Efficacy and Prognostic Analysis of Neuro-Navigation Robot-Assisted Puncture Drainage for Thalamic Hemorrhage: A Comparison With Neuro-Endoscopy and External Ventricular Drainage

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AIM: This study aims to compare the clinical efficacy of three surgical techniques—robot-assisted neuro-navigation, external ventricular drainage (EVD), and neuro-endoscopy—in evacuating intracranial hematomas in patients with thalamic hemorrhage.
METHODS: This retrospective study included 110 patients, divided into three groups based on the surgical method: robot group (n = 30), EVD group (n = 37), and neuro-endoscopy group (n = 43). Baseline characteristics, perioperative parameters, neurological function, inflammatory response, complications, and functional outcomes were compared and analyzed among the three patient groups.
RESULTS: Compared with the EVD and neuro-endoscopy groups, the robot group had shorter operative times ($p < 0.001$), higher hematoma clearance rates ($p < 0.001$), better postoperative neurological function ($p < 0.05$), a lower inflammatory response ($p < 0.05$), fewer complications ($p < 0.05$), and better functional outcomes ($p < 0.05$). Robot-assisted neuro-navigation-guided puncture drainage was associated with better clinical outcomes than EVD and neuro-endoscopy in this retrospective study.
CONCLUSIONS: Robot-assisted neuro-navigation-guided puncture drainage was associated with improved neurological recovery and short-term outcomes in patients with thalamic hemorrhage.

Keywords: neuro-navigation robot; thalamic hemorrhage; external ventricular drainage; neuro-endoscopy; clinical efficacy; prognosis

Introduction

Thalamic hemorrhage (TH) is a common form of intracerebral hemorrhage associated with high morbidity and disability rates. It is mainly caused by hypertension and other cerebrovascular diseases and clinically presents with symptoms such as aphasia, limb paralysis, and disturbances of consciousness [1]. TH has an acute onset, and delayed treatment may lead to high mortality. Early detection and treatment usually result in a relatively good prognosis, but residual deficits such as limb paralysis often remain and can affect patients' daily lives. The key to treating TH is rapid hematoma evacuation and relief of intracranial hypertension to reduce secondary brain injury [2]. In addition to jeopardizing human health, this condition readily diminishes patients' quality of life and imposes significant negative impacts on society and families. Therefore, reducing intracerebral hemorrhage mortality and improving patients' quality of life have long been the central focuses of clinical medical research.

Because the thalamus lies deep in the brain and is surrounded by dense neural structures, conventional craniotomy often involves greater technical difficulty and a higher risk of complications, and is particularly likely to exacerbate intracerebral hemorrhage and injure neural structures [3]. In recent years, advances in medical treatment and the development and refinement of surgical equipment and instruments have contributed to a decline in mortality associated with hypertension-related intracerebral hemorrhage; however, such technological improvements in medicine do not facilitate a reduction in disability rates among affected patients [4]. The primary existing surgical approaches for intracerebral hemorrhage include craniotomy for hematoma evacuation, neuro-endoscopic hematoma evacuation, and minimally invasive hematoma drainage [5]. Compared with traditional craniotomy, minimally invasive surgery offers clear advantages of less surgical trauma, greater localization accuracy, and shorter operative time [6]. Compared with conventional craniotomy, neuro-endoscopic surgery can significantly reduce blood loss and operative time, increase the hematoma evacuation rate, and lead to better recovery of neurological function and daily living activities [7]. In comparison with external ventricular drainage, neuro-endoscopic surgery is also associated with a higher hematoma evacuation rate, a lower incidence of pulmonary infection, and a shorter hospital stay [8]. Furthermore, robot-assisted treatment has been reported to result in significantly lower rebleeding and intracranial infection rates after intracerebral hemorrhage compared with traditional

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craniotomy hematoma evacuation, leading to improved patient prognoses [9]. A neuro-navigation robot is a highly integrated neurosurgical assistive device. Unlike traditional frameless stereotactic systems, it uses a computer software system as the robot's central hub, importing the patient's computed tomography (CT), computed tomography angiography (CTA), or magnetic resonance imaging (MRI) data for three-dimensional visualization and multi-angle inspection of cranial structures, and for planning an optimal surgical trajectory that avoids critical blood vessels and functional brain regions. The positioning device functions as the robot's vision system: by identifying specific head markers or matching facial scans, it can perform verification-point checks before surgery to ensure accuracy, and it provides real-time monitoring to ensure that the robotic arm moves precisely along the planned trajectory. The robotic arm serves as the robot's executing component, precisely locating the puncture site according to the completed surgical plan and verification results. By ensuring that the puncture trajectory and depth meet the predefined targets, it can effectively reduce intraoperative errors and improve surgical precision. However, limited studies have investigated the application of robot-assisted neuro-navigation-guided puncture drainage, external ventricular drainage, and neuro-endoscopic surgery in patients with TH.

This study aimed to retrospectively analyze the potential clinical efficacy of robot-assisted neuro-navigation-guided puncture drainage, external ventricular drainage, and neuro-endoscopic surgery in patients with TH. This paper provides a comparative analysis of the three methods in terms of baseline characteristics, perioperative parameters, neurological function, inflammatory response, complications, and functional outcomes, with the aim of informing the selection of appropriate surgical approaches for treating TH.

Methods

Patients

Clinical records of 110 patients with TH who underwent surgical treatment at Lanxi People's Hospital between July 2021 and July 2025 were retrospectively reviewed. According to the surgical method, patients were divided into the neuro-endoscopy group (receiving neuro-endoscopic minimally invasive surgery, n = 43), the EVD group (receiving external ventricular drainage, n = 37), and the robot group (receiving neuro-navigation robot, n = 30). The inclusion criteria are as follows: (1) age 18–75 years; (2) CT-confirmed thalamic hemorrhage; and (3) time from onset <24 hours. The exclusion criteria are as follows: (1) concomitant intracranial diseases, such as brain tumor or cerebrovascular malformations; (2) severe cardiac, pulmonary, hepatic, or renal failure; (3) severe coagulation disorders or other contraindications to surgery; (4) contraindications to anesthesia; and (5) incomplete clinical data.

Surgical Methods

Neuro-Endoscopy

During neuro-endoscopic hematoma evacuation, either an occipital or lateral-ventricle approach was employed based on preoperative computed tomography (CT) localization of the hematoma. Following a small scalp incision, the dura was punctured, and a catheter and dilators were used to create a surgical corridor, through which the neuro-endoscope was inserted. Under high-definition endoscopic visualization, the hematoma was clearly distinguished from the surrounding brain tissue. The hematoma was then gradually evacuated using fine instruments, including suction devices and clot graspers, under low suction pressure, to reduce traction and injury to brain tissue through minimization of overly aggressive single-session aspiration. For deep or hard-to-reach hematoma areas, micro-clot graspers were used for more precise removal to ensure complete evacuation. After hematoma removal, hemostasis was achieved, followed by dura closure and incision suturing.

External Ventricular Drainage

Patients who meet the indications for ventricular external drainage surgery should be placed in the supine position. The Kocher puncture point on the forehead was marked, and the area was routinely disinfected, draped, and locally anesthetized. A hole was drilled in the skull at the marked point, and the dura mater was incised. The ventricular drainage tube was slowly inserted along the predefined trajectory. Once cerebrospinal fluid outflow was confirmed, the catheter depth was adjusted and properly fixed in place. Depending on the extent of intraventricular hemorrhage, unilateral or bilateral EVD was selected. A follow-up CT scan was performed 3–5 days postoperatively to confirm complete hematoma drainage before removal of the drainage catheter.

Neuro-Navigation Robot

In the neuro-navigation robot group, preoperative CT was performed, and Digital Imaging and Communications in Medicine (DICOM) images were imported into the robotic system to reconstruct the three-dimensional models of the skin, skull, and hematoma. Based on these models, the optimal targets and entry points were selected. Under general anesthesia with airway management and arterial pressure monitoring, the head was fixed with a three-pin head frame and the entry site exposed. Facial and robotic-arm registration were then performed, after which the planned puncture site was identified and marked. Following standard surgical preparation and draping, the puncture site was re-verified, a skin incision was made, and a burr hole was drilled along the planned trajectory. The dura was electrocauterized and opened in a cruciate fashion; small cortical vessels were coagulated. A suction (aspiration) needle was placed into the robotic guidance system and used to puncture along the predetermined trajectory to the target. After reaching the tar-

get, the needle stylet was withdrawn, and a 5 mL syringe was used to slowly aspirate the hematoma cavity. Aspiration was stopped when resistance was encountered, and saline was used for lavage and replacement; the needle was then moved up and down along the planned trajectory to aspirate the hematoma. If resistance persisted, repeated irrigation was performed along the hematoma cavity. Once the irrigation fluid ran clear, the aspiration needle was removed, and the aspirated clot was collected. A drainage tube was placed at the center of the hematoma cavity and secured. The skin incision was closed with sutures, sterile dressings were applied, and an immediate postoperative head CT was performed to assess the hematoma evacuation. After 2 to 3 days of the operation, a CT scan was conducted to confirm adequate drainage, after which the drainage tube was removed.

Hematoma Volume

According to a previously reported method [10], hematoma volume was calculated using Broderick's method (length × width × height /2).

Hematoma Clearance Rate

Hematoma clearance rate was calculated using the formula in the following:

Hematoma clearance rate (%) = [(Preoperative hematoma volume – Hematoma volume at postoperative day 5) / Preoperative hematoma volume] × 100.

Collection of Baseline and Clinical Characteristics

(1) General data of all patients, including sex, age, time from onset to surgery, hematoma volume, history of hypertension, diabetes, and coronary heart disease, were collected. Hematoma volume was determined using CT, hematoma clearance rate was calculated, and operative time was defined as the time from the start of the surgical procedure to its completion, and was recorded in minutes. (2) Neurological function was evaluated preoperatively and at 14 and 30 days postoperatively using the National Institutes of Health Stroke Scale (NIHSS) and the Glasgow Coma Scale (GCS). The NIHSS assesses 11 domains, including consciousness, eye and limb movements, sensory function, and language, with higher scores indicating more severe neurological impairment [11]. The GCS assesses eye opening, verbal, and motor responses, with lower scores indicating more severe impairment of consciousness [12]. (3) Fasting venous blood was drawn preoperatively and one week postoperatively. The blood was centrifuged at 1500 rpm for 10 minutes, and the plasma was then stored at −80 ℃. High-sensitivity C-reactive protein (hs-CRP) levels in all three groups were measured by means of latex-enhanced immunoturbidimetry (batch number: 20182400030, Weishang Biotechnology Co., Ltd., Hefei, China), and tumor necrosis factor-α (TNF-α) levels were measured by enzyme-linked immunosorbent assay (batch number: DTA00D, R&D Systems, Minneapolis, MN, USA). (4) Data on postoperative complications, such as pulmonary infection, urinary tract infection, intracranial infection, intracranial rebleeding, and postoperative death, were collected during 30 days after treatment. (5) Short-term prognosis was assessed at 30 days after treatment using the Glasgow Outcome Scale (GOS). The GOS is a five-point scale ranging from 1 to 5, with scores defined as follows: 1 = death, 2 = persistent vegetative state, 3 = severe disability, 4 = mild disability, 5 = good recovery. In this study, a GOS score >3 was considered a favorable outcome [13].

Statistical Analysis

The statistical analysis was conducted using the SPSS 23.0 software (SPSS Inc., Chicago, USA). The Shapiro–Wilk method was employed to assess the normal distribution of continuous variables. Continuous data were presented as mean ± standard deviation, and inter-group comparisons were conducted using analysis of variance (ANOVA) coupled with Tukey's post-hoc multiple tests. Categorical data were expressed as counts and percentages, and inter-group comparisons were conducted using the chi-square test. Bonferroni correction was applied to adjust for multiple pairwise comparisons. Repeated-measures analysis was used to evaluate changes in variables at different time points and compare differences among groups. A value of $p < 0.05$ was considered statistically significant.

Results

Baseline and Clinical Characteristics

A total of 110 patients with TH were enrolled, with 43 in the neuro-endoscopy group, 37 in the EVD group, and 30 in the robot group. There were no significant differences between the three groups in age, sex, hematoma volume, hypertension, diabetes, coronary heart disease, or time from onset to surgery ($p > 0.05$). As shown in Table 1, compared with the neuro-endoscopy group and the EVD group, the robot group had a shorter operative time ($p < 0.001$) and a higher hematoma clearance rate ($p < 0.05$).

Neurological Function Recovery

Preoperatively, there were no statistically significant differences in GCS or NIHSS scores among the three groups ($p > 0.05$). At 14 and 30 days postoperatively, the robot group had significantly higher GCS scores and significantly lower NIHSS scores than the neuro-endoscopy group ($p < 0.05$) (Table 2).

Levels of Inflammatory Factors

Preoperative hs-CRP and TNF-α levels did not differ significantly among the three groups ($p > 0.05$). Postoperatively, hs-CRP and TNF-α levels in the robot group were significantly lower than those in the neuro-endoscopy group and the EVD group ($p < 0.05$), as shown in Table 3.

Table 1. Comparison of baseline and clinical characteristics between the three groups.

Variables	Neuro-endoscopy group (n = 43)	Robot group (n = 30)	EVD group (n = 37)	F/χ^2	p
Age (years)	60.59 ± 12.72	59.67 ± 11.35	61.58 ± 9.65	0.234	0.791
Sex, n (%)				0.004	0.998
Male	20 (46.51)	14 (46.67)	17 (45.95)		
Female	23 (53.49)	16 (53.33)	20 (54.05)		
Hematoma volume (mL)	35.28 ± 8.40	36.90 ± 7.87	37.83 ± 7.56	1.048	0.354
Hypertension, n (%)				0.928	0.629
No	18 (41.86)	10 (33.33)	12 (32.43)		
Yes	25 (58.14)	20 (66.67)	25 (67.57)		
Diabetes, n (%)				4.959	0.084
No	28 (65.12)	21 (70)	32 (86.49)		
Yes	15 (34.88)	9 (30)	5 (13.51)		
Coronary heart disease, n (%)				0.571	0.751
No	30 (69.77)	22 (73.33)	24 (64.86)		
Yes	13 (30.23)	8 (26.67)	13 (35.14)		
Time from onset to surgery (h)	10.68 ± 3.20	11.34 ± 1.50	11.46 ± 2.35	1.083	0.342
Operative time (min)	170.23 ± 34.56	132.80 ± 15.69[a]	180.46 ± 33.67[b]	22.28	<0.001
Hematoma clearance rate (%)	88.46 ± 3.89	92.56 ± 2.46[a]	89.32 ± 2.76[b]	15.47	<0.001

Notes: [a] $p < 0.05$ compared with the neuro-endoscopy group, [b] $p < 0.05$ compared with the robot group. Abbreviation: EVD, external ventricular drainage.

Table 2. Comparison of preoperative and postoperative neurological recovery between the three groups.

Groups	GCS score			NIHSS score		
	At admission	At 14 days postoperatively	At 30 days postoperatively	At admission	At 14 days postoperatively	At 30 days postoperatively
Neuro-endoscopy group (n = 43)	7.89 ± 0.38	9.89 ± 1.54[b]*	11.56 ± 1.26[b]*	30.85 ± 2.34	26.24 ± 1.57[b]*	23.99 ± 1.03[b]*
Robot group (n = 30)	7.99 ± 1.02	11.92 ± 1.01*	13.74 ± 1.89*	29.60 ± 4.31	21.89 ± 3.31*	17.77 ± 1.50*
EVD group (n = 37)	7.86 ± 0.34	9.99 ± 1.03[b]*	11.93 ± 0.88[b]*	31.76 ± 2.34	25.97 ± 1.45[b]*	22.35 ± 1.26[ab]*
F	F_{inter} = 10.52 F_{time} = 453.70 F_{group} = 49.00			F_{inter} = 7.68 F_{time} = 462.40 F_{group} = 99.27		
p	p_{inter} < 0.001 p_{time} < 0.001 p_{group} < 0.001			p_{inter} < 0.001 p_{time} < 0.001 p_{group} < 0.001		

Notes: [a] $p < 0.05$ compared with the neuro-endoscopy group, [b] $p < 0.05$ compared with the robot group, * $p < 0.05$ compared with the values at admission. Abbreviations: GCS, Glasgow Coma Scale; NIHSS, National Institutes of Health Stroke Scale.

Table 3. Comparison of inflammatory factor levels between the three groups.

Groups	hs-CRP (mg/L)		TNF-α (pg/mL)	
	At admission	Postoperative	At admission	Postoperative
Neuro-endoscopy group (n = 43)	20.53 ± 1.59	15.89 ± 0.55[b]*	50.69 ± 3.25	30.48 ± 2.25[b]*
Robot group (n = 30)	20.20 ± 1.72	8.39 ± 1.59*	50.02 ± 4.01	25.85 ± 2.20*
EVD group (n = 37)	19.75 ± 1.03	16.23 ± 0.98[ab]*	51.92 ± 2.94	40.62 ± 2.78[ab]*
F	F_{inter} = 204.7 F_{time} = 1486 F_{group} = 190.2		F_{inter} = 95.55 F_{time} = 2358 F_{group} = 132.30	
p	p_{inter} < 0.001 p_{time} < 0.001 p_{group} < 0.001		p_{inter} < 0.001 p_{time} < 0.001 p_{group} < 0.001	

Notes: [a] $p < 0.05$ compared with the neuro-endoscopy group, [b] $p < 0.05$ compared with the robot group, * $p < 0.05$ compared with values at admission. Abbreviations: hs-CRP, high-sensitivity C-reactive protein; TNF-α, tumor necrosis factor-α.

Complication Occurrence Rate

In the neuro-endoscopy group, postoperative complications occurred in 14 patients (32.56%). In the robot group, postoperative complications occurred in 5 patients (16.67%). There was a difference in the overall postoperative complication rate between the neuro-endoscopy group and the robot group, but it was not statistically significant (χ^2 = 2.318, p = 0.128). In addition, 18 cases of postoperative complications were documented in the EVD group (48.65%). Compared with the robot group, the EVD group experienced a significantly higher complication rate (χ^2 = 7.517, $p < 0.05$). There was a significant overall difference among the three groups (χ^2 = 7.628, p = 0.022) (Table 4).

Table 4. Comparison of postoperative complications between the three groups.

Group	Pulmonary infection	Urinary tract infection	Intracranial infection	Intracranial rebleeding	Occurrence rate
Neuro-endoscopy group (n = 43)	5 (11.63%)	3 (6.98%)	3 (6.98%)	3 (6.98%)	32.56% (14/43)
Robot group (n = 30)	2 (6.67%)	1 (3.33%)	1 (3.33%)	1 (3.33%)	16.67% (5/30)
EVD group (n = 37)	10 (27.03%)	2 (5.41%)	2 (5.41%)	4 (10.81%)	48.65% (18/37)[b]
χ^2					7.628
p					0.022

Note: [b] $p < 0.05$ compared with the robot group. Abbreviation: EVD, external ventricular drainage.

Prognostic Comparison

At 30 days after treatment, in the robot group, 22 patients achieved a GOS score of 4 and 8 had a score of 5, resulting in an average score of 4.27 ± 0.45. In the neuro-endoscopy group, 21 patients had a GOS score of 3, 21 had a score of 4, and 1 had a score of 5, with an average score of 3.53 ± 0.55. In the EVD group, 30 patients achieved a score of 3 and 7 individuals had a score of 4, with an average score of 3.19 ± 0.40. There were significant differences among the three groups (χ^2 = 56.886, $p < 0.001$). Post-hoc pairwise comparisons revealed that the robot group had significantly higher GOS scores than both the neuro-endoscopy group (χ^2 = 28.846, $p < 0.001$) and the EVD group (χ^2 = 53.450, $p < 0.001$).

Discussion

Thalamic hemorrhage (TH) presents major treatment challenges because of the thalamus's complex anatomy, rich blood supply, and diverse neurological functions. TH is characterized by acute onset, impaired thalamic function, and severe clinical symptoms; bleeding can extend into the ventricles, obstruct cerebrospinal fluid circulation, and lead to hydrocephalus [14,15]. Acute intraventricular hemorrhage can damage the structures surrounding the ventricles, such as the thalamus, fornix, basal ganglia, brainstem, and other critical neural structures, and produce compressive effects, resulting in secondary injury [16]. Most patients present with impaired consciousness; in severe cases, they may develop dilated pupils and respiratory-circulatory failure. The thalamus lies deep and is surrounded by critical structures. Failure to promptly evacuate blood from the thalamus and ventricles, relieve ventricular system obstruction, and restore cerebrospinal fluid circulation will reduce clinical efficacy and increase disability and mortality [1,17]. A previous study has shown that cerebral edema develops rapidly after TH, causing disruption of the blood–brain barrier [18], and thereby worsening whole-brain edema. Neisewander et al. [15] found that mortality from severe TH can reach up to 60%–75%; therefore, selecting effective surgical methods to promptly evacuate blood from the thalamus and ventricles and restore cerebrospinal fluid circulation is crucial for improving patient prognosis.

The key to clinical management of TH is prompt evacuation of blood from the thalamus and ventricles, relief of intracranial hypertension, restoration of cerebrospinal fluid circulation, and reduction of secondary injury to surrounding critical neural structures [3]. Ullman et al. [16] summarized clinical data from 500 patients with TH that had ruptured into ventricles and concluded that early, effective hematoma evacuation and restoration of cerebrospinal fluid circulation are crucial for neurological recovery. Traditional surgical treatments, such as EVD, are rapid and simple procedures that have been widely adopted by medical centers and remain a standard treatment for severe thalamic hemorrhage [3]. Although continuous drainage of bloody cerebrospinal fluid and late-stage lumbar cistern drainage have some efficacy in treating TH that has ruptured into the ventricles [19], research has shown that prognosis remains poor for patients with severe intraventricular hemorrhage [20]. This may be due to failure to promptly relieve ventricular system obstruction and hematoma mass effect; moreover, prolonged retention of the ventricular drainage catheter increases the risk of intracranial infection [21]. After analyzing 39 patients with intraventricular hemorrhage and Graeb scores exceeding 6, Johnson et al. [22] found that EVD was ineffective in rapidly evacuating ventricular and thalamic hematomas and was associated with a significantly higher incidence of hydrocephalus requiring subsequent shunt surgery. Shimizu et al. [23] found that rapid evacuation of ventricular and thalamic hematomas significantly reduces the likelihood of hydrocephalus requiring subsequent shunt surgery. Recent years have seen an increasing adoption of minimally invasive approaches for hematoma evacuation. Neuro-endoscopic hematoma removal requires only a small bone window in the skull to access and remove the clot; its high-definition visualization effectively reduces damage to surrounding brain tissue, blood vessels, and nerves [24]. However, neuro-endoscopic procedures rely on CT markers for surface localization, and manual marking during this process can reduce puncture accuracy. In addition, the endoscopic view is two-dimensional and lacks depth perception, making image distortion a potential issue. Moreover, the working space in neuro-endoscopy is limited; the endoscope lens is not only easily contaminated by blood but also requires repeated angle adjustments. Therefore, neuro-endoscopic hematoma evacuation

demands a high level of surgical skill and precision. These findings further indicate the clinical necessity of pursuing new, more precise surgical treatment methods.

With ongoing advances in neurosurgical treatments and supporting equipment, neuro-navigation robots have been widely applied in clinical practice [25]. Neuro-navigation robots are a modern neurosurgical technology that integrates advanced imaging modalities with computer-aided design to guide surgical procedures. By combining medical images with surgical navigation software, a three-dimensional intracranial model is constructed, enabling precise localization of the lesion site, planning of the surgical approach, and ensuring the precise execution of the surgery. Neuro-navigation robots have unique advantages over traditional surgeries in removing intracranial hemorrhage. Compared to traditional craniotomy, the adoption of neuro-navigation robots in surgery necessitates smaller incisions, which significantly reduce pain, shorten recovery time, and lower the complexity of postoperative care. Additionally, compared to systems based on surgical frames, this innovative surgical approach requires no preoperative cranial screws, reducing patient anxiety; it also obviates the need to conduct repeated preoperative CT examinations, minimizes surgical steps, and shortens operative time [26]. In terms of accuracy and safety, the neuro-navigation robotic system can perform highly repeatable and consistent operations, thereby improving operative predictability. Its minimal navigation error and high localization accuracy allow precise targeting of specific intracranial regions and comprehensive hematoma evacuation along predetermined trajectories. This may increase the hematoma clearance rate, improve surgical safety, and reduce unnecessary damage to surrounding brain tissue during the operation. Postoperative infection is one of the most lethal complications for neurosurgical patients and is a key determinant for assessing both their short- and long-term prognosis. Any degree of infection can delay wound healing, potentially worsen the condition, and result in longer hospital stays, higher costs, and increased readmission rates [27]. In this study, neuro-navigation robot-assisted puncture drainage resulted in a significantly higher hematoma clearance rate than the EVD and neuro-endoscopy groups. Timely evacuation of blood from the thalamus and ventricles not only relieves the mass effect on surrounding brain tissue but also promotes early restoration of cerebrospinal fluid circulation and reduces secondary injury [28]. Additionally, the robot group had numerically lower rates of postoperative pulmonary, urinary tract, and intracranial infections compared with the EVD and neuro-endoscopy groups. Similar findings have been reported in patients with basal ganglia hemorrhage [29].

As an important "information hub" of the brain, the thalamus participates in multiple functions—such as sensation, movement, and language—and its injury often results in widespread neurological dysfunction [30]. Neurological recovery following TH is often influenced by multiple factors, including hematoma volume, intraoperative injury, and postoperative complications. In this study, the robot group had significantly lower NIHSS scores and significantly higher GCS scores than the EVD and neuro-endoscopy groups, suggesting that neuro-navigation robot–assisted surgery may be associated with better postoperative neurological recovery [31]. hs-CRP and TNF-α are commonly used clinical serologic markers that effectively reflect the degree of tissue injury and inflammatory response. These inflammatory factors cross the blood–brain barrier into brain tissue, and elevated levels of these markers can increase cerebral microvascular permeability, trigger cerebral edema, and even worsen the patient's condition. Their levels are closely associated with disease severity in patients with TH [32]. In this study, postoperative hs-CRP and TNF-α levels in the robot group were lower than those in the EVD and neuro-endoscopy groups, suggesting that robot-assisted neuro-navigation-guided puncture drainage can attenuate the inflammatory response, potentially owing to its minimally invasive nature, reduced surgical trauma, and decreased intraoperative bleeding. The advantages of neuro-navigation robot-assisted puncture drainage in effectively evacuating hematomas, protecting brain tissue, and reducing complications are further reflected in patient prognosis. This study showed that the robot group had significantly higher GOS scores than the EVD and neuro-endoscopy groups, further supporting that three-dimensional hematoma reconstruction enables surgeons to better remove the clot while avoiding injury to other vessels and surrounding brain tissue, thereby reducing postoperative complications and improving patient outcomes. A previous study of brainstem hemorrhage reported potential benefits of robot-assisted drainage for functional recovery [31]; however, the applicability of these findings to thalamic hemorrhage remains uncertain.

Although this study demonstrated the advantages of robot-assisted neuro-navigation-guided puncture drainage in treating TH, several limitations remain. First, the relatively small sample size and the limited number of evaluated variables, such as the absence of documented intraventricular hemorrhage and hydrocephalus, may restrict the generalizability of the findings. Second, the retrospective design may introduce selection bias, and the postoperative follow-up period was relatively short, preventing adequate assessment of long-term efficacy and complications. Finally, the lack of international consensus regarding surgical decision-making criteria and the limited range of outcome indicators may have introduced potential bias and influenced the interpretations of the findings. Therefore, future studies should adopt a multicenter, prospective research design with an expanded sample size to validate these findings and further explore the application value and long-term effects of neuro-navigation robot-assisted puncture drainage across various forms of TH.

Conclusions

In summary, neuro-navigation robot-assisted puncture drainage was associated with favorable short-term outcomes in the treatment of TH. This surgical approach not only effectively evacuates hematomas, reduces surgical trauma, and promotes neurological recovery, but also markedly attenuates the inflammatory response, may be associated with a lower incidence of postoperative complications, and improves patient prognosis.

Availability of Data and Materials

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

Author Contributions

KHL, LYS and FT designed the research study. XXG and XLX performed the research. YH and YJH analyzed the data. KHL drafted the manuscript. All authors contributed to critical revision of the manuscript for important intellectual content. 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 was approved by the Ethics Committee of Lanxi People's Hospital (approval number 2026-16) and strictly adhered to the Declaration of Helsinki. As this is a retrospective study analysing only historical clinical records, the Ethics Committee has granted an exemption from the requirement for informed consent for this study.

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Conflict of Interest

The authors declare no conflict of interest.

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