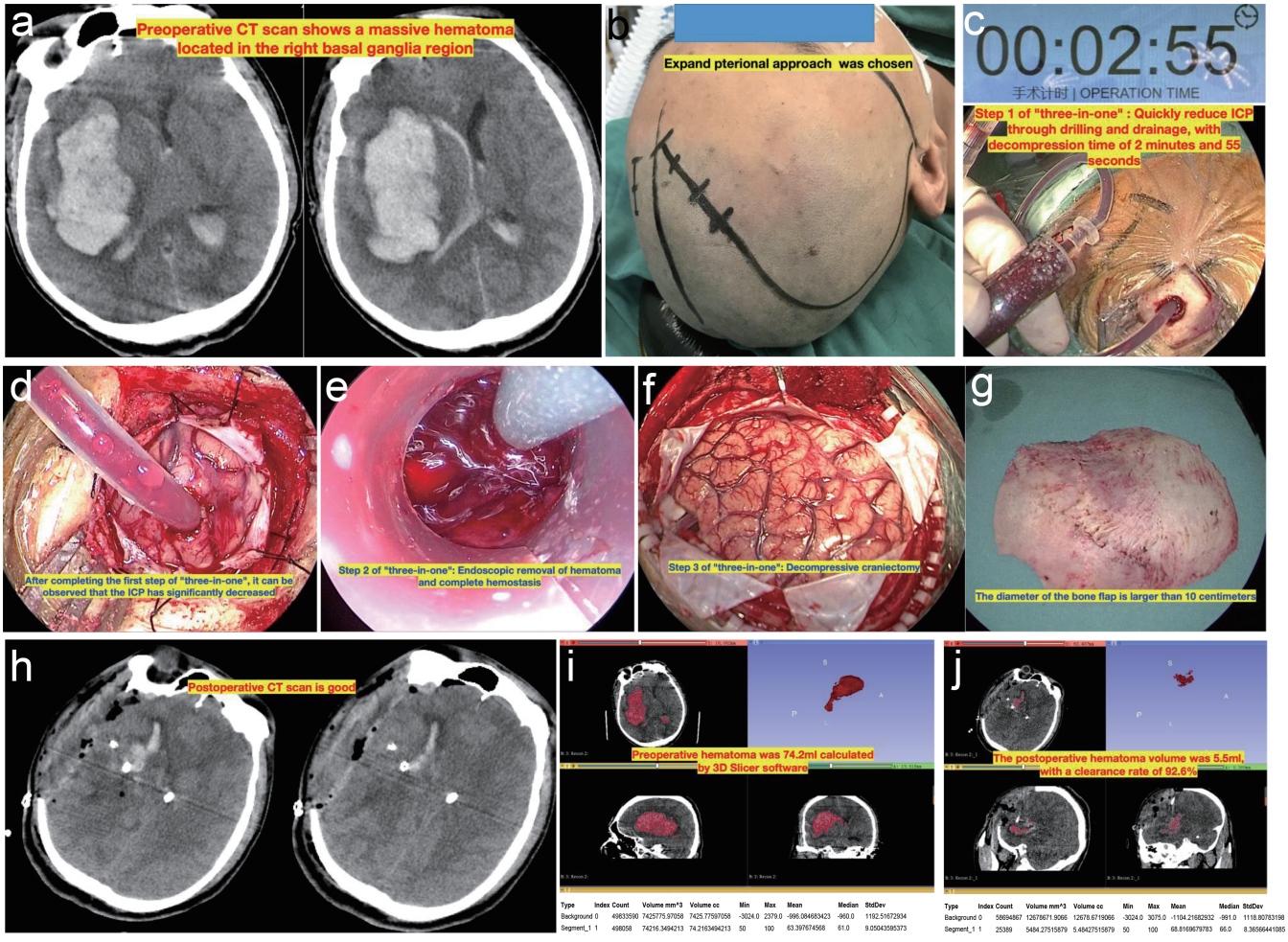


Fig. 3. The three-in-one surgical strategy for large hematoma volume. (a) Preoperative non-contrast axial CT image demonstrating a massive hypertensive hematoma in the right basal ganglia region with significant mass effect and midline shift. (b) An expanded pterional approach was chosen. (c) ICP was quickly reduced through drilling and drainage, with a decompression time of 2 min and 55 s (defined as the interval from skin incision to the first observed reduction of intracranial pressure on the ICP monitor). (d) After completing the first step of "three-in-one", it can be observed that the ICP has significantly decreased. (e) Endoscopic removal of the hematoma and complete hemostasis. (f) Decompressive craniectomy. (g) The diameter of the bone flap was larger than 10 cm. (h) Postoperative CT scan showing that the hematoma was removed satisfactorily. (i) Preoperative hematoma volume was 74.2 mL, calculated by 3D Slicer software. (j) The postoperative hematoma volume was 5.5 mL, with a clearance rate of 92.6%. CT, computed tomography; ICP, intracranial pressure.

prognosis. To further investigate whether surgical approach was an independent prognostic factor in Group I patients, logistic regression analysis was performed. Univariate analysis identified several factors significantly associated with favorable outcomes, including Group I-B (OR = 0.546, P = 0.018), superficial hematoma (OR = 1.739, P = 0.021), absence of IVH (OR = 1.816, P = 0.007), smaller hematoma volume (OR = 0.963, P = 0.002), higher preoperative GCS score (OR = 1.105, P = 0.024), and midline shift (OR = 0.225, P < 0.001). Multivariate analysis confirmed Group I-B (aOR = 0.522, P = 0.019), superficial hematoma (aOR = 1.768, P = 0.028), absence of IVH (aOR = 1.800, P = 0.015), smaller hematoma volume (aOR = 0.967, P = 0.014), higher GCS score (aOR = 1.113, P = 0.025), and midline shift (aOR = 0.225, P < 0.001) as independent predictors of favorable prognosis. Gender, age, diabetes, preoperative systolic blood pressure, basal cistern effacement, and acute hydrocephalus showed no significant association. Furthermore, the "two-in-one" strategy was linked to improved long-term prognosis compared with stereotactic aspiration (Table 5).

Discussion

SSICH patients may experience increased ICP due to hematoma occupying space and subsequent brain edema. Research has found that approximately 67% of all these patients will experience intracranial hypertension.[13–16] Patients undergoing surgical treatment generally had larger hematoma volumes than those managed conservatively, which may imply a higher burden of mass effect and intracranial hypertension and therefore a greater need for ICP-directed management.[17–19] Moreover, the relationship between hematoma and ICP is not linear, but rather follows a "pressure–volume curve" relationship. Therefore, when the hematoma volume reaches a certain critical value, ICP will significantly and rapidly increase, endangering the patient's life. Therefore, one of the most important goals of surgical treatment for SSICH is to reduce ICP, especially for patients with concomitant cerebral herniation. Rapid and sufficient reduction of ICP is critical for surgical success and patient survival.

At present, there are three main surgical strategies for reduc-

Table 3. Surgical procedure and prognosis of patients in Group I

Characteristics	"Two-in-one" strategy, Group I-A (n = 198)	Stereotactic aspiration, Group I-B (n = 92)	Neuroendoscopy, Group I-C (n = 84)	*P*-value
Gender, n (%)				
M	105 (53.03%)	44 (47.83%)	39 (46.43%)	0.517[a]
F	93 (46.97%)	48 (52.17%)	45 (53.57%)	
Age	53.53 ± 9.83	55.55 ± 10.56	54.77 ± 12.82	0.317[b]
Diabetes, n (%)	64 (32.32%)	24 (26.09%)	21 (25.00%)	0.436[a]
Preop. SBP	151.50 ± 17.52	148.89 ± 15.62	154.23 ± 18.21	0.102[b]
Hemorrhage location, n (%)				
Superficial	53 (26.77%)	28 (30.43%)	25 (29.76%)	0.673[a]
Deep	145 (73.23%)	64 (69.57%)	59 (70.24%)	
Midline shift (mm)	2.45 ± 0.43	2.50 ± 0.48	2.34 ± 0.39	0.064[b]
Basal cistern effacement, n (%)	4 (2.02%)	1 (1.09%)	2 (2.38%)	0.824[c]
IVH, n (%)	68 (34.34%)	36 (39.13%)	25 (29.76%)	0.544[a]
Preop. acute hydrocephalus, n (%)	35 (17.68%)	13 (14.13%)	15 (17.86%)	0.562[a]
Preop. volume (mL)	36.44 ± 8.85	35.52 ± 7.53	37.51 ± 8.53	0.196[b]
Preop. GCS	8.14 ± 2.41	8.51 ± 2.81	7.85 ± 2.97	0.122[b]
Time to decrease ICP (min)	4.65 ± 0.60	4.51 ± 0.70	10.84 ± 2.50	<0.001[b]
Postop. volume (mL)	2.83 ± 2.13	19.57 ± 4.60	3.60 ± 2.88	<0.001[b]
Evacuation rate (%)	92.15 ± 5.47	44.55 ± 8.53	90.58 ± 6.80	<0.001[b]
Postop. rebleeding, n (%)	8 (4.04%)	11 (11.96%)	6 (7.14%)	0.047[a]
Intracranial infection, n (%)	1 (0.51%)	3 (3.26%)	1 (1.19%)	0.206[c]
Postop. seizure, n (%)	17 (8.59%)	6 (6.52%)	8 (9.52%)	0.784[a]
CSF leak, n (%)	3 (1.52%)	2 (2.17%)	1 (1.19%)	0.874[c]
Hydrocephalus, n (%)	16 (8.08%)	12 (13.04%)	9 (10.71%)	0.422[a]
GOS at discharge, n (%)				
2–3	95 (47.98%)	44 (47.83%)	37 (44.05%)	0.724[a]
4–5	103 (52.02%)	48 (52.17%)	47 (55.95%)	
6-month mRS, n (%)				
0–2	120 (60.61%)	42 (45.65%)	48 (57.14%)	0.034[a]
3–6	78 (39.39%)	50 (54.35%)	36 (42.86%)	

[a]chi-square test, [b]ANOVA, [c]Fisher's exact test. Data are presented as mean ± standard deviation or n (%). ANOVA, analysis of variance; CSF, cerebrospinal fluid; GCS, Glasgow Coma Scale; GOS, Glasgow Outcome Scale; ICP, intracranial pressure; IVH, intraventricular hemorrhage; mRS, modified Rankin Scale; Postop., postoperative; Preop., preoperative; SBP, systolic blood pressure. *P*-values were calculated by comparing all three groups (Group I-A: "Two-in-one" strategy, Group I-B: Stereotactic aspiration, Group I-C: Neuroendoscopy) using the chi-square test for categorical variables and ANOVA for continuous variables.

ing ICP: external ventricular drainage, decompressive craniectomy, and hematoma removal. The first two methods are indirect surgical methods for reducing ICP because they cannot clear the hematoma. Hematoma clearance remains the most important and direct surgical method for SSICH at present. In addition, three main methods for hematoma removal: craniotomy, stereotactic aspiration, and neuroendoscopy. These three surgical methods each have their own advantages and disadvantages.[20,21] Stereotactic aspiration can achieve rapid reduction of ICP in the shortest possible time, but due to its low efficiency in removing hematoma, the decrease in ICP is not sufficient.[22] Neuroendoscopy can efficiently remove hematomas and effectively reduce ICP, but the decompression time from the beginning of surgery to hematoma removal is longer than that of stereotactic aspiration.[23] Craniotomy can also achieve efficient removal of hematoma, but its decompression time is significantly longer than that of stereotactic aspiration and neuroendoscopic surgery, which is not conducive to patients with combined cerebral herniation. A single surgical method has inherent limitations and is not an ideal approach.

The combined surgical strategy can compensate for the shortcomings of various surgical methods and leverage their advantages, making it an ideal strategy. The most common combined surgical strategy is craniotomy for hematoma removal plus bone flap decompression.[24–26] However, its hematoma clearance is based on

Table 4. Surgical procedure and prognosis of patients in Group II

Characteristics	"Three-in-one" strategy, Group II-A (n = 32)	Decompressive craniectomy, Group II-B (n = 45)	*P*-value
Gender, n (%)			
M	18 (56.25%)	29 (64.44%)	0.483[a]
F	14 (43.75%)	16 (35.56%)	
Age	52.66 ± 10.84	56.67 ± 11.86	0.132[b]
Diabetes, n (%)	10 (31.25%)	11 (24.44%)	0.605[a]
Preop. SBP	162.50 ± 20.15	168.56 ± 19.85	0.192[b]
Hemorrhage location, n (%)			
Superficial	8 (25.00%)	9 (20.00%)	0.782[a]
Deep	24 (75.00%)	36 (80.00%)	
Midline shift (mm)	8.21 ± 1.21	7.81 ± 1.05	0.126[b]
Basal cistern effacement, n (%)	28 (87.50%)	43 (95.56%)	0.233[c]
IVH, n (%)	8 (25.00%)	14 (31.11%)	0.620[a]
Preop. acute hydrocephalus, n (%)	5 (15.63%)	10 (22.22%)	0.571[c]
Preop. volume (mL)	79.45 ± 13.88	84.56 ± 11.85	0.083[b]
Preop. GCS	4.84 ± 1.14	5.22 ± 1.35	0.190[b]
Time to decrease ICP (min)	4.73 ± 0.77	37.85 ± 7.78	<0.001[b]
Postop. volume (mL)	15.02 ± 11.73	31.15 ± 13.16	<0.001[b]
Evacuation rate (%)	80.51 ± 15.76	63.50 ± 13.85	<0.001[b]
Postop. rebleeding, n (%)	3 (9.38%)	6 (13.33%)	0.727[c]
Intracranial infection, n (%)	1 (3.13%)	2 (4.44%)	>0.999[c]
Postop. seizure, n (%)	8 (25.00%)	9 (20.00%)	0.782[a]
CSF leak, n (%)	1 (3.13%)	3 (6.67%)	0.641[c]
Hydrocephalus, n (%)	8 (25.00%)	7 (15.56%)	0.380[c]
GOS at discharge, n (%)			
1–2	19 (59.38%)	31 (68.89%)	0.482[a]
3–4	13 (40.63%)	14 (31.11%)	

[a]chi-square test, [b]t-test, [c]Fisher's exact test. Data are presented as mean ± standard deviation or n (%). CSF, cerebrospinal fluid; GCS, Glasgow Coma Scale; GOS, Glasgow Outcome Scale; ICP, intracranial pressure; IVH, intraventricular hemorrhage; Postop., postoperative; Preop., preoperative; SBP, systolic blood pressure.

craniotomy surgery, which has greater trauma and longer decompression time, and its advantages have not been fully demonstrated. In addition, there are other combined surgical strategies such as hematoma puncture drainage plus decompressive craniectomy and external ventricular drainage plus decompressive craniectomy.[27] These strategies have not effectively cleared the hematoma, so their decompression effect is not sufficient.

We have improved traditional surgical strategies and developed a combined surgical strategy that rapidly reduces ICP while efficiently clearing hematomas. This surgical strategy emphasizes rapid reduction of ICP while also considering effective removal of hematoma. In this preliminary study, we proposed a "two-in-one" surgical strategy of "stereotactic aspiration + neuroendoscopic evacuation". Our research results show that for patients without cerebral herniation, we used a "two-in-one" surgical strategy. The average decompression time was 4.6 minutes, and the average hematoma clearance rate was 92.1%. For patients with combined cerebral herniation, we used a "three-in-one" surgical strategy, with an average decompression time of 4.7 minutes and an average hematoma clearance efficiency of 80.5%. For this combined surgical strategy, the average decompression time was 4.7 min, which is similar to the stereotactic aspiration group and significantly faster than the craniotomy and endoscopic groups. The average hematoma clearance rate was 90.5%, similar to the endoscopic group and significantly higher than that of the stereotactic aspiration group and craniotomy group. In patients without significant cerebral herniation, the combined surgery group demonstrated significantly better six-month mRS scores compared to the control group. In both herniation and non-herniation subgroups, however, although the combined surgery group exhibited slightly higher GOS scores at discharge than the control group, these differences did not reach statistical significance. These findings indicate that the biggest advantage of the combined surgical strategy is rapid decompression and efficient removal of hematoma. This approach offers significant advantages for SSICH patients with elevated ICP, especially in patients with concomitant cerebral herniation, and the combined

Table 5. Logistic regression analysis for prognosis in Group I patients based on preoperative indicators

Characteristics	Univariate analysis		Multivariate analysis	
	Odds ratio (95% CI)	*P*-value	Odds ratio (95% CI)	*P*-value
Gender				
Male	Reference			
Female	1.219 (0.810–1.836)	0.342		
Age	0.991 (0.972–1.011)	0.384		
Diabetes				
Yes	Reference			
No	1.313 (0.839–2.055)	0.233		
Group I				
Group I-A	Reference		Reference	
Group I-B	0.546 (0.331–0.900)	0.018	0.522 (0.303–0.898)	0.019
Group I-C	0.867 (0.516–1.454)	0.588	0.851 (0.482–1.501)	0.577
Preop. SBP	0.990 (0.979–1.001)	0.078		
Hemorrhage location				
Deep	Reference		Reference	
Superficial	1.739 (1.088–2.779)	0.021	1.768 (1.063–2.941)	0.028
Midline shift (mm)	0.225 (0.131–0.386)	< 0.001	0.225 (0.130–0.390)	< 0.001
Basal cistern effacement				
Yes	Reference			
No	7.937 (0.946–66.590)	0.056		
IVH				
Yes	Reference		Reference	
No	1.816 (1.180–2.794)	0.007	1.800 (1.124–2.885)	0.015
Preop. acute hydrocephalus				
Yes	Reference			
No	1.400 (0.814–2.409)	0.224		
Preop. volume (mL)	0.963 (0.940–0.986)	0.002	0.967 (0.942–0.993)	0.014
Preop. GCS	1.105 (1.013–1.205)	0.024	1.113 (1.014–1.222)	0.025

Group I-A, "two-in-one" strategy group; Group I-B, stereotactic aspiration group; Group I-C, neuroendoscopy group. CI, confidence interval; GCS, Glasgow Coma Scale; IVH, intraventricular hemorrhage; Preop., preoperative; SBP, systolic blood pressure.

surgical strategy of rapid decompression is of great significance.

Several limitations should be acknowledged in this study. First, as a retrospective analysis conducted in a single center, the findings may not be fully generalizable to other institutions with different surgical protocols, patient populations, or levels of expertise. Second, the effectiveness of neuroendoscopic procedures, particularly in the combined strategies described, is highly dependent on the surgeon's experience and technical proficiency, which requires prolonged and systematic training. Variability in operator skill may influence both the efficiency of hematoma evacuation and the incidence of procedure-related complications, a factor not quantitatively adjusted for in our analysis. Third, despite statistical adjustments for key prognostic variables, unmeasured confounders inherent to non-randomized designs may persist. Fourth, for patients in Group II (herniation subgroup), long-term functional outcomes at six months could not be assessed due to the critical nature of their condition and the associated high mortality and loss to follow-up, which is a common challenge in studies involving severely ill populations. Consequently, our analysis for this subgroup was limited to short-term outcomes, and the impact of the combined surgical strategy on long-term prognosis in patients with cerebral herniation remains to be determined in future studies with more complete follow-up. Future prospective, multicenter studies involving standardized surgical training and competency assessment would help to validate these techniques and clarify their role in the management of SICH.

Conclusions

This integrated new combined surgical strategy synthesizes the technical principles of minimally invasive stereotactic aspiration, neuroendoscopic evacuation, and decompressive craniectomy. It is

designed to address the critical pathophysiological challenges in SSICH by enabling both rapid reduction of ICP and efficient, visualized hematoma clearance. In this retrospective cohort, it showed procedural advantages over conventional approaches, with potential prognostic benefit in selected patients. Further large-scale prospective studies are needed to validate its efficacy and clarify its indications.

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Conflict of interest

The authors declare no competing interests. The authors state that none of the material in the paper has been published or is under consideration for publication elsewhere, and no potential conflicts of interest were disclosed.

Author contributions

Article design and draft writing (ZL, JW, WW, ML), data collection and processing (ZS, QH, PS, LZ), and review of the article (QC). All authors approved the final version of the manuscript for publication.

Ethical statement

The study protocol was reviewed and approved by the Ethics Committee of Renmin Hospital of Wuhan University (Approval No. WDRM2022-KS002). All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 2013 Helsinki Declaration and its later amendments or comparable ethical standards. The requirement for obtaining informed consent from patients was waived due to the retrospective nature of the study, which utilized anonymized data collected as part of routine clinical care.

Data sharing statement

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

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