Article

Assessing the Effect of Neuroendoscopic Surgery on Cerebral Hemodynamics and Functional Recovery in Patients With Brain Hemorrhage

Ann. Ital. Chir., 2025 96, 3: 371–379
https://doi.org/10.62713/aic.3907

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AIM: This study aims to investigate the impact of neuroendoscopic surgery on cerebral hemodynamics and functional recovery in patients with different brain hemorrhage severities.
METHODS: This study included 161 patients with brain hemorrhage who were admitted to the Affiliated Hospital of Putian University, China, between January 2021 and January 2022. Patients were divided into a neuroendoscopy group and a minimally invasive drilling group based on the surgical techniques. Furthermore, patients in the neuroendoscopy group were further stratified into mild, moderate, and severe subgroups based on their Glasgow Coma Scale (GCS) scores. Surgical outcomes, including hemorrhage volume, hematoma clearance rate, surgical duration, and postoperative hemorrhage volume, were compared between the two groups. Additionally, cerebral hemodynamic parameters, such as critical pressure (CP), mean blood flow quantity (Qmean), peripheral resistance (Rv), mean blood flow velocity (Vm), and pulsatility index (PI), were recorded before surgery and 7 days postoperatively. Functional recovery was assessed using the National Institutes of Health Stroke Scale (NIHSS), the Fugl-Meyer Assessment (FMA), and the Coma Recovery Scale-Revised (CRS-R).
RESULTS: Compared to the minimally invasive drilling group, the neuroendoscopy group exhibited greater intraoperative hemorrhage volume ($p < 0.001$), higher hematoma clearance rate at 24 hours post-surgery ($p < 0.001$), longer surgical duration ($p < 0.001$), and lower postoperative hemorrhage volume ($p < 0.001$). However, 7 days postsurgery, the neuroendoscopy group demonstrated significantly higher Qmean ($p < 0.001$) and Vm ($p < 0.001$) and lower CP ($p < 0.001$), Rv ($p < 0.001$), and PI ($p < 0.001$) compared to the minimally invasive drilling group. Within the neuroendoscopy group, patients in the severe subgroup had higher PI values 7 days after surgery than those in the mild and moderate subgroups. Assessment of functional recovery outcomes indicated that the neuroendoscopy group had greater improvements, with significantly lower NIHSS scores ($p < 0.01$) and higher FMA ($p < 0.01$) and CRS-R scores ($p < 0.01$) compared to the minimally invasive drilling group. Furthermore, mild and moderate subgroups showed greater reductions in NIHSS scores ($p < 0.05$) and increases in FMA ($p < 0.05$) and CRS-R scores ($p < 0.05$) than the severe subgroup.
CONCLUSIONS: Neuroendoscopic treatment may effectively improve cerebral hemodynamics and promote functional recovery in patients with brain hemorrhage, with the impacts being more pronounced in patients with mild or moderate hemorrhage compared to those with severe conditions.

Keywords: brain hemorrhage; neuroendoscopy; functional recovery; cerebral hemodynamics

Introduction

Brain hemorrhage, a severe neurovascular condition, is characterized by bleeding within brain tissue and is often associated with significant neurological impairments and high mortality rates [1]. It is a leading cause of death and disability worldwide, predominantly impacting older individuals [2]. Furthermore, the 30-day mortality rate among affected individuals remains drastically high, reaching up to 50% [3,4]. Critical risk factors for brain hemorrhage include hypertension, arteriosclerosis, and brain arteriovenous malformations [5]. Treatment approaches for this condition involve conservative management and surgical intervention. Conservative treatment approaches generally aim to control blood pressure using anticoagulants, anticonvulsants, and dehydrating agents [6]. However, the effectiveness of this treatment method is limited, especially in cases of extensive or severe hemorrhage, where functional recovery outcomes are often poor [7]. Traditional craniotomy, despite being widely employed, leads to significant brain trauma and suboptimal therapeutic outcomes [8]. In contrast, neuroendoscopic treatment has emerged as a minimally invasive surgical approach, offering advantages like reduced trauma, faster recovery, and fewer complications. This approach has demonstrated promising therapeutic outcomes in managing cerebrovascular conditions, including brain hemorrhage and intracranial aneurysms [9].

Submitted: 9 December 2024 Revised: 3 January 2025 Accepted: 20 January 2025 Published: 10 March 2025
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Cerebral hemodynamics is often disrupted in neurological conditions such as traumatic brain injury and brain hemorrhage, potentially impacting patient prognosis and the risk of secondary injury [10]. Moreover, remote ischemic preconditioning in subarachnoid hemorrhage patients alleviated cerebral arterial blood flow velocity [11]. Furthermore, hemodynamic changes in subarachnoid hemorrhage have been found to disrupt energy metabolism, with intracranial pressure negatively associating with the glutamine/glutamate ratio [12].

Despite these observations, research on the impacts of neuroendoscopic therapy on cerebral hemodynamics and functional recovery in patients with varying severities of brain hemorrhage remains limited. Therefore, this study investigated the effect of neuroendoscopic treatment on vascular reconstruction and functional recovery in patients with brain hemorrhage. By comparing the outcomes of neuroendoscopic therapy with those of minimally invasive drilling, this study aims to elucidate the therapeutic significance of neuroendoscopic intervention in the rehabilitation of patients with brain hemorrhage.

Materials and Methods

General Information

This retrospective study included 161 patients with brain hemorrhage admitted to the Affiliated Hospital of Putian University, China, between January 2021 and January 2022. All patients met the surgical criteria for hematoma evacuation as outlined in the *Chinese guidelines for diagnosis and treatment of acute intracerebral hemorrhage 2019* [13]. These criteria include significant neurological deterioration, a hematoma volume >30 mL, and a midline shift of >5 mm on imaging. These criteria were consistently applied to both the neuroendoscopic and minimally invasive drilling study groups to ensure comparability. Based on the surgical method, patients were divided into the neuroendoscopy group (n = 81) and the minimally invasive drilling group (n = 80). The selection of surgical procedure was guided by clinical factors, including hematoma size, location, proximity to critical structures, and the patient's neurological status, as evaluated by the neurosurgeons. To ensure consistency in surgical techniques and minimize outcomes variability, the surgeries of all the included cases were performed by the same experienced surgical team. Patients in the neuroendoscopy group underwent minimally invasive neuroendoscopic treatment, while those in the minimally invasive drilling group received conventional minimally invasive hematoma clearance.

Patients within the neuroendoscopy group were further classified into mild ($13 \leq$ Glasgow Coma Scale (GCS) ≤ 14, n = 45), moderate ($9 \leq$ GCS ≤ 12, n = 23), and severe ($3 \leq$ GCS ≤ 8, n = 13) subgroups based on their GCS scores. The study design followed the Declaration of Helsinki and was approved by the Ethics Committee of the Affiliated Hospital of Putian University (no. PTUH2022412). All procedures adhered to ethical guidelines and written informed consent was obtained from all participants.

The study inclusion criteria were as follows: ① patients aged 50–80 years who met the diagnostic criteria for brain hemorrhage as outlined in the *Chinese guidelines for diagnosis and treatment of acute intracerebral hemorrhage 2019* [13], ② a time interval from symptom onset to surgery within 6 hours, with the surgical intervention performed for the first time, and ③ availability of complete clinical data for analysis.

Patients were excluded if they met any of the following conditions: ① presence of severe hepatic or renal dysfunction, cardiopulmonary dysfunction, malignant tumors, or severe infectious diseases, ② brain hemorrhage caused by trauma, stroke, cerebrovascular malformations, or intracranial aneurysms, as determined by imaging findings from computed tomography angiography (CTA) or magnetic resonance angiography (MRA), which were conducted for all patients before surgery, and ③ mental illness or other conditions disrupting their ability to communicate effectively.

Surgical Procedures

Neuroendoscopy Group

Patients in the neuroendoscopy group underwent minimally invasive neuroendoscopic hematoma clearance. They were positioned supine with their heads stabilized, and general anesthesia was administered. The lesion and drilling sites were identified using preoperative computed tomography (CT) imaging (Optima 660, GE Healthcare, Chicago, IL, USA). A scalp incision was made near the hematoma site, and a bone drill (SA302, Nangjing SansBio Co., Ltd., Nangjing, China) was used to create a burr hole (2.5–3.3 cm in diameter) at the center of the hematoma.

The dura mater was then incised, and the functional and vascular areas of the cerebral cortex were carefully navigated to avoid any damage. A neuroendoscope was inserted to assess the brain tissue. Once the lesion was identified, a disposable brain puncture cannula was used to access the hematoma cavity. The inner core of the cannula was removed to create an operational channel. Hematoma evacuation was performed using a syringe and a small suction tip under neuroendoscopic guidance, with careful attention to protecting surrounding brain tissue and minimizing iatrogenic injury. Hemostasis was confirmed by ensuring no active bleeding remained. Approximately 55%–75% of the hematoma was removed during the procedure.

A drainage tube was placed postoperatively, and every 4 hours, 40,000–60,000 U of urokinase (H44022742, 10,000 U/bottle, Guangdong Techpool Bio-Pharma Co., Ltd., Guangzhou, China) dissolved in 3 mL of 0.9% sodium chloride solution was administered through the tube to clear residual hematoma. The drainage was discontinued once the drainage fluid became blood-free.

Minimally Invasive Drilling Group

Similarly, patients in the minimally invasive drilling group received general anesthesia. They were positioned supine, and preoperative CT was used to identify the area with the thickest hematoma. The puncture site and trajectory were located accordingly. A 1.5–2.0 cm scalp incision was made at the designated site, followed by the creation of a burr hole in the skull using a bone drill. The dura mater was incised, and a drainage tube with a needle tip was carefully inserted into the hematoma cavity, avoiding essential blood vessels and functional brain areas. Approximately 30%–50% of the hematoma volume was aspirated, and the drainage tube was left in place. Postoperatively, the drainage tube was flushed with 20,000 U of urokinase, sealed for 2 hours, and reopened. This drainage process continued for 3–7 days until the hematoma was substantially cleared, after which the tube was removed.

Postoperative Care

All patients were given hyperbaric oxygen therapy in the early postoperative period, followed by symptomatic treatment and rehabilitation exercises.

Data Collection and Assessment of Surgical and Clinical Parameters

Baseline Assessments

Patient information, including gender, age, body mass index (BMI), underlying diseases (e.g., hypertension, diabetes, arteriosclerosis), brain hemorrhage volume, time from symptom onset to surgical intervention, and Glasgow Coma Scale (GCS) score at admission, and hemorrhage site (subarachnoid or intracranial hemorrhage) was collected before surgical procedure. Intraoperative data recorded included intraoperative hemorrhage volume, surgical duration, postoperative hemorrhage volume, complications (e.g., primary hemorrhage, lung infection, electrolyte imbalance, gastrointestinal bleeding), length of hospital stay, and hematoma clearance rate within 24 hours after surgery. Furthermore, postoperative hemorrhage volume was assessed using CT imaging performed within 24 hours after surgery.

The hematoma clearance rate was determined by comparing the hematoma volume on pre- and postoperative imaging performed within 24 hours after surgery. The hematoma clearance rate (%) was calculated using the following formula: Hematoma clearance rate (%) = [(Preoperative hematoma volume–Postoperative hematoma volume)/Preoperative hematoma volume] $\times$ 100.

Hematoma volumes were calculated using the ABC/2 method [14], where A indicates the largest diameter of the hematoma on CT, B represents the diameter perpendicular to A, and C shows the number of slices containing the hematoma multiplied by the slice thickness. The hematoma clearance rate was then determined by comparing these calculated volumes.

Cerebral Hemodynamics

Cerebral hemodynamic parameters were assessed using Transcranial Doppler ultrasonography (DWL Doppler Box X, DWL, Singen, Germany), with cerebral artery designated as the target vessel. To evaluate essential parameters such as critical pressure (CP), mean blood flow quantity (Qmean), peripheral resistance (Rv), mean blood flow velocity (Vm), and pulsatility index (PI), a 2.0 MHz probe was positioned at the temporal window between the orbital rim and the ear, above both zygomatic arches. These measurements were obtained preoperatively and 7 days postoperatively.

Assessment of Functional Recovery

Postoperatively, functional recovery was examined on the 7th, 30th, and 90th days using three standardized assessments: the National Institutes of Health Stroke Scale (NIHSS) [15], the Fugl-Meyer Assessment (FMA) [16], and the Coma Recovery Scale-Revised (CRS-R) [17]. Each tool evaluated specific aspects of recovery, including neurological function, motor abilities, and consciousness. The NIHSS was employed to assess neurological function based on the scoring criteria established by the Academic Conference of Cerebrovascular Diseases, which assigns scores ranging from 0 to 42, with higher scores reflecting more severe neurological dysfunction [18]. The FMA assessed motor function, specifically in the upper and lower limbs, with a total score of 100, where 66 points are for upper limb motor function and 34 points for lower limb motor function. Higher scores indicate better motor function and overall recovery [19]. The CRS-R evaluated consciousness recovery in six dimensions, including speech, hearing, touch, arousal level, movement, and vision. It assigns a maximum score of 23, with higher scores indicating better recovery of consciousness and cognitive responsiveness [20].

Statistical Analysis

Statistical analyses were performed using SPSS (version 20; IBM Corporation, Armonk, NY, USA). Continuous variables were examined for normality using the Kolmogorov-Smirnov test or the Shapiro-Wilk test, depending on the sample size. Normally distributed variables were expressed as mean $\pm$ standard deviation (SD), and comparisons between groups were conducted using the independent-sample t-test. Moreover, non-normally distributed variables were expressed as median and interquartile range (IQR) and analyzed using the Mann-Whitney U test. Categorical data were expressed as frequencies and percentages, with comparisons between groups conducted using the chi-square test. Additionally, analysis of variance (ANOVA) with post hoc tests was used for multiple group comparisons within the normally distributed data, while the Kruskal-Wallis test was used for non-normally distributed data. A p-value of $<$0.05 was considered statistically significant.

Table 1. Comparison of baseline characteristics between the two groups.

Variables	Neuroendoscopy group (n = 81)	Minimally invasive drilling group (n = 80)	t/χ^2	p-value
Gender (n, %)			0.450	0.502
Male	58 (71.6%)	61 (76.3%)		
Female	23 (28.4%)	19 (23.7%)		
Age (year)	58.68 ± 4.82	58.55 ± 4.62	0.173	0.863
BMI	21.66 ± 1.85	21.70 ± 1.72	–0.155	0.877
Presence of underlying disease			0.057	0.812
No	66 (81.5%)	64 (80.0%)		
Yes	15 (18.5%)	16 (20.0%)		
Hemorrhage position			0.055	0.814
Subarachnoid hemorrhage	65 (80.2%)	63 (78.7%)		
Intracranial hemorrhage	16 (19.8%)	17 (21.3%)		
Time from onset to treatment of brain hemorrhage (h)	3.91 ± 1.48	3.99 ± 1.34	–0.333	0.740
GCS score of admission	9.97 ± 4.21	9.20 ± 2.02	1.493	0.138

Data were pressed as mean ± SD or n (%). BMI, body mass index; GCS, Glasgow Coma Scale; SD, standard deviation.

Results

Comparison of Baseline Characteristics between the Two Experimental Groups

This study included 161 patients who underwent hematoma clearance. Of these, 81 patients received neuroendoscopic treatment, comprising 58 males and 23 females, with a mean age of 58.68. The neuroendoscopic group comprised 65 patients with subarachnoid hemorrhage, while 16 had intracranial parenchymal hemorrhage. However, the remaining 80 patients underwent minimally invasive drilling, including 61 males and 19 females, with a mean age of 58.55. The minimally invasive drilling group included 63 cases of subarachnoid hemorrhage and 17 cases of intracranial parenchymal hemorrhage. There were no statistically significant differences between the two groups regarding baseline characteristics such as gender, age, or disease duration ($p > 0.05$, Table 1).

Comparison of Surgical Indicators between the Two Groups

The neuroendoscopy group exhibited significantly higher intraoperative hemorrhage volume and hematoma clearance rate, longer surgical duration, and lower postoperative hemorrhage volume than the minimally invasive drilling group ($p < 0.001$, Table 2). However, the two groups were comparable in terms of postoperative complication rates and hospital stays ($p > 0.05$, Table 2).

To further explore the impact of neuroendoscopy on patients with varying severities of brain hemorrhage, surgical indicators were analyzed across mild, moderate, and severe subgroups. The analysis revealed a significant difference in the total complication rate among the three groups ($p = 0.018$), but no statistically significant difference was found between any of the two groups ($p > 0.05$). Furthermore, no significant differences were found in other surgical indicators, including intraoperative hemorrhage volume, hematoma clearance rate, surgical duration, postoperative hemorrhage volume, and hospital stays ($p > 0.05$, Table 3).

Comparison of Cerebral Hemodynamics between the Two Groups

The effects of the two surgical methods on cerebral hemodynamics were compared between the neuroendoscopy and minimally invasive drilling groups. Both groups demonstrated significant postoperative improvements in cerebral hemodynamic parameters. Specifically, Qmean was significantly increased, while CP, Rv, and PI were decreased compared to preoperative levels ($p < 0.05$), indicating that both neuroendoscopy and minimally invasive drilling effectively improved cerebral hemodynamics in patients with brain hemorrhage. Moreover, there was no significant difference in preoperative cerebral hemodynamic indicators between the two groups. However, seven days after surgery, the neuroendoscopy group showed significantly higher Qmean and Vm and lower CP, Rv, and PI than the minimally invasive drilling group ($p < 0.05$, Table 4). These findings suggest that neuroendoscopy provides superior improvement in cerebral hemodynamics compared to minimally invasive drilling.

The impact of neuroendoscopy on cerebral hemodynamics was further analyzed among patients with mild, moderate and severe brain hemorrhage, with no significant differences observed in the preoperative cerebral hemodynamic indicators among the three subgroups ($p > 0.05$). After surgery, the PI of patients in the severe group was significantly higher than that in the mild and moderate groups ($p < 0.05$, Table 5), indicating that the degree of brain hemorrhage influences the extent of improvement in certain cerebral hemodynamic parameters following neuroendoscopy.

Table 2. Comparison of surgical indicators between the neuroendoscopy and minimally invasive drilling groups.

Parameters	Neuroendoscopy group (n = 81)	Minimally invasive drilling group (n = 80)	$t/Z/\chi^2$	p-value
Intraoperative hemorrhage volume (mL)	94.28 ± 4.89	86.68 ± 3.40	12.979	<0.001
Hematoma clearance rate at 24 h after surgery	82.20 ± 8.70	71.50 ± 11.40	6.689	<0.001
Surgical time (min)	112.44 ± 10.09	56.08 ± 5.96	43.201	<0.001
Postoperative hemorrhage (mL)	21.75 ± 2.33	31.03 ± 4.50	–16.391	<0.001
Hospital stays (day)	36 (23, 48.5)	40 (22.25, 69.5)	–1.125	0.261
Complications (n)	18 (22.2%)	24 (30.0%)	1.263	0.261

Data were pressed as mean ± SD, median (interquartile spacing) or n (%).

Table 3. Comparison of surgical indicators in patients with different degrees of brain hemorrhage across the neuroendoscopy group.

Parameters	Mild group (n = 45)	Moderate group (n = 23)	Severe group (n = 13)	$F/H/\chi^2$	p-value
Intraoperative hemorrhage volume (mL)	94.07 ± 4.75	96.30 ± 4.66	95.00 ± 6.03	0.180	0.836
Hematoma clearance rate at 24 h after surgery	82.67 ± 8.88	82.14 ± 8.19	80.68 ± 9.44	0.261	0.771
Surgical time (min)	112.49 ± 8.58	110.70 ± 11.76	115.38 ± 11.86	0.895	0.413
Postoperative hemorrhage (mL)	22.07 ± 2.37	21.30 ± 2.29	21.46 ± 2.26	0.937	0.396
Hospital stays (day)	38 (26, 51.5)	34 (22, 41)	43 (19, 63.5)	2.226	0.329
Complications (n)	7 (15.56%)	4 (17.39%)	7 (53.85%)	7.714	0.018

Data were pressed as mean ± SD, median (interquartile spacing) or n (%).

Comparison of Functional Recovery

The NIHSS, FMA, and CRS-R scales were used to assess the impact of the two surgical methods on functional recovery in patients with brain hemorrhage. Both minimally invasive drilling and neuroendoscopy significantly reduced the NIHSS scores while increasing the FMA and CRS-R scores, indicating that both surgical approaches could improve neurological and motor functions. However, the neuroendoscopy group demonstrated superior outcomes. Ninety days after surgery, patients in the neuroendoscopy group had significantly lower NIHSS scores and significantly higher FMA and CRS-R scores compared to the minimally invasive drilling group ($p < 0.01$, Fig. 1A–C). These results suggest that neuroendoscopy is more effective in promoting functional recovery.

The impact of neuroendoscopy on functional recovery in patients with different severities of brain hemorrhage was further examined. Patients in the mild and moderate groups exhibited significantly greater decreases in NIHSS scores and notable increases in FMA and CRS-R scores 90 days after surgery compared to those in the severe group ($p < 0.05$, Fig. 1D–F). These results indicate that neuroendoscopic treatment is more effective in improving neurological and motor functions in patients with less severe conditions, particularly those with milder comas.

Discussion

Brain hemorrhage is characterized by the sudden rupture of blood vessels in brain tissue, resulting in blood infiltration into the brain parenchyma or subarachnoid space [21]. As a type of stroke, brain hemorrhage is often associated with risk factors such as hypertension, cerebral aneurysms, and arteriosclerosis [22,23]. Current treatment options for brain hemorrhage include conservative management and surgical intervention. Conservative treatment is generally recommended for cases with low hemorrhage volume that are not life-threatening [6], whereas surgical intervention is prioritized for patients with extensive hemorrhage and life-threatening conditions.

Neuroendoscopic surgery has shown significant benefits in improving cerebral blood flow and enhancing recovery outcomes after a brain hemorrhage. Mezzacappa *et al*. [24] reported that neuroendoscopy, owing to its high precision, provides more precise visualization of the hematoma, enabling more accurate removal and improving hematoma clearance rates. Similarly, Lv *et al*. [25] demonstrated that neuroendoscopy minimizes damage to surrounding brain tissue and blood vessels, reducing the risk of postoperative hemorrhage and associated complications. Our findings reveal that neuroendoscopic surgery offers advantages over minimally invasive drilling, such as more effective blood clot removal, reduced postoperative bleeding, and faster early recovery. Furthermore, due to its minimally invasive nature, neuroendoscopy could be the preferred treatment option for patients with mild to moderate brain hemorrhage, where its benefits are most evident. Future research should validate these findings in larger and more diverse patient groups. Additionally, more extended follow-up studies are needed to evaluate the long-term recovery effects of neuroendoscopy. Further investigation into patient selection criteria and cost comparisons with other methods will also help guide its use in routine medical practice.

Table 4. Comparison of cerebral hemodynamics between the two groups.

Parameters	Neuroendoscopy group (n = 81)	Minimally invasive drilling group (n = 80)	*t*	*p*-value
CP (kpa)				
Before surgery	9.46 ± 0.58	9.51 ± 0.60	–0.546	0.586
7 days after surgery	8.33 ± 0.63*	8.95 ± 0.65*	–6.155	<0.001
Qmean (mL/s)				
Before surgery	8.53 ± 0.62	8.50 ± 0.59	0.258	0.797
7 days after surgery	9.54 ± 0.65*	9.00 ± 0.62*	5.368	<0.001
Rv [Pa/(s.L)]				
Before surgery	1.51 ± 0.26	1.59 ± 0.25	–1.882	0.062
7 days after surgery	1.07 ± 0.30*	1.40 ± 0.27*	–7.380	<0.001
Vm (cm/s)				
Before surgery	16.68 ± 1.20	16.69 ± 1.27	–0.037	0.970
7 days after surgery	17.90 ± 1.19*	16.97 ± 1.27	4.822	<0.001
PI				
Before surgery	1.06 ± 0.07	1.07 ± 0.08	–0.113	0.910
7 days after surgery	0.81 ± 0.10*	0.95 ± 0.08*	–9.894	<0.001

CP, critical pressure; Qmean, quantity of mean blood flow; Rv, peripheral resistance; Vm, mean blood flow velocity; PI, pulsatility index. $^{*}p < 0.05$ *vs.* before surgery.

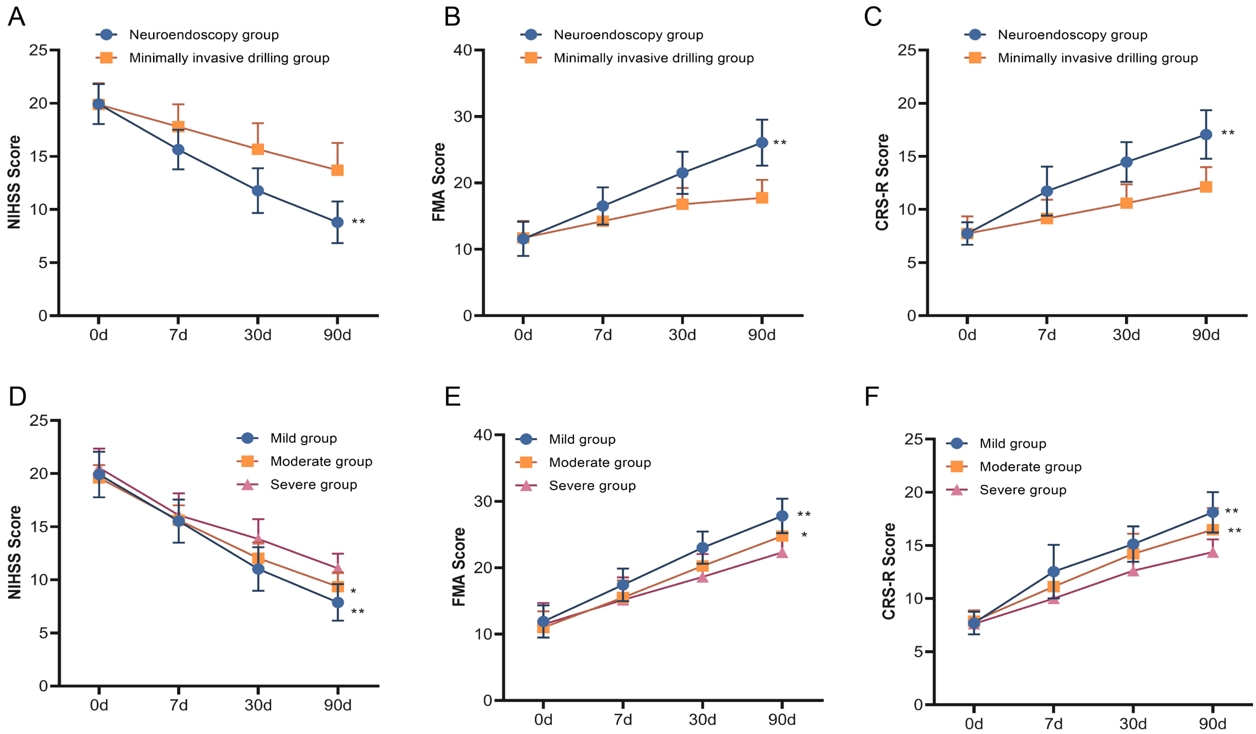

Fig. 1. Comparison of functional recovery. (A–C) The NIHSS (A), FMA (B), and CRS-R (C) scores in the neuroendoscopy and minimally invasive drilling groups were assessed at 0-, 7-, 30-, and 90-days post-surgery. The neuroendoscopy group showed significantly better outcomes with $^{**}p < 0.01$ than the minimally invasive drilling group. (D–F) The NIHSS (D), FMA (E), and CRS-R (F) scores in the mild, moderate, and severe subgroups within the neuroendoscopy group were evaluated on the 0-, 7-, 30-, and 90-days after surgery. Patients in the mild and moderate groups demonstrated significantly better recovery than those in the severe group ($^{*}p < 0.05$, $^{**}p < 0.01$). NIHSS, National Institutes of Health Stroke Scale; FMA, Fugl-Meyer Assessment; CRS-R, Coma Recovery Scale-Revised. The graph was plotted by GraphPad Prism 9.0 (GraphPad Software, San Diego, CA, USA).

Our study observed that the incidence of postoperative complications was significantly lower in patients with mild brain hemorrhage than in those with severe brain hemorrhage within the neuroendoscopy group. This finding aligns with Xu *et al.* [26], who reported that mild patients with brain hemorrhage are at a relatively lower risk of complications during hematoma clearance, whereas those with severe hemorrhage experience higher risks. The lower com-

Table 5. Comparison of cerebral hemodynamics in patients with different degrees of brain hemorrhage in the neuroendoscopic group.

Parameters	Mild group (n = 45)	Moderate group (n = 23)	Severe group (n = 13)	F	*p*-value
CP (kpa)					
Before surgery	9.46 ± 0.53	9.47 ± 0.60	9.43 ± 0.73	0.015	0.985
7 days after surgery	8.36 ± 0.65*	8.34 ± 0.63*	8.20 ± 0.61*	0.328	0.721
Qmean (mL/s)					
Before surgery	8.51 ± 0.62	8.62 ± 0.67	8.40 ± 0.55	0.544	0.583
7 days after surgery	9.50 ± 0.65*	9.65 ± 0.70*	9.45 ± 0.56*	0.518	0.598
Rv [Pa/(s.L)]					
Before surgery	1.51 ± 0.27	1.55 ± 0.24	1.47 ± 0.27	0.469	0.628
7 days after surgery	1.06 ± 0.30*	1.13 ± 0.30*	1.00 ± 0.31*	0.793	0.456
Vm (cm/s)					
Before surgery	16.75 ± 1.27	16.42 ± 1.17	16.89 ± 0.98	0.822	0.443
7 days after surgery	17.90 ± 1.25*	17.80 ± 1.20*	18.10 ± 0.97*	0.260	0.772
PI					
Before surgery	1.06 ± 0.07	1.07 ± 0.08	1.08 ± 0.08	0.466	0.629
7 days after surgery	0.76 ± 0.07*	0.84 ± 0.08*	0.93 ± 0.08*#&	30.098	<0.001

CP, critical pressure; Qmean, quantity of mean blood flow; Rv, peripheral resistance; Vm, mean blood flow velocity; PI, pulsatility index. $^{*}p < 0.05$ *vs.* before surgery. $^{\#}p < 0.05$ *vs.* mild group. $^{\&}p < 0.05$ *vs.* moderate group.

plication rates observed in mild cases can be attributed to the smaller hematoma size and reduced hemorrhage volume, resulting in less severe neurological impairment. Conversely, patients in the severe group often present with larger hematomas, greater hemorrhage volumes, and more severe neurological damage, which collectively increase surgical complexity and the likelihood of complications.

After brain hemorrhage, varying degrees of hypoperfusion occurs in the tissues surrounding the hematoma, potentially leading to secondary injury and adversely affecting the patient's prognosis. A previous study reported elevated PI in subarachnoid hemorrhage patients, with hemorrhage volume significantly contributing to this increase [27]. In our study, neuroendoscopy showed superior efficacy in improving cerebral hemodynamics in patients with brain hemorrhage compared to minimally invasive drilling. Seven days post-surgery, the PI in mild and moderate cases reduced significantly than in severe cases within the neuroendoscopy group. These findings suggest that the effect of neuroendoscopic therapy on cerebral hemodynamics is more pronounced in patients with mild brain hemorrhage compared to those with severe conditions.

Neuroendoscopic surgery, as a minimally invasive technique, offers significant advantages over traditional craniotomy. It involves smaller incisions and causes less trauma, thereby minimizing postoperative inflammatory responses and edema while promoting nerve tissue repair and recovery [28]. In our study, patients in the neuroendoscopy group exhibited significant postoperative improvements in neurological and motor functions, with these enhancements being substantially greater than those observed in the minimally invasive drilling group. These results highlight the positive impact of neuroendoscopy on the postoperative rehabilitation of patients with brain hemorrhage. Additionally, neuroendoscopy demonstrated varying levels of effectiveness in improving functional recovery across different brain hemorrhage severities. Patients with severe brain hemorrhage exhibited significantly higher NIHSS scores and lower FMA and CRS-R scores than mild and moderate cases, indicating that neuroendoscopy is more effective in enhancing neurological and motor functions in patients with milder conditions. Similarly, previous studies have highlighted that neuroendoscopy can enhance patient prognosis, promote neurological recovery, and improve overall quality of life [29,30]. These findings further support that neuroendoscopic therapy has a positive and multifaceted impact on postoperative rehabilitation, particularly for those with less severe brain hemorrhages.

This study has certain limitations. Firstly, hematoma volume and the distance from the hematoma to the cortex were not measured, as these data were not documented in the case records. These factors are crucial in influencing surgical decisions and patient prognosis. Future studies should include these parameters to provide a more comprehensive understanding of their impact on surgical outcomes and recovery. Secondly, our study primarily focused on outcomes 7 days post-surgery to evaluate the early effects of neuroendoscopic surgery; however, long-term follow-up data (e.g., 3–6 months) were not collected. This was due to the retrospective study design and logistical challenges in obtaining extended follow-up information for all participants. We acknowledge the significance of long-term outcomes in providing comprehensive insights and recommend that future studies adopt a prospective approach to include extended follow-up assessments. Lastly, as a single-center retrospective study, the generalizability of our findings is limited. Hence, multicenter prospective studies are needed to validate the benefits of neuroendoscopic surgery observed in this study.

Conclusions

Neuroendoscopic surgery can effectively improve cerebral hemodynamics and promote functional recovery in patients with brain hemorrhage. Neuroendoscopy may offer substantial clinical advantages, such as higher hematoma clearance rates, less postoperative hemorrhage volumes, and faster early functional recovery compared to minimally invasive drilling. Due to its minimally invasive nature and superior outcomes, neuroendoscopy could be considered the preferred surgical approach for patients with mild to moderate brain hemorrhage, where its therapeutic benefits are most pronounced. Further studies are warranted to validate these findings in larger, more diverse patient populations and through long-term follow-up assessments.

Availability of Data and Materials

The data used to support the findings of this study are available from the corresponding author upon request.

Author Contributions

YK and QZ made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas. YK drafted this manuscript. Both authors contributed to important editorial changes in the manuscript. Both authors read and approved the final manuscript. Both authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

The study design followed the Declaration of Helsinki and was approved by the Ethics Committee of the Affiliated Hospital of Putian University (no. PTUH2022412). All procedures adhered to ethical guidelines and written informed consent was obtained from all participants.

Acknowledgment

Not applicable.

Funding

This research received no external funding.

Conflict of Interest

The authors declare no conflict of interest.

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