Comparative Analysis of Neurological Function and Prognosis After Stereotactic Aspiration and Neuroendoscopic Surgery for Hypertensive Intracerebral Hemorrhage

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AIM: In recent years, minimally invasive surgery has become a preferred treatment for hypertensive intracerebral hemorrhage (HICH). This study aims to comprehensively compare the neurological function and prognosis of neuroendoscopic surgery (NS) and stereotactic aspiration (SA) in patients with HICH.

METHODS: A total of 247 patients with HICH admitted to Taizhou Hospital of Zhejiang Province affiliated to Wenzhou Medical University from April 2020 to December 2023 were included. Patients were divided into the NS group (65 cases) and the SA group (182 cases). The perioperative indicators, serum neurological function, complications, and functional prognosis were compared between the two groups.

RESULTS: The SA group demonstrated higher hematoma clearance rate with lower hematoma residual volumes and intraoperative blood loss than the NS group ($p < 0.05$). Compared with these before surgery, serum brain-derived neurotrophic factor (BDNF) levels increased, neuron-specific enolase (NSE) and glial fibrillary acidic protein (GFAP) levels decreased in both groups at 1 and 3 months post-surgery ($p < 0.05$). The SA group showed higher BDNF and lower NSE and GFAP levels at 1 and 3 months post-surgery than the NS group ($p < 0.05$). Compared with these before surgery, both groups showed lower National Institutes of Health Stroke Scale (NIHSS) and modified Rankin Scale (mRS) score and higher Glasgow Outcome Scale (GOS) scores at 1 and 3 months post-surgery, with the SA group performing better than the NS group post-surgery ($p < 0.05$). There was no difference in the complications rates between the two groups ($p > 0.05$). At 3- and 6-months post-surgery, the SA group showed higher Mini-Mental State Examination (MMSE) scores than the NS group ($p < 0.05$). At 3 months post-surgery, the SA group showed higher activities of daily living (ADL) scores than the NS group ($p < 0.05$), but no difference at 6 months post-surgery ($p > 0.05$).

CONCLUSIONS: In the treatment of HICH, compared to NS, SA offers advantages in hematoma clearance and intraoperative bleeding reduction. Additionally, SA more effectively improves neurological function, quality of life, and cognitive ability in HICH patients.

Keywords: stereotactic aspiration; neuroendoscopic surgery; hypertensive intracerebral hemorrhage; neurological function; prognosis

Introduction

Intracerebral hemorrhage (ICH) is a type of bleeding caused by the non-traumatic rupture of blood vessels in the brain parenchyma, with hypertension-induced ICH being the most common [1,2]. Patients with hypertensive intracerebral hemorrhage (HICH) often experience substantial blood accumulation, which compresses and damages adjacent tissues. If not promptly treated, intracranial hematomas can expand, exert pressure on brain tissue, increase intracranial pressure, cause severe neurological damage, impair brain function, and even lead to death [3,4]. Previously, craniotomy and hematoma aspiration were the primary surgical interventions for HICH [5]. However, traditional open hematoma evacuation procedures are time-consuming and highly invasive, potentially damaging surrounding brain tissue and frequently leading to numerous surgical complications [6].

In recent years, advancements in minimally invasive techniques have brought increased attention to neuroendoscopic surgery (NS) and stereotactic aspiration (SA) for the treatment of ICH [7–9]. NS utilizes an endoscope to access the hematoma cavity through a minimally invasive approach, providing clear visualization and precise manipulation for hematoma removal, thereby minimizing damage to normal brain tissue [10]. SA, guided by computed tomography (CT) or magnetic resonance imaging (MRI), involves accurately positioning a needle at the hematoma's center, using negative pressure suction to aspirate the hematoma, and applying urokinase to dissolve residual blood clots. This

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method allows for precise targeting while avoiding critical brain functional areas, offering both accuracy and procedural simplicity [7].

Studies have shown that NS and SA are more effective than traditional craniotomy in improving the prognosis of HICH patients [8,11,12]. However, despite their recognized advantages, comparative studies evaluating their distinct effects on postoperative neurological function and long-term functional outcomes remain scarce, particularly in patients with HICH [13]. This lack of direct comparison limits clinicians in making well-informed decisions when selecting the most beneficial surgical approach for individual patients. Therefore, this study specifically analyzes the impact of NS and SA on postoperative neurological function and prognosis in patients with HICH, aiming to provide valuable reference data for optimizing intervention and treatment strategies.

Materials and Methods

Research Object

From April 2020 to December 2023, a total of 247 patients with HICH at Taizhou Hospital of Zhejiang Province affiliated to Wenzhou Medical University were retrospectively analyzed. Based on the surgical treatment method, they were divided into the NS group (n = 65) and the SA group (n = 182). This study has been approved by the Ethics Review Committee of Taizhou Hospital of Zhejiang Province (Approval number: No. KL20250110) and strictly adheres to the principles outlined in the Declaration of Helsinki. The patients included in the study have signed the informed consent form.

Inclusion and Exclusion Criteria

Inclusion criteria included meeting the clinical standards for the diagnosis and treatment of hypertensive cerebral hemorrhage as outlined in the *Guidelines for Diagnosis and Treatment of Cerebral Hemorrhage in China (2014)* [14]; having the bleeding site in the basal ganglia, frontal lobe, occipital lobe, cerebellum, thalamus, or pons; being the first onset of hemorrhage; presence of a space-occupying hematoma; being under the age of 75; having treatment starting within 48 hours of symptom onset; and having clear surgical indications with no obvious contraindications for surgery, as well as signing informed consent for the procedure.

Exclusion criteria included having brainstem hemorrhage; unstable vital signs; severe heart, liver, or renal insufficiency; cerebrovascular malformations or cranial aneurysms detected by cerebrovascular examination; significantly abnormal coagulation function; and incomplete clinical data.

Surgical Methods

NS: Under general anesthesia, NS was performed using the LOTTA monitoring system (https://www.karlstorz.com/cn/zh/search.htm?cat=1000222708). A surgical plan was developed based on CT scan results. Patients were placed under general anesthesia and underwent endotracheal intubation through the pre-designed approach. An incision was made at the scalp nearest to the hematoma, and a milling cutter was used to open a small bone flap with a diameter of 3 cm. After achieving hemostasis of the dura mater with electrocautery, the dura was incised, and a puncture trocar was inserted to establish the surgical pathway. Intraoperatively, ultrasound was used for hematoma localization if necessary. The cortex was punctured, and an endoscopic drill sheath was advanced to the hematoma site. The sheath served as an endoscopic guide and was placed at angles of 0° or 30°, under which the hematoma was cleared. As the central hematoma was removed, the peripheral areas collapsed inward, and brain tissue applied constant pressure to the residual blood clot in the catheter, aiding in its removal. During this process, the sheath was continuously retracted to clear most of the hematoma. Arterial bleeding was observed under the microscope and suctioned at the bleeding points. Bipolar electrocautery was used for hemostasis. If a blood clot became lodged in the cavity, electrocautery was paused to separate the clot, followed by immediate irrigation. Pressure or scrubbing was applied to stop superficial scalp bleeding. After hematoma removal, the dura was repaired and sutured. The bone flap was replaced and fixed, followed by layer-by-layer suturing of the scalp and skull.

SA: Under general anesthesia, the Leksell stereotactic system (8.3.1, Elekta AB, Stockholm, Sweden) was used to guide the intracerebral hematoma puncture needle. An approximately 4 cm incision was made on the scalp at the cranial entrance, with an electric drill used to create a hole (about 8 mm in diameter) through the scalp and skull layer by layer. After reaching the subdural space, the electric drill was removed, and the puncture needle was placed at the center of the hematoma. A drainage tube was connected, and the needle core was withdrawn. A medical syringe was used to aspirate the hematoma. Aspiration was stopped when the volume reached 1/3 of the total bleeding volume. A needle-shaped crusher (YHEP-100 × 60, Hebi City Yinhe Analytical Instrument Chemical Co., Ltd., Hebi, China) was then connected, and the blood cavity was washed three times under a high-pressure jet. Urokinase (15,000 U/kg, Guoyao Zhunzi H20030199, Nanjing Nanda Pharmaceutical Co., Ltd., Nanjing, China) was injected into the hematoma cavity at a dose of 30,000 U to fully dissolve the hematoma. The drainage tube was closed, and after 3 hours, the tube was loosened to allow the hematoma to flow out. Depending on the patient's condition, hematoma dissolution could be performed 1 to 3 times. After the dissolution process was completed, the stereotactic frame was removed, and the patient was returned to the ward. The amount of hematoma drainage was monitored, and a cranial CT re-examination was performed. If residual hematoma remained, secondary dissolution and drainage were performed until the hematoma was fully drained, at which

point the tube was removed. The catheter was typically removed within 5–10 days postoperatively.

All the aforementioned procedures were performed by the same neurosurgical team at Taizhou Hospital of Zhejiang Province affiliated to Wenzhou Medical University, with each surgeon having over 5 years of experience in cerebral hemorrhage surgery. Both the operators and their assistants have undergone training and certification in neurosurgery, ensuring the elimination of potential biases.

Observation Indicators

Well-trained researchers collected patient data through a standardized process, which included:

(I) Clinical baseline information includes gender, age, hypertension grade, preoperative hematoma volume, preoperative Glasgow Coma Scale (GCS) score, smoking status, alcohol consumption status, location of cerebral hemorrhage, and duration of hypertension. Hypertension grade was classified as follows: Grade I hypertension was defined as systolic blood pressure (SBP) 140–159 mmHg and/or diastolic blood pressure (DBP) 90–99 mmHg; Grade II hypertension was defined as SBP 160–179 mmHg and/or DBP 100–109 mmHg; and Grade III hypertension was defined as SBP $\geq$180 mmHg and/or DBP $\geq$110 mmHg [15]. The GCS score was used to assess the degree of coma in patients, with a maximum score of 15 indicating full consciousness. Scores of 13 to 14 were classified as mild coma; scores of 9 to 12 as moderate coma; and scores $\leq$8 as severe coma. The lower the score, the greater the impairment of consciousness [16].

(II) Perioperative indicators include intraoperative blood loss, postoperative residual hematoma volume, and hematoma clearance rate. The hematoma clearance rate is calculated as follows: Hematoma clearance rate = (preoperative hematoma volume-postoperative residual hematoma volume)/preoperative hematoma volume, calculated using 3D slicer software.

(III) Serum neurofunctional markers include brain-derived neurotrophic factor (BDNF), neuron-specific enolase (NSE), and glial fibrillary acidic protein (GFAP). The specific analysis methods are as follows: Venous blood samples (3 mL) were collected from patients 7 days before surgery, and 1 month and 3 months after surgery. After centrifugation, the supernatant was stored at –40 °C for later analysis. The levels of BDNF (SCA011Hu), NSE (SEA537Hu), and GFAP (SEA068Hu) were measured using enzyme-linked immunosorbent assay (ELISA; Cloud-Clone Corp., Wuhan, China).

(IV) Neurofunctional scores include the National Institutes of Health Stroke Scale (NIHSS) score, modified Rankin Scale (mRS) score, and Glasgow Outcome Scale (GOS) score. These scores were recorded 7 days before surgery and 1 month and 3 months after surgery to evaluate the recovery of neurological function. The NIHSS evaluates levels of consciousness, gaze, vision, limb movement, ataxia, sensation, language, etc., with scores ranging from 0 to 4. The total score ranges from 0 to 42: a score $\leq$15 points indicates mild neurological impairment, a score of 16–20 points indicates moderate impairment, and a score >20 points indicates severe impairment, with higher scores indicating more severe neurological deficits and disease severity [17]. The mRS has a scoring range of 0 (no symptoms), 1 (symptomatic but no significant disability), 2 (mild disability), 3 (moderate disability), 4 (moderate to severe disability), 5 (severe disability), and 6 (death) [18]. The GOS is a 5-point scale: 5 (good recovery), 4 (moderate disability), 3 (severe disability), 2 (vegetative state), and 1 (death) [19].

(V) Complications: Postoperative complications were recorded, including pulmonary infection, intracranial infection, renal insufficiency, and secondary cerebral hemorrhage.

(VI) Functional prognosis scores: Functional outcome scores were recorded at 3 and 6 months after surgery for both groups, assessing the activities of daily living (ADL) score and Mini-Mental State Examination (MMSE) score. The ADL scale is used to evaluate self-care abilities, while the MMSE is used to assess cognitive function. The ADL scale includes 10 items: defecation, urination, grooming, toileting, eating, mobility, activity, dressing, stair climbing, and bathing. The maximum score for this scale is 100 points; the higher the score, the greater the ability to perform daily activities. A score below 20 indicates extremely severe functional impairment, rendering the patient unable to care for themselves independently; a score between 20 and 40 suggests that the patient requires significant assistance in daily life; a score between 40 and 60 indicates that the patient needs some help with daily activities; and a score above 60 indicates that the patient can live independently [20]. The MMSE scale includes 7 aspects: temporal orientation, place orientation, immediate memory, attention and calculation, delayed memory, language, and visual-spatial skills, comprising a total of 30 questions. Each correct answer scores one point, while incorrect answers or "do not know" responses score zero. The total score ranges from 0 to 30 points, with a higher score indicating better cognitive function [21].

Statistical Analysis

Data were analyzed using SPSS (V.21.0, IBM, Armonk, NY, USA). The Kolmogorow-Smironov (K-S) test was used to analyze the normality of continuous variables, which are expressed as mean $\pm$ standard deviation ($\bar{x} \pm$ s). The independent sample *t*-test was used for between-group comparisons. For within-group comparisons before and after treatment, a paired sample *t*-test was employed. Categorical data are expressed as frequencies and percentages [n (%)], with differences among the categorical data analyzed using the chi-square test. In the chi-square test, if all theoretical frequencies were T $\geq$5 and the total sample size (n) $\geq$40, the Pearson chi-square test was used. If 1 $\leq$ T

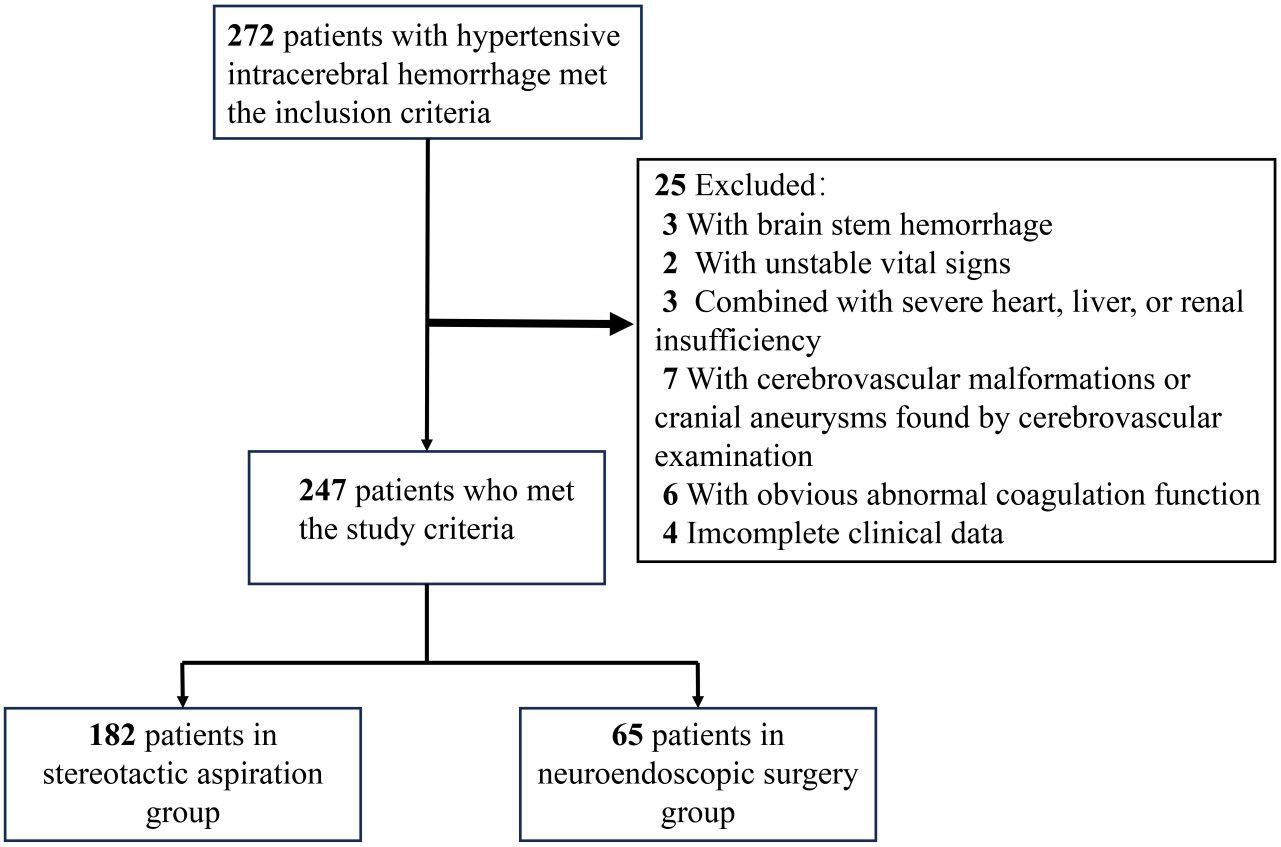

Fig. 1. The selection flow chart of patients.

< 5 and $n \geq 40$, the chi-square test with Yates's correction was applied. A p value < 0.05 was considered statistically significant.

Results

Basic Characteristics

As shown in Fig. 1, a total of 247 patients with HICH were included according to the inclusion and exclusion criteria. Of these, 65 underwent NS (NS group) and 182 underwent SA (SA group). There were no significant differences in gender, age, hypertension classification, preoperative hematoma volume, preoperative GCS score, smoking status, alcohol consumption status, site of cerebral hemorrhage, or the duration of hypertension between the two groups, indicating that the groups were comparable ($p > 0.05$) (Table 1).

Perioperative Period Index

The residual hematoma and intraoperative bleeding volume in the SA group were lower than those in the NS group, and the hematoma clearance rates in the SA group were higher than that in the NS group ($p < 0.05$) (Table 2).

Indicators of Neurological Function in Serum

At 7 days before surgery, there were no statistically significant differences in the levels of BDNF, NSE, and GFAP between the two groups ($p > 0.05$). Compared to baseline levels at 7 days before surgery, BDNF levels significantly increased in both groups at 1 month and 3 months after surgery ($p < 0.001$), with the SA group showing higher BDNF levels than the NS group ($p < 0.05$). Conversely, compared to baseline levels at 7 days before surgery, NSE and GFAP levels decreased in both groups at 1 month and 3 months after surgery ($p < 0.05$), with the SA group showing lower NSE and GFAP levels than the NS group ($p < 0.05$) (Table 3).

Neurological Function Scores

There were no significant differences in NIHSS, mRS, and GOS scores between the NS group and the SA group at 7 days before surgery ($p > 0.05$). Compared to 7 days before surgery, NIHSS and mRS scores decreased in both groups, and GOS scores increased in both groups at 1 month and 3 months after surgery ($p < 0.001$). At 1 month and 3 months after surgery, NIHSS and mRS scores in the SA group were lower than those in the NS group, and the GOS score was higher in the SA group than in the NS group ($p < 0.05$) (Table 4).

Table 1. The baseline characteristics of patients.

Characteristic/Group	NS group (n = 65)	SA group (n = 182)	t/χ^2 value	p value
Gender (%)			0.767	0.381
Male	45 (69.23)	115 (63.19)		
Female	20 (30.77)	67 (36.81)		
Age ($\bar{x} \pm$ s, years)	58.27 ± 9.62	55.46 ± 11.37	1.778	0.077
Hypertension grade (%)			0.419	0.811
Grade I hypertension	18 (27.69)	45 (24.73)		
Grade II hypertension	32 (49.23)	98 (53.85)		
Grade III hypertension	15 (23.08)	39 (21.43)		
Preoperative hematoma volume ($\bar{x} \pm$ s, mL)	51.63 ± 11.78	52.41 ± 13.59	0.411	0.682
Preoperative GCS score ($\bar{x} \pm$ s)	9.21 ± 2.43	9.67 ± 3.12	1.077	0.282
Smoking, yes (%)	20 (30.77)	52 (28.57)	0.112	0.738
Alcohol drinking, yes (%)	17 (26.15)	50 (27.47)	0.042	0.837
Site of cerebral hemorrhage (%)			0.436	0.804
Basal nuclei	24 (36.92)	72 (39.56)		
Frontal lobe	24 (36.92)	59 (32.42)		
Occipital lobe (%)	17 (26.15)	51 (28.02)		
Course of hypertension ($\bar{x} \pm$ s, years)	6.43 ± 1.12	6.25 ± 1.48	0.893	0.373

NS, neuroendoscopic surgery; SA, stereotactic aspiration; GCS, Glasgow Coma Scale.

Table 2. Comparison of perioperative indexes between the two groups ($\bar{x} \pm$ s).

Characteristic/Group	NS group (n = 65)	SA group (n = 182)	t value	p value
Residual hematoma volume (mL)	7.89 ± 1.23	6.17 ± 1.68	7.558	<0.001
Hematoma clearance rate (%)	84.23 ± 9.48	88.62 ± 12.71	2.542	0.012
Intraoperative blood loss (mL)	60.74 ± 15.69	43.16 ± 14.52	8.201	<0.001

Complications

The incidence of postoperative pulmonary infection, intracranial infection, renal insufficiency and secondary cerebral hemorrhage and the total incidence of these complications in the SA group were lower than those in the NS group, but there was no statistical significance in the above incidence between the NS group and the SA group ($p > 0.05$) (Table 5).

Functional Prognostic Scores

MMSE scores in the SA group were higher than those in the NS group at 3 and 6 months after surgery ($p < 0.05$). And ADL scores in the SA group were higher than those in the NS group at 3 months after surgery ($p < 0.05$), with no significance between the 2 groups at 6 months after surgery ($p > 0.05$) (Table 6).

Discussion

HICH is a common subtype of intracranial hemorrhage, accounting for a significant proportion of these cases, and is associated with a high disease burden and mortality rate. Patients with HICH often experience long-term neurological dysfunction [22]. Minimally invasive intracranial hematoma surgery, a new technique for treating ICH, effectively removes the hematoma through a safe evacuation channel while minimizing damage to adjacent tissues, thus promoting neurological recovery and improving outcomes [23]. This study compares two minimally invasive techniques for treating HICH, demonstrating that SA more effectively removes the hematoma, improves neurological function, and enhances patient prognosis.

The removal of intracranial hematomas is crucial for reducing cerebral edema and stabilizing intracranial pressure in patients with HICH, thereby minimizing neurological damage [24]. Research shows that SA has a higher hematoma evacuation rate compared to conservative treatment and effectively reduces the mechanical compression caused by the hematoma, limiting its toxic effects on neurons and glial cells [25]. Compared to mini-craniectomy, SA involves less trauma, reduced bleeding, fewer complications, and faster recovery, making it a suitable treatment for HICH [8]. Our results support these findings, further demonstrating that patients undergoing SA experience more effective hematoma removal than those receiving NS, with reduced intraoperative bleeding.

SA features low invasiveness and a short surgical duration, involving precise catheter placement under image guidance for blood aspiration [26]. A small dose of a thrombolytic agent is intermittently administered through this catheter, facilitating the gradual removal of residual hematoma [27,28]. Furthermore, SA effectively reduces iatrogenic blood loss in patients with cerebral hemorrhage. The procedure allows for quick puncture and aspiration of

Table 3. Comparison of serum neurological function indexes between the two groups ($\bar{x} \pm s$).

Characteristic/Group	NS group (n = 65)	SA group (n = 182)	t value	p value
BDNF (μg/L)				
7 days before surgery	3.52 ± 0.67	3.61 ± 0.39	1.300	0.195
1 month after surgery	4.93 ± 0.82**	5.81 ± 1.17**	5.590	<0.001
3 months after surgery	6.43 ± 1.25**	7.65 ± 2.87**	3.313	0.001
NSE (ng/L)				
7 days before surgery	32.26 ± 5.46	33.27 ± 5.61	1.255	0.211
1 month after surgery	25.64 ± 4.29**	22.85 ± 4.53**	4.321	<0.001
3 months after surgery	15.68 ± 3.21**	14.25 ± 3.34**	2.993	0.003
GFAP (ng/mL)				
7 days before surgery	10.24 ± 1.72	10.57 ± 2.33	1.044	0.297
1 month after surgery	9.66 ± 1.38*	8.45 ± 1.71**	5.137	<0.001
3 months after surgery	8.32 ± 1.41**	7.79 ± 1.62**	2.339	0.020

BDNF, brain-derived neurotrophic factor; NSE, neuron-specific enolase; GFAP, glial fibrillary acidic protein.

Compared to 7 days before the surgery in the same group, *$p < 0.05$, **$p < 0.001$.

Table 4. Comparison of neurological function scores between two groups ($\bar{x} \pm s$).

Characteristic/Group	NS group (n = 65)	SA group (n = 182)	t value	p value
NIHSS score				
7 days before surgery	20.86 ± 7.81	20.13 ± 7.24	0.683	0.495
1 month after surgery	16.32 ± 4.37**	14.65 ± 3.85**	2.895	0.004
3 months after surgery	13.83 ± 3.61**	10.55 ± 2.46**	8.089	<0.001
mRS score				
7 days before surgery	4.59 ± 0.48	4.46 ± 0.71	1.368	0.173
1 month after surgery	3.77 ± 0.26**	3.35 ± 0.39**	8.061	<0.001
3 months after surgery	3.06 ± 0.83**	2.64 ± 0.52**	4.717	<0.001
GOS score				
7 days before surgery	2.62 ± 0.40	2.74 ± 0.51	1.717	0.087
1 month after surgery	3.43 ± 0.49**	3.82 ± 0.67**	4.298	<0.001
3 months after surgery	3.98 ± 0.32**	4.25 ± 0.61**	3.402	<0.001

NIHSS, National Institutes of Health Stroke Scale; mRS, modified Rankin Scale; GOS, Glasgow Outcome Scale.

Compared to 7 days before the surgery in the same group, **$p < 0.001$.

the liquid component of the hematoma, thereby reducing intracranial pressure [29]. It should be noted, however, that the NS technique requires the creation of a working sheath several centimeters in diameter to access the deepest part of the hematoma, which can increase intracranial content and pressure, potentially raising the risk of intraoperative bleeding [30].

Neurological function is a critical pathological indicator for assessing the severity and prognosis of patients with HICH [31]. BDNF, a neurotrophic cytokine, is upregulated to aid in neuronal repair following brain injury [32]. NSE serves as a specific and sensitive biomarker for evaluating the severity of craniocerebral injury and predicting prognosis [33,34]. GFAP, expressed predominantly in central nervous system (CNS) astrocytes, rises in serum during cerebral hemorrhage and brain injury, making it a key biomarker for CNS damage and prognosis [35,36]. In our study, we found that 1 and 3 months postoperatively, the SA group exhibited higher serum BDNF levels and lower serum NSE and GFAP levels compared to the NS group.

The NIHSS is a key indicator of neurological function [37], while the mRS and GOS are commonly used to assess neurological recovery in patients with intracranial hemorrhage [29]. The results from these three neurological scores further reinforce our finding that SA is more effective than NS in promoting neurological function recovery in patients with HICH. This improvement can be attributed to the minimally invasive nature and accuracy of SA, along with its higher hematoma clearance rate compared to NS, as observed in this study. These factors significantly contribute to better neurological recovery in patients treated with SA. Additionally, SA reduces surgical stress and inflammation, facilitating the release of neurotrophic factors and enhancing neural regeneration [38].

On the other hand, NS requires more operative space, which can subject brain tissue to traction and pressure, leading to

Table 5. Comparison of complications between the two groups (%).

Characteristic/Group	NS group (n = 65)	SA group (n = 182)	χ^2 value	p value
Pulmonary infection, n (%)	4 (6.15)	9 (4.95)	0.003	0.959
Intracranial infection, n (%)	5 (7.69)	8 (4.40)	0.487	0.485
Renal insufficiency, n (%)	3 (4.62)	8 (4.40)	0.076	0.782
Secondary cerebral hemorrhage, n (%)	3 (4.62)	5 (2.75)	0.104	0.747
Total occurrence, n (%)	15 (23.08)	30 (16.48)	1.397	0.237

Table 6. Comparison of functional prognostic scores between the two groups ($\bar{x} \pm s$).

Characteristic/Group	NS group (n = 65)	SA group (n = 182)	t value	p value
ADL score				
3 months after surgery	74.35 ± 8.62	77.30 ± 10.20	2.081	0.039
6 months after surgery	81.74 ± 6.38	83.46 ± 8.56	1.479	0.140
MMSE score				
3 months after surgery	19.85 ± 2.24	22.51 ± 5.63	3.702	<0.001
6 months after surgery	21.82 ± 3.67	25.47 ± 4.95	5.443	<0.001

ADL, activities of daily living; MMSE, Mini-Mental State Examination.

greater neural trauma compared to the minimally invasive approach of SA [30]. Another key factor contributing to the observed differences is intraoperative bleeding, which can negatively affect cranial nerve function or hinder the recovery of damaged nerves [39]. In this study, patients in the SA group had significantly reduced intraoperative bleeding compared to those in the NS group, allowing for better recovery of damaged nerves.

This study revealed significantly higher ADL scores in the SA group compared to the NS group at 3 months postoperatively. However, there was no significant difference in ADL scores between the two groups at 6 months postoperatively. This suggests that patients in the SA group recovered their ADL abilities more quickly than those in the NS group. Previous research has demonstrated that for moderate-volume thalamic-capsular intracerebral hemorrhage, SA offers advantages, such as reduced hospital stays and lower complication rates, compared to conservative treatment [25]. These benefits likely stem from the precise CT-guided localization of the minimally invasive stereotactic puncture drainage technique, which operates within the hematoma cavity, minimizing damage to surrounding brain tissue and promoting faster recovery [40]. By 6 months post-surgery, the ADL scores between the two groups were statistically similar, likely due to the impact of postoperative rehabilitation programs, including physical and speech therapy. Multidisciplinary rehabilitation studies, lasting from 3 to 14 weeks and involving neuropsychiatry, psychology, physical therapy, occupational therapy, and occasional speech therapy, have shown significant improvements in physical function and quality of life for most patients with impaired ADL [41–43]. Therefore, it is expected that ADL abilities in both groups will eventually converge over time.

MMSE score was used to assess cognitive function, where a higher score indicates better cognitive ability [44]. According to our study's results, the SA group had higher MMSE scores at 3 and 6 months postoperatively, suggesting superior cognitive restoration. This finding could be attributed to SA's enhanced ability to facilitate neurological recovery, as cognitive function improvement is partly dependent on the overall recovery of neurological function [45]. In contrast, NS, due to its greater surgical trauma, results in slower recovery of cognitive function postoperatively.

This study has several limitations. First, despite collecting extensive confounder data, the retrospective design may have missed potential confounders, such as the impact of preoperative hemostasis and vasospasm prevention drugs on surgical outcomes. Second, the non-randomized patient assignment based on clinical judgment may introduce selection bias. Furthermore, the relatively small sample size from a single center limits the generalizability of the findings. To address these limitations, prospective, multi-center studies with larger sample sizes are needed. These future studies should incorporate randomization, detailed data collection plans, and record information on preoperative hemostatic measures and drug use. Additionally, extending the follow-up period to assess the one-year and long-term efficacy of the two surgical approaches for treating HICH will provide more convincing and comprehensive results.

Conclusions

For the treatment of HICH, SA shows superior outcomes compared to NS in terms of more effective hematoma removal and reduced intraoperative bleeding. Additionally, SA contributes to better improvement in patients' neurological function, quality of life, and cognitive abilities.

Availability of Data and Materials

The data analyzed are available from the corresponding authors upon reasonable request.

Author Contributions

TG and DJL designed the research study. QQZ, CYZ and ZXZ performed the research. HFC and XFP analyzed the data. TG and DJL draft the manuscript. All authors contributed to important editorial changes in the manuscript. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

This study has been approved by the Ethics Review Committee of Taizhou Hospital of Zhejiang Province (Approval number: No. KL20250110) and strictly adheres to the principles outlined in the Declaration of Helsinki. The patients included in the study have signed the informed consent form.

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Not applicable.

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Conflict of Interest

The authors declare no conflict of interest.

References

[1] Luo MY, Su JH, Gong SX, Liang N, Huang WQ, Chen W, *et al*. Ferroptosis: New Dawn for Overcoming the Cardio-Cerebrovascular Diseases. Frontiers in Cell and Developmental Biology. 2021; 9: 733908. https://doi.org/10.3389/fcell.2021.733908.

[2] Shah S, Ojha R, Chamlagain R, Chhetri S, Prasad P, Baral B, *et al*. Therapeutic drug level of tacrolimus causing intracranial hemorrhage in a patient with renal transplant. Clinical Case Reports. 2022; 10: e05788. https://doi.org/10.1002/ccr3.5788.

[3] Li CF, Lu XJ, Wang GH, Li L, Li B, Tu S, *et al*. Efficacy and safety of intraoperative ultrasound-assisted neuroendoscopy in the treatment of hypertensive intracerebral hemorrhage via transsylvian approach. Zhonghua Yi Xue Za Zhi. 2021; 101: 620–623. (In Chinese) https://doi.org/10.3760/cma.j.cn112137-20200607-01792.

[4] Ai M, Zhang H, Feng J, Chen H, Liu D, Li C, *et al*. Research advances in predicting the expansion of hypertensive intracerebral hemorrhage based on CT images: an overview. PeerJ. 2024; 12: e17556. https://doi.org/10.7717/peerj.17556.

[5] de Oliveira Manoel AL. Surgery for spontaneous intracerebral hemorrhage. Critical Care. 2020; 24: 45. https://doi.org/10.1186/s13054-020-2749-2.

[6] Hostettler IC, Seiffge DJ, Werring DJ. Intracerebral hemorrhage: an update on diagnosis and treatment. Expert Review of Neurotherapeutics. 2019; 19: 679–694. https://doi.org/10.1080/14737175.2019.1623671.

[7] Guo W, Liu H, Tan Z, Zhang X, Gao J, Zhang L, *et al*. Comparison of endoscopic evacuation, stereotactic aspiration, and craniotomy for treatment of basal ganglia hemorrhage. Journal of Neurointerventional Surgery. 2020; 12: 55–61. https://doi.org/10.1136/neurintsurg-2019-014962.

[8] Mao Y, Shen Z, Zhu H, Yu Z, Chen X, Lu H, *et al*. Observation on therapeutic effect of stereotactic soft channel puncture and drainage on hypertensive cerebral hemorrhage. Annals of Palliative Medicine. 2020; 9: 339–345. https://doi.org/10.21037/apm.2020.03.12.

[9] Ibrahim A, Arifianto MR, Al Fauzi A. Minimally Invasive Neuroendoscopic Surgery for Spontaneous Intracerebral Hemorrhage: A Review of the Rationale and Associated Complications. Acta Neurochirurgica. Supplement. 2023; 130: 103–108. https://doi.org/10.1007/978-3-030-12887-6_13.

[10] Gui C, Gao Y, Hu D, Yang X. Neuroendoscopic minimally invasive surgery and small bone window craniotomy hematoma clearance in the treatment of hypertensive cerebral hemorrhage. Pakistan Journal of Medical Sciences. 2019; 35: 377–382. https://doi.org/10.12669/pjms.35.2.463.

[11] Xu X, Zhang H, Zhang J, Luo M, Wang Q, Zhao Y, *et al*. Minimally invasive surgeries for spontaneous hypertensive intracerebral hemorrhage (MISICH): a multicenter randomized controlled trial. BMC Medicine. 2024; 22: 244. https://doi.org/10.1186/s12916-024-03468-y.

[12] Tang C, Zhang M, Li W. Meta-analysis of stereotactic hematoma removal and craniotomy hematoma removal in the treatment of hypertensive intracerebral hemorrhage in the elderly. Medicine. 2023; 102: e36533. https://doi.org/10.1097/MD.0000000000036533.

[13] Xie Q, Zhang X, Ding Y, Zhang L. Assessing the Clinical Efficacy of Stereotactic Puncture in Combination with Postoperative Rehabilitation Training for Hypertensive Cerebral Hemorrhage. Alternative Therapies in Health and Medicine. 2024; 30: 122–127.

[14] Chinese Medical Association Neurology Branch Cerebrovascular Disease Group, Chinese Medical Association Neurology Branch. Guidelines for Diagnosis and Treatment of Cerebral Hemorrhage in China (2014). Chinese Journal of Neurology. 2015; 48: 435–444. (In Chinese)

[15] Unger T, Borghi C, Charchar F, Khan NA, Poulter NR, Prabhakaran D, *et al*. 2020 International Society of Hypertension Global Hypertension Practice Guidelines. Hypertension. 2020; 75: 1334–1357. https://doi.org/10.1161/HYPERTENSIONAHA.120.15026.

[16] Sternbach GL. The Glasgow coma scale. The Journal of Emergency Medicine. 2000; 19: 67–71. https://doi.org/10.1016/s0736-4679(00)00182-7.

[17] Kwah LK, Diong J. National Institutes of Health Stroke Scale (NIHSS). Journal of Physiotherapy. 2014; 60: 61. https://doi.org/10.1016/j.jphys.2013.12.012.

[18] Quinn TJ, Dawson J, Walters MR, Lees KR. Reliability of the modified Rankin Scale: a systematic review. Stroke. 2009; 40: 3393–3395. https://doi.org/10.1161/STROKEAHA.109.557256.

[19] Wilson JT, Pettigrew LE, Teasdale GM. Structured interviews for the Glasgow Outcome Scale and the extended Glasgow Outcome Scale: guidelines for their use. Journal of Neurotrauma. 1998; 15: 573–585. https://doi.org/10.1089/neu.1998.15.573.

[20] Mlinac ME, Feng MC. Assessment of Activities of Daily Living, Self-Care, and Independence. Archives of Clinical Neuropsychology. 2016; 31: 506–516. https://doi.org/10.1093/arclin/acw049.

[21] Folstein MF, Folstein SE, McHugh PR. "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. Journal of Psychiatric Research. 1975; 12: 189–198. https://doi.org/10.1016/0022-3956(75)90026-6.

[22] Chen J, Yuan XY, Zhang X. Intracerebral hemorrhage influences hippocampal neurogenesis and neurological function recovery via Notch1 signaling. Neuroreport. 2021; 32: 489–497. https://doi.org/10.1097/WNR.0000000000001614.

[23] Tang Y, Yin F, Fu D, Gao X, Lv Z, Li X. Efficacy and safety of minimal invasive surgery treatment in hypertensive intracerebral hemorrhage: a systematic review and meta-analysis. BMC Neurology. 2018; 18: 136. https://doi.org/10.1186/s12883-018-1138-9.

[24] Li Y, Yang S, Zhou X, Lai R, Tan D. A Retrospective Cohort Study

of Neuroendoscopic Surgery versus Traditional Craniotomy on Surgical Success Rate, Postoperative Complications, and Prognosis in Patients with Acute Intracerebral Hemorrhage. Computational Intelligence and Neuroscience. 2022; 2022: 2650795. https://doi.org/10.1155/2022/2650795.

[25] Yang S, Liu Y, Wang S, Peng H, Luo H, Cai Z, *et al*. Stereotactic Puncture Surgery for the Treatment of Moderate Volume of Thalamus-Internal Capsule Area Hemorrhage: An Analysis of Real-World Data. World Neurosurgery. 2024; 186: e213–e226. https://doi.org/10.1016/j.wneu.2024.03.107.

[26] Ding Y, Qi M, Zhang X, Dong J, Wu D. Stereotactic hematoma puncture and drainage for primary pontine hemorrhage: Clinical outcomes and predictive model. Heliyon. 2024; 10: e27487. https://doi.org/10.1016/j.heliyon.2024.e27487.

[27] Chen D, Tang Y, Nie H, Zhang P, Wang W, Dong Q, *et al*. Primary Brainstem Hemorrhage: A Review of Prognostic Factors and Surgical Management. Frontiers in Neurology. 2021; 12: 727962. https://doi.org/10.3389/fneur.2021.727962.

[28] Vitt JR, Sun CH, Le Roux PD, Hemphill JC, 3rd. Minimally invasive surgery for intracerebral hemorrhage. Current Opinion in Critical Care. 2020; 26: 129–136. https://doi.org/10.1097/MCC.0000000000000695.

[29] Xiong Y, Guo X, Huang X, Kang X, Zhou J, Chen C, *et al*. Efficacy and safety of tranexamic acid in intracranial haemorrhage: A meta-analysis. PLoS ONE. 2023; 18: e0282726. https://doi.org/10.1371/journal.pone.0282726.

[30] Lu W, Wang H, Feng K, He B, Jia D. Neuroendoscopic-assisted versus mini-open craniotomy for hypertensive intracerebral hemorrhage: a retrospective analysis. BMC Surgery. 2022; 22: 188. https://doi.org/10.1186/s12893-022-01642-8.

[31] Zhi C, Zeng S, Chen Y, Liao D, Lai M, Wang Z, *et al*. Clemastine promotes recovery of neural function and suppresses neuronal apoptosis by restoring balance of pro-inflammatory mediators in an experimental model of intracerebral hemorrhage. International Journal of Medical Sciences. 2021; 18: 639–645. https://doi.org/10.7150/ijms.51150.

[32] Keefe KM, Sheikh IS, Smith GM. Targeting Neurotrophins to Specific Populations of Neurons: NGF, BDNF, and NT-3 and Their Relevance for Treatment of Spinal Cord Injury. International Journal of Molecular Sciences. 2017; 18: 548. https://doi.org/10.3390/ijms18030548.

[33] Zhang H, Huo Q, Jing R, Dong M. Clinical analysis of acute poisoning in children. BMC Pediatrics. 2024; 24: 212. https://doi.org/10.1186/s12887-024-04697-z.

[34] Thelin EP, Zeiler FA, Ercole A, Mondello S, Büki A, Bellander BM, *et al*. Serial Sampling of Serum Protein Biomarkers for Monitoring Human Traumatic Brain Injury Dynamics: A Systematic Review. Frontiers in Neurology. 2017; 8: 300. https://doi.org/10.3389/fneur.2017.00300.

[35] Shah MA, Park DJ, Kang JB, Kim MO, Koh PO. Baicalin attenuates lipopolysaccharide-induced neuroinflammation in cerebral cortex of mice via inhibiting nuclear factor kappa B (NF-κB) activation. The Journal of Veterinary Medical Science. 2019; 81: 1359–1367. https://doi.org/10.1292/jvms.19-0281.

[36] Messing A, Brenner M. GFAP at 50. ASN Neuro. 2020; 12: 1759091420949680. https://doi.org/10.1177/1759091420949680.

[37] Sun TK, Chiu SC, Yeh SH, Chang KC. Assessing reliability and validity of the Chinese version of the stroke scale: scale development. International Journal of Nursing Studies. 2006; 43: 457–463. https://doi.org/10.1016/j.ijnurstu.2005.07.004.

[38] Gong X, Dong HQ, Li X, Liu ZJ. Comparative analysis of clinical efficacy of stereotactic robot-guided puncture hematoma drainage and conventional puncture hematoma drainage in the treatment of intracerebral hemorrhage. Pakistan Journal of Medical Sciences. 2024; 40: 1675–1681. https://doi.org/10.12669/pjms.40.8.8833.

[39] Kruger AJ, Walker PJ, Foster WJ, Jenkins JS, Boyne NS, Jenkins J. Important observations made managing carotid body tumors during a 25-year experience. Journal of Vascular Surgery. 2010; 52: 1518–1523. https://doi.org/10.1016/j.jvs.2010.06.153.

[40] Hwang K, Hwang G, Kwon OK, Bang JS, Oh CW. CT Fluoroscopy-guided Aspiration of Intracerebral Hematomas: Technique and Outcomes. Journal of Cerebrovascular and Endovascular Neurosurgery. 2015; 17: 7–12. https://doi.org/10.7461/jcen.2015.17.1.7.

[41] Demartini B, Batla A, Petrochilos P, Fisher L, Edwards MJ, Joyce E. Multidisciplinary treatment for functional neurological symptoms: a prospective study. Journal of Neurology. 2014; 261: 2370–2377. https://doi.org/10.1007/s00415-014-7495-4.

[42] Jordbru AA, Smedstad LM, Klungsøyr O, Martinsen EW. Psychogenic gait disorder: a randomized controlled trial of physical rehabilitation with one-year follow-up. Journal of Rehabilitation Medicine. 2014; 46: 181–187. https://doi.org/10.2340/16501977-1246.

[43] McCormack R, Moriarty J, Mellers JD, Shotbolt P, Pastena R, Landes N, *et al*. Specialist inpatient treatment for severe motor conversion disorder: a retrospective comparative study. Journal of Neurology, Neurosurgery, and Psychiatry. 2014; 85: 895–900. https://doi.org/10.1136/jnnp-2013-305716.

[44] Hou Z, Yu X, Chen J, Brenner JS, Sun Z, Shang H. Does acupuncture have advantages in the rehabilitation of vascular mild cognitive impairment? A systematic review and meta-analysis. Heliyon. 2023; 9: e18955. https://doi.org/10.1016/j.heliyon.2023.e18955.

[45] James LM, Leuthold AC, Dolan S, Georgopoulos AP. Dependence of cognitive ability on synchronous neural interactions determined by magnetoencephalography. Journal of Neurophysiology. 2023; 129: 963–967. https://doi.org/10.1152/jn.00077.2023.