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Robot-assisted puncture versus conservative treatment for severe brainstem hemorrhage: clinical outcomes comparison with experience of 138 cases in a single medical center

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Abstract

Introduction The application of robot-assisted surgical technology in treating brainstem hemorrhage has garnered increasing attention. Treatments such as stereotactic hematoma aspiration and neuroendoscopic surgery are becoming more prevalent in China. The aim of this study is to provide a detailed comparative analysis of the clinical effects of robot-assisted puncture technology versus traditional conservative treatment, offering a scientific basis for optimizing treatment plans and improving patient outcomes.

Methods A retrospective observational study was conducted from January 2019 to December 2023 at a single neurosurgery center. A total of 138 patients with severe brainstem hemorrhage were included, with 103 in the conservative treatment group and 35 in the robot-assisted puncture group.ROSA robot-assisted brainstem hemorrhage drainage is a precise neurosurgical procedure involving pre-surgical evaluations and examinations, including cranial CT, to determine the hemorrhage's location, extent, and severity. Baseline data was extracted from the hospital's electronic medical record system, including demographics, medical history, and clinical characteristics. Statistical analysis was performed to compare outcomes between the two treatment groups.

Results The baseline characteristics of the patients in both groups were similar, with no significant differences in age, gender, smoking history, alcohol consumption, or other relevant factors. The median stay time was longer in the robot-assisted group (21.0 days) compared to the conservative group (15.0 days), with a significant difference ($p = 0.004$). The median cost of hospitalization was also higher in the robot-assisted group (105231.0 yuan) compared to the conservative group (55221.5 yuan), with a significant difference ($p < 0.001$). The mortality rate of the robot assisted group was significantly lower than that of the conservative treatment group, and the difference was

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significant. Additionally, the robot-assisted group had a lower discharge hematoma volume and a trend towards better clinical outcomes, as measured by the Glasgow Coma Scale (GCS) and modified Rankin Scale (mRS) scores.

Discussion The results suggest that robot-assisted puncture technology may offer improved clinical outcomes in patients with brainstem hemorrhage compared to traditional conservative treatment. The precision and accuracy of the ROSA robot may contribute to better hematoma drainage and reduced complications. While the cost of hospitalization was higher in the robot-assisted group, the potential for improved patient outcomes and reduced long-term healthcare costs should be considered when evaluating the cost-effectiveness of this treatment approach. Further research is needed to validate these findings in larger, multicenter studies and to explore the potential benefits of robot-assisted treatment in different subpopulations of patients with brainstem hemorrhage.

Conclusion This study provides preliminary evidence that robot-assisted puncture technology may offer improved clinical outcomes in patients with brainstem hemorrhage compared to traditional conservative treatment. The precision and accuracy of the ROSA robot may contribute to better hematoma drainage and reduced complications, although the higher cost of hospitalization should be taken into account. Future research is needed to further validate these findings and explore the potential benefits of this innovative treatment approach.

Introduction

Severe brainstem hemorrhage is a serious neurological disorder with extremely high mortality and disability rates. Even with minimal bleeding, it can lead to serious consequences [1]. The mortality rate of severe brainstem hemorrhage is as high as 70–80% [2, 3], and even after the use of modern medical techniques such as microsurgery or stereotactic drainage, the prognosis of patients is still poor.

At present, most neurosurgical experts in the world still hold a conservative treatment attitude towards brainstem hemorrhage [4, 5]. Although traditional conservative treatment can alleviate the condition to a certain extent, the effect is limited and it can easily lead to neurological dysfunction. In recent years, with the rapid development of robot assisted surgical technology, its application in the treatment of brainstem hemorrhage has gradually received attention. The proportion of treatments for brainstem hemorrhage in China, including stereotactic hematoma aspiration and neuroendoscopic surgery, is gradually increasing [6–10].

This article aims to provide a detailed comparative analysis of the clinical application effects of robot assisted puncture technology and traditional conservative treatment methods in cases of brainstem hemorrhage, with the aim of providing solid and scientific basis for medical decision-makers to optimize treatment plans and improve patient prognosis.

Materials and methods

This retrospective observational study was conducted from January 2019 to December 2023 at a single neurosurgery center. During the study period, we included a total of 138 patients with severe brainstem hemorrhage, including 103 in the conservative treatment group and 35 in the robot assisted puncture group.For patients with acute obstructive hydrocephalus in both groups, routine ventricular drainage surgery will be performed, but it should be noted that this surgery is not the basis for determining the grouping of the two groups.

Inclusion and exclusion criteria

Inclusion criteria (1) Patients with cerebral hemorrhage volume > 5 ml, (2) The maximum cross-sectional area of hematoma is greater than half of the same level brainstem, (3) Progressive aggravation of consciousness state, with or without severe disruption of vital signs.

Exclusion criteria (1) Traumatic intracranial hemorrhage, (2) Coagulation dysfunction, such as hemophilia, thrombocytopenia, hepatitis, etc., (3) Merge severe heart, liver, kidney, lung diseases or functional failure, etc., (4) CT and MRI scans reveal suspected or confirmed conditions such as cavernous malformations, aneurysms, arteriovenous malformations, moyamoya disease, and tumor necrosis during surgery, (5) Late stage of cerebral hernia: patients with bilateral dilated pupils upon admission, those requiring blood pressure boosting medication for maintenance, and those who have interrupted the treatment process (such as giving up treatment), (6) Lost follow-up, (7) Without obtaining the consent of the patient's legal representative.

ROSA robot-assisted hematoma puncture treatment

ROSA robot assisted brainstem hemorrhage drainage is a precise neurosurgical procedure. Before surgery, the doctor will conduct a comprehensive evaluation and examination of the patient, including imaging examinations such as cranial CT, to determine the location, extent, and severity of bleeding. Subsequently, the CT data is imported into the ROSA robot system, with registration accuracy typically controlled within 1 mm, utilizing its high-precision robotic arm and 3D display technology for surgical planning. During the surgery, based on the precise positioning of the bleeding location with

the assistance of robots, puncture and drainage are carried out along the planned path. The robotic arm has extremely high precision, ensuring the accuracy and safety of the surgery.

The core of the conservative treatment strategy for brain stem hemorrhage is to implement a series of comprehensive and delicate measures: ensure that patients are strictly confined to bed and closely monitor the changes of their vital signs, use precise drug strategies to effectively control intracranial pressure and brain edema, strictly regulate blood pressure levels, and at the same time strengthen mental protection measures, and integrate personalized rehabilitation acupuncture and moxibustion treatment programs. In addition, actively prevent the occurrence of various complications and provide comprehensive and balanced nutritional support to ensure that patients can smoothly pass the critical period and accelerate the recovery process.

Data collection and definition

The baseline data was extracted from the hospital's electronic medical record system, including gender, age, whether it had ruptured into the ventricles, SBP and DBP at admission, smoking history, alcohol consumption history, previous history of cerebral hemorrhage, complications, etc.(summarized in Tables 1 and 2) The initial Glasgow Coma Scale (GCS) score was used to evaluate the severity of neurological impairment in patients with severe brainstem hemorrhage, and the improved mRS was used to assess the degree of neurological improvement in patients.

Statistical analysis

All statistical analyses were conducted using SPSS (version 26.0.0.2, IBM SPSS for statistical data) and R software (version 4.2.6; The R Foundation for Statistical Computing). Descriptive statistics were utilized to present continuous variables, with means and standard deviations (SDs) for normally distributed data, and medians with interquartile ranges [IQRs] for non-normally distributed data. Categorical variables were expressed as numbers and percentages.

Results

During the study period, our neuromedical center admitted a total of 278 patients with spontaneous brainstem hemorrhage, and ultimately 138 eligible patients were enrolled in the study. This retrospective study analyzed 35 patients who underwent robot-assisted hematoma puncture and drainage surgery and 103 patients who received conservative treatment, comparing the two groups in terms of baseline characteristics, surgical indicators, and efficacy data. The baseline characteristics of the patients showed no significant differences between the two groups in age, gender, hypertension, diabetes, coronary heart disease, smoking, or drinking habits.

There were no significant differences in the proportions of multifocal hemorrhage, pontine hemorrhage, and medullary hemorrhage between the two groups. The proportions of ventricular rupture were similar between the two groups, with no statistically significant difference. Regarding lifestyle habits and underlying diseases, there were no significant differences in the proportions of smoking and drinking between the two groups. The proportion of patients with hypertension was significantly higher in the robot-assisted group (82.9%) than in the overall patient group (63.1%) ($P = 0.05$). There were no significant differences in the proportions of diabetes and history of cerebral hemorrhage between the two groups. The proportions of patients initially presenting with headache and coma were similar between the two groups, with no significant differences.

From the perspective of patient treatment effectiveness, compared with the conservative treatment group,

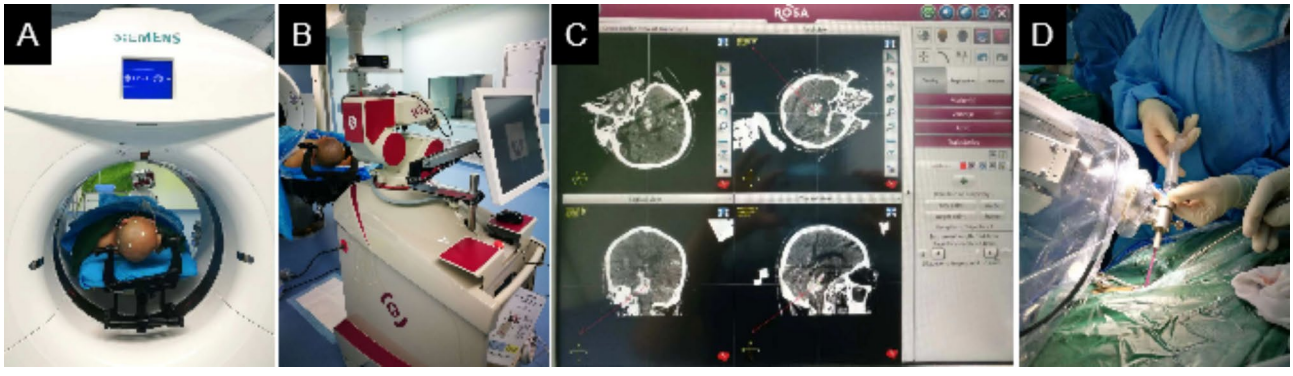

Fig. 1 Schematic diagram of puncture and drainage of brainstem hemorrhage assisted by ROSA robot. After admitting a patient with severe brainstem hemorrhage and obtaining the consent of the patient's family, we used ROSA robot assisted puncture and external drainage surgery. Prior to the surgery, a marker was attached to the surface of the skull, and a thin-layer CT scan of the head was performed again in a composite operating room (**A**). Using 3D reconstruction software, the optimal puncture path was generated (**B**, **C**), and the hematoma puncture and drainage were completed according to the plan using supporting components (**D**)

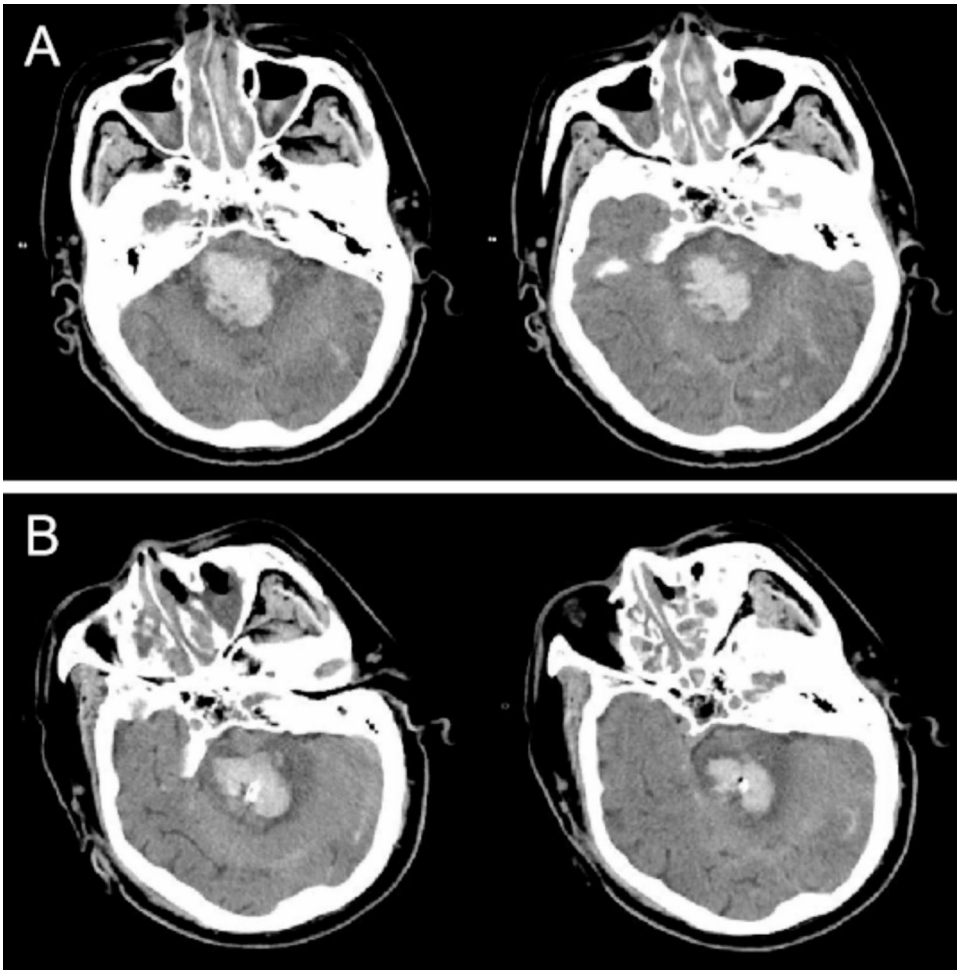

Fig. 2 Comparison of electronic computed tomography techniques before (**A**) and after (**B**) puncture for brainstem hemorrhage. CT scan after hematoma puncture showed precise positioning of the drainage tube

the robot assisted therapy group significantly reduced the mortality rate of patients at discharge and follow-up for 30 and 60 days.

In terms of complication rates, the robot-assisted group had significantly higher complication rates at certain levels compared to the overall patient group, with specific differences in distribution. Only 12 patients in the conservative group did not experience any complications, while the majority of patients in both groups had 2–3 comorbidities (as shown in the "Complication" column of Table 2). The intracranial infection rate (14.3%) and lung infection rate (100.0%) were significantly higher in the robot-assisted group than in the overall patient group ($P = 0.001$, $P = 0.002$), which may be related to invasive procedures. Due to the high infection rates, the antibiotic usage rate was significantly higher in the robot-assisted group (94.3%) than in the overall patient group (53.4%) ($P < 0.001$).

Regarding concurrent epilepsy, only one patient who experienced early seizures survived, whereas all patients with late seizures did not survive during the 60-day follow-up after discharge (as shown in Table 2).

Regarding length of hospital stay and hospitalization costs, the median length of stay was significantly longer in the robot-assisted group (21.0 days) than in the overall patient group (15.0 days) ($P = 0.004$). The median total cost was significantly higher in the robot-assisted group (105,231.0 yuan) than in the overall patient group (55,221.5 yuan) ($P < 0.001$) (as shown in Table 3). This was attributed to the costs associated with robot activation, the usual placement of drainage tubes after puncture, and the higher proportion of antibiotic use compared to the conservative treatment group.

Regarding prognosis, the median GCS score was significantly lower in the robot-assisted group (3.0) than in the overall patient group (5.0) ($P < 0.001$). At discharge, the median hematoma volume was significantly smaller in the robot-assisted group (0.5 ml) than in the overall patient group (2.8 ml) ($P < 0.001$), with no significant difference at admission between the two groups. The

Table 1 Baseline characteristics of the total, conservative and robot-assisted cohorts

		Total	Conservative	Robot-Assisted	*p*
		N **= 138**	***N*** **= 103**	***N*** **= 35**	
Age (median [IQR])		55.0 [49.0, 61.8]	56.0 [49.0,64.5]	54.0 [46.5,57.5]	0.111
Gender (%)	Man	100 (72.5)	74 (71.8)	26 (74.3)	0.952
	Woman	38 (27.5)	29 (28.2)	9 (25.7)	
location (%)	Multifocal	21 (15.2)	16 (15.5)	5 (14.3)	0.304
	Pons	53 (38.4)	43 (41.7)	10 (28.6)	
	Medulla oblongata	64 (46.4)	44 (42.7)	20 (57.1)	
Incursion into ventricle (%)	No	88 (63.8)	66 (64.1)	22 (62.9)	1
	Yes	50 (36.2)	37 (35.9)	13 (37.1)	
Smoke (%)	No	93 (67.4)	69 (67.0)	24 (68.6)	1
	Yes	45 (32.6)	34 (33.0)	11 (31.4)	
Drink (%)	No	97 (70.3)	73 (70.9)	24 (68.6)	0.965
	Yes	41 (29.7)	30 (29.1)	11 (31.4)	
Hypertension (%)	No	44 (31.9)	38 (36.9)	6 (17.1)	0.05
	Yes	94 (68.1)	65 (63.1)	29 (82.9)	
Diabetes (%)	No	118 (85.5)	90 (87.4)	28 (80.0)	0.428
	Yes	20 (14.5)	13 (12.6)	7 (20.0)	
History of cerebral hemorrhage (%)	No	126 (91.3)	92 (89.3)	34 (97.1)	0.284
	Yes	12 (8.7)	11 (10.7)	1 (2.9)	
Onset Symptoms					
Headache (%)	No	127 (92.0)	95 (92.2)	32 (91.4)	1
	Yes	11 (8.0)	8 (7.8)	3 (8.6)	
Unconsciousness (%)	No	31 (22.5)	25 (24.3)	6 (17.1)	0.523
	Yes	107 (77.5)	78 (75.7)	29 (82.9)	
Others (%)	No	114 (82.6)	80 (77.7)	34 (97.1)	0.018
	Yes	24 (17.4)	23 (22.3)	1 (2.9)	
SBP (median [IQR])		165.5 [139.0, 185.0]	163.0 [137.0, 183.5]	167.0 [155.0, 188.5]	0.21
DBP (median [IQR])		91.0 [81.0, 103.0]	90.0 [80.0, 104.0]	98.0 [88.0, 102.5]	0.193
GCS (median [IQR])		4.0 [3.0, 5.0]	5.0 [3.0, 6.0]	3.0 [3.0, 4.0]	< 0.001
Hematoma volume upon admission(median [IQR])		11.5 [8.7, 15.1]	11.7 [8.5, 15.9]	11.4 [9.5, 13.6]	0.454

median MRS score was 5.0 in both groups, with no significant difference ($P = 0.461$). The survival rate was significantly higher in the robot-assisted group (65.7%) than in the overall patient group (37.9%), with a correspondingly lower mortality rate ($P = 0.008$).

Discussion

Comparison of therapeutic effects

In our study comparing robot assisted puncture and conservative treatment for severe brainstem hemorrhage, we found that the former has significant advantages in patient prognosis. Brain stem hemorrhage is a devastating disease with a high mortality rate [11], especially when the hematoma size exceeds 5 milliliters [12–14]. The grouping of conservative treatment and robot assisted surgery in this study was not due to differences in hematoma volume, but rather because conservative treatment was chosen due to family members' refusal. For patients with severe brainstem hemorrhage, conservative treatment often fails to timely and adequately relieve the compression of the hematoma on the brainstem and the secondary neurological damage. Robot hematoma puncture can significantly reduce the remaining amount of hematoma, and there is a significant difference between the two groups of patients ($p < 0.001$) [14, 15].

At present, although stereotactic surgery can improve the neurological function of some patients, the improvement of neurological function in most patients cannot reach the level that allows patients to live and work independently. Compared with conservative treatment, there is no significant difference in mRS scores in group of robot assisted puncture ($p > 0.05$), which is considered to be related to severe primary damage [12, 16]. In addition, the initial GCS score of the robot assisted therapy group was worse than that of the conservative treatment group [13, 15, 17].

Table 2 Comparison of prognosis and complications between conservative group and Robot-assisted group

		Total	Conservative	Robot-Assisted	*p*
		N = 138	*N* = 103	*N* = 35	
Effect (%)	Live	62 (44.9)	39 (37.9)	23 (65.7)	0.008
	Die	76 (55.1)	64 (62.1)	12 (34.3)	
Effect (30 day, %)	Live	57 (41.3)	34 (33.0)	23 (65.7)	0.001
	Die	81 (58.7)	69 (67.0)	12 (34.3)	
Effect (60 day, %)	Live	50 (36.2)	30 (29.1)	20 (57.1)	0.006
	Die	88 (63.8)	73 (70.9)	15 (42.9)	
Discharge hematoma volume (median [IQR])		2.0 [0.0, 5.1]	2.8 [0.9, 7.2]	0.5 [0.0, 1.0]	< 0.001
mRS (median [IQR])		5.0 [5.0, 6.0]	5.0 [5.0, 6.0]	5.0 [5.0, 6.0]	0.461
Complication (%)	0	12 (8.7)	12 (11.7)	0 (0.0)	< 0.001
	1	49 (35.5)	43 (41.7)	6 (17.1)	
	2	47 (34.1)	34 (33.0)	13 (37.1)	
	3	23 (16.7)	10 (9.7)	13 (37.1)	
	4	7 (5.1)	4 (3.9)	3 (8.6)	
Intracranial infection (%)	No	133 (96.4)	103 (100.0)	30 (85.7)	0.001
	Yes	5 (3.6)	0 (0.0)	5 (14.3)	
Pulmonary infection (%)	No	26 (18.8)	26 (25.2)	0 (0.0)	0.002
	Yes	112 (81.2)	77 (74.8)	35 (100.0)	
Stress ulcer (%)	No	106 (76.8)	80 (77.7)	26 (74.3)	0.859
	Yes	32 (23.2)	23 (22.3)	9 (25.7)	
Epilepsy (%)	No	130 (94.2)	100 (97.1)	30 (85.7)	0.03
	Early	1 (0.7)	0 (0.0)	1 (2.9)	
	Late	7 (5.1)	3 (2.9)	4 (11.4)	
Epilepsy_Live (%)	No	7(87.5)	3(100)	4 (80)	1
	Yes	1(12.5)	0(0)	1 (20)	
Rebleeding (%)	No	133 (96.4)	99 (96.1)	34 (97.1)	1
	Yes	5 (3.6)	4 (3.9)	1 (2.9)	
DVT (%)	No	116 (84.1)	89 (86.4)	27 (77.1)	0.305
	Yes	22 (15.9)	14 (13.6)	8 (22.9)	
Central hyperthermia (%)	No	82 (59.4)	67 (65.0)	15 (42.9)	0.035
	Yes	56 (40.6)	36 (35.0)	20 (57.1)	
Antibiotics (%)	No	50 (36.2)	48 (46.6)	2 (5.7)	< 0.001
	Yes	88 (63.8)	55 (53.4)	33 (94.3)	

Table 3 Duration and cost of hospitalization between conservative group and robot-assisted group

	Total	Conservative	Robot-Assisted	*p*
	N = 138	*N* = 103	*N* = 35	
Stay time (median [IQR])	16.0 [6.0, 26.0]	15.0 [3.5, 24.5]	21.0 [13.0, 29.0]	0.004
Cost (median [IQR])	66208.5 [30659.0, 105724.2]	55221.5 [16799.8, 91345.0]	105231.0 [85935.2, 158112.2]	< 0.001

In contrast, robot assisted puncture and drainage surgery provides a more effective solution. Advanced imaging technology and robotic systems promote precise targeting, ensuring the accuracy of interventions, minimizing volume of hemmorahge, and protecting brainstem function. Our research findings indicate that compared to conservative treatment [14, 18], robot assisted surgery significantly reduced mortality rates [10, 14, 15], which is consistent with previous research results, possibly due to its timeliness, accuracy, and minimally invasive nature [15, 19].

Risk mitigation and prevention of complications

A key consideration for any surgical intervention, especially in fragile brainstem areas, is to reduce surgical risks and prevent complications. Preoperative planning and intraoperative monitoring play a crucial role in further reducing these risks. However, it is important to acknowledge that no surgical technique can completely eliminate all risks [5, 6, 12, 19, 20]. Due to the non-invasive nature of conservative treatment, the incidence of intracranial infections is lower in the conservative group compared to the robot assisted puncture group. However, due to the early relief of hematoma compression, the overall incidence of complications in the robot

assisted puncture group is much lower than that in the conservative group.

In terms of the treatment of intracranial infections, compared with the conservative treatment group, patients in the robotic puncture drainage group had a significantly increased risk of infection due to the invasive operation involved in this treatment method, with an infection rate increased to 14.3%. However, there were no infection cases in the conservative treatment group (14.3% vs. 0%, $p = 0.001$). Due to the problem of pneumonia caused by long-term bed rest, both groups maintained a high incidence of pulmonary infection, making it difficult to effectively reduce it.

There is a statistical difference in the incidence of epilepsy between the two groups. This may be due to the fact that during the process of robot puncture drainage, the drainage pipeline may cause certain damage to nerve cells, and some damaged nerve cells may subsequently produce abnormal discharges, thereby increasing the risk of epileptic seizures. Therefore, the incidence of epilepsy in patients in the robot puncture drainage group was relatively high. Studies have shown that patients with stroke or intracranial hemorrhage, particularly those experiencing late-stage seizures, exhibit a significantly higher mortality rate [21, 22]. Our research further verifies this finding, indicating that none of the patients who developed late-stage seizures following brainstem hemorrhage survived the 60-day follow-up period.

Meanwhile, there was a statistically significant difference ($p < 0.05$) in central hyperthermia between the two groups. However, there was no statistically significant difference in the incidence of other complications such as stress ulcers, rebleeding, and deep vein thrombosis in the lower lim

Duration and cost of hospitalization

The clinical manifestations of brainstem hemorrhage are complex and diverse, including consciousness disorders, respiratory disorders, etc. The timing and severity of these symptoms are closely related to the amount and location of bleeding, also affect the duration and cost of hospitalization [12, 15, 17]. Our retrospective study found significant differences in hospitalization costs and duration between the conservative group and the robot assisted group.The average hospitalization time for the robot group is 21 days, which is relatively longer compared to the conservative group's 15 days. This difference may be attributed to some patients in the conservative group who unfortunately passed away shortly after admission, resulting in a shorter hospital stay and thus lowering the average length of hospital stay in this group. In terms of average hospitalization costs, the robot group was as high as 105,231 yuan, significantly exceeding the conservative group's 55221.5 yuan. In order to ensure that the patient does not have any complications after surgery, it is necessary to closely monitor for a longer period of time in the neurological intensive care unit, which also increases the hospitalization costs accordingly [23]. In the realm of medical decision-making, securing optimal treatment outcomes and facilitating prognosis recovery for patients suffering from critical and severe brainstem hemorrhages holds a paramount and indispensable position. While the financial expenditure associated with such treatments may be substantial, these investments prove exceptionally justified and vital when they lead to significant improvements in patient's quality of life, an extension of their lifespan, and a marked decrease in the necessity for subsequent treatments and the risks of complications. Upon thorough cost-effectiveness analysis, we are firmly convinced that incurring higher clinical costs is unequivocally worthwhile in pursuing superior clinical outcomes for patients with brainstem hemorrhages.

Conclusion

For patients suffering from severe brainstem hemorrhage, especially those whose vital signs are affected, robot assisted surgery should be considered as a first-line treatment option. Robot assisted puncture provides a superior alternative to conservative treatment for severe brainstem hemorrhage, significantly reducing mortality and complications. However, due to sample size limitations, larger multicenter prospective cohort studies may be needed to further validate the efficacy and evaluate the longer-termoutcomes.

Abbreviations

ROSA	Robot of Stereotactic Assistant
CT	Computed Tomography
MRI	Magnetic Resonance Imaging
GCS	the Glasgow Coma Scale
mRS	modified Rankin Scale
SBP	Systolic Blood Pressure
DBP	Diastolic Blood Pressure
DVT	Deep venous thrombosis

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Author contributions

Xingwang Sun and Junhao Zhu authored the main manuscript. Xingwang Sun and Miao Lu conducted the data analysis. Zhibin Zhang prepared Figs. 1 and 2. Cuiling Li served as the lead surgeon who performed the surgery. Rucai Zhan designed the study and made substantial revisions to the manuscript. All authors reviewed the final version of the manuscript.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
Not applicable for a retrospective study.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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