Heliyon 10 (2024) e27487

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Stereotactic hematoma puncture and drainage for primary pontine hemorrhage: Clinical outcomes and predictive model

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A R T I C L E I N F O

Keywords:
Primary pontine hemorrhage
Stroke
Stereotactic hematoma puncture and drainage
Nomogram
Outcome

A B S T R A C T

Primary pontine hemorrhage (PPH) is a particularly grave form of hemorrhagic stroke, characterized by its significant mortality rate. stereotactic hematoma puncture and drainage is a procedure that has been shown to improve the prognosis of patients with PPH. However, there are currently no established criteria for selecting patients for this procedure. We contrasted the clinical outcomes of PPH patients treated with stereotactic hematoma puncture and drainage with those who received conservative treatment in this study. We conducted logistic regression analysis to identify the risk factors associated with postoperative mortality. A mortality risk nomogram was then constructed using these risk factors. A total of 127 conservatively treated patients and 96 patients who underwent stereotactic hematoma puncture and drainage were included in this study. In the surgical group, the 30-day mortality rate stood at 28.1%, significantly lower than the 43.3% observed in the control group ($p = 0.02$). Age, along with the Glasgow Coma Scale (GCS) score and hematoma size, were identified as independent risk factors associated with death within 30 days post-surgery. The mortality risk nomogram was well calibrated and discriminatory, with a c-index of 0.878 (95% CI 0.80–0.95) as validated by bootstrapping, and a c-index of 0.849. This study provides a predictive model for selecting patients who are most likely to benefit from stereotactic hematoma puncture and drainage. The results of this study could be helpful to neurosurgeons in their decision-making process. However, further external validation is necessary to confirm these findings.

1. Introduction

Primary pontine hemorrhage (PPH) is a subtype of intracranial hemorrhage (ICH) that occurs in 5–10% of cases and has a high mortality rate [1]. PPH is most frequently attributed to hypertension [2]. Despite the need for effective and safe treatments, the management of PPH remains a challenge [3]. In the past, conservative management has been the standard approach for treating PPH. However, with advancements in microsurgery and technology, surgical intervention has become a viable option [4]. Patients with Glasgow Coma Scale (GCS) scores of 7 or lower and hematoma sizes of 5 mL or larger are considered good candidates for surgical intervention [5]. Endoscopic hematoma removal, stereotactic hematoma puncture and drainage, and craniotomy are the most

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https://doi.org/10.1016/j.heliyon.2024.e27487
Received 28 December 2023; Received in revised form 28 February 2024; Accepted 29 February 2024
Available online 8 March 2024
2405-8440/

Abbreviation

PPH	Primary pontine hemorrhage
GCS	Glasgow coma scale
ICH	Intracranial hemorrhage
EVD	External ventricular drainage
HIS	Hospital information system
BMI	Body mass index
ROC	Operating characteristic curve
DCA	Decision curve analysis
VIF	Variance inflation factor
OR	Odd ratio
CI	Confidence interval
IQR	Interquartile range

common surgical treatments for PPH [4]. The rationale may be to remove or reduce the volume of the hematoma, thereby mitigating the primary injury and preventing secondary injury [6]. Stereotactic hematoma puncture and drainage is gaining popularity due to its minimally invasive nature and ease of operation. Takahama et al. reported the first successful use of this method for the treatment of PPH [7]. Previous research conducted by Hara T et al. demonstrated that stereotactic hematoma puncture and drainage significantly improves the prognosis of PPH patients [8]. Despite the growing evidence supporting the positive impact of surgical intervention on PPH patient outcomes, there is still debate surrounding the selection of appropriate candidates for surgery [6].

In this study, our aim was to validate the efficacy and safety of stereotactic hematoma puncture drainage by assessing clinical outcomes at 30 days in patients with PPH. In addition, we formulated a postoperative survival prediction model based on patient characteristics, aiming to assist neurosurgeons in identifying optimal surgical candidates.

2. Methods

2.1. Patients

Clinical data were gathered from PPH patients receiving treatment at the Neurosurgery Department of the 904th Hospital of People's Liberation Army (PLA) between January 2014 and December 2022, as well as at the Yixing People's Hospital Affiliated Jiangsu University from June 2018 to January 2023. Inclusion criteria were: (1) age >18 years; (2) the presence of symptoms, signs, and radiological data consistent with the diagnosis of PPH; (3) GCS ≤7 points and hematoma size ≥5 ml; (4) conservative treatment, external ventricular drainage (EVD) treatment, and patients submitted to stereotactic hematoma puncture and drainage, whose procedure was consent by family members by signing a surgical informed consent. Exclusion criteria were: (1) secondary brainstem hemorrhage from other conditions, including brain tumors, traumatic brain injury, cavernous angiomas, post-infarction hemorrhage,

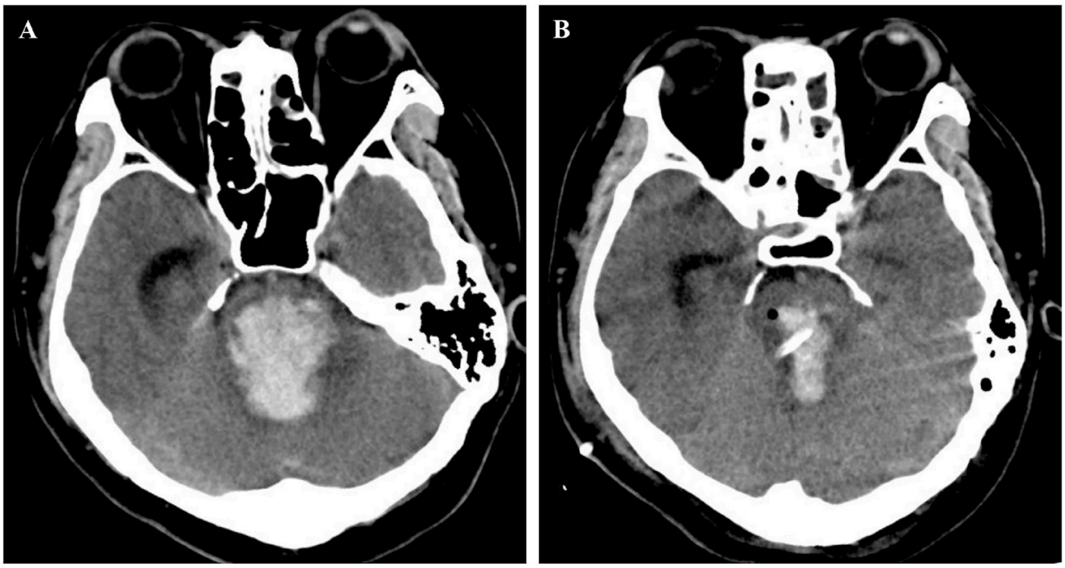

Fig. 1. Preoperative and postoperative CT images of patients with PPH. Preoperative head CT images (A). postoperative head CT images (B).

among others; (2) patients with severe comorbidities, including heart, blood system diseases, liver, and kidney insufficiency, among others; (3) other surgical options including craniotomy, endoscopic hematoma removal, among others; (4) incomplete clinical data. The study received approval from the hospital ethics committee, which waived the need for informed consent due to its retrospective nature.

2.2. Surgical procedure

A preoperative CT examination was performed to define the site of the hematoma and calculate the point of scalp projection at the largest level of the hematoma (Fig. 1A). After general anesthesia, the scalp was first incised, then the hole was drilled and the dura was incised. A Leksell stereotactic system was used to place the ventricular catheter stereotactically. The goal of insertion is to center the catheter on the long axis of the hematoma. After placement of the catheter, the hematoma is aspirated with a syringe until there is significant resistance to aspiration. The catheter is usually left in the hematoma after aspiration is completed and the scalp incision is closed. The selection of EVD is based on the occurrence of ventricular hematoma or/and hydrocephalus. Postoperative review of head CT to assess catheter placement was performed routinely (Fig. 1B). The catheter was removed within 5–7 days after the procedure. Patients then receive the same principles of medical treatment as those treated conservatively. This included close monitoring, airway protection, administration of cardiovascular support and correction of potential hemostatic abnormalities. In addition, management of blood glucose and blood pressure was performed.

2.3. Data collection

Clinical data of admitted patients obtained from the medical records of the Hospital Information System (HIS) include: (1) age, gender, and body mass index (BMI); (2) history of taking antiplatelet and anticoagulant drugs; (3) past medical history; (4) blood pressure at admission (5) GCS score at admission; (6) temperature at admission; (7) anisocoria and absence of light reflex; (8) EVD and need for mechanical ventilation; (9) preoperative and postoperative CT imaging; (10) onset to surgery time.

2.4. Radiological analysis

One radiologist and two independent neurosurgeons reviewed the CT images. The analyzed data encompassed hematoma size, classification, and extension (including intraventricular extension and extrapontine extension), as well as the presence of hydrocephalus and postoperative residual hematoma size. The calculation of hematoma size utilized the formula ABC/2, where A and B denote the perpendicular maximal diameters of the lesion, while C represents the total length in the vertical plane [9]. Extrapontine extension is defined as hematoma extending into the midbrain, medulla, or both. Hematomas were classified into three types according to Wessels' classification method: (1) dorsal; (2) ventral; (3) massive [10]. Hematoma clearance rate = (1 - postoperative hematoma size/preoperative hematoma size) × 100%.

2.5. Outcome evaluation

The clinical outcomes for PPH patients were evaluated utilizing the modified Rankin Scale (mRS). Outcome data were obtained from outpatient follow-ups or medical records. Consistent with prior research, a poor outcome was defined as mRS score ≥4 [11].

2.6. Development and validation of the nomogram prediction model

Patient death within 30 days post-surgery served as the study's endpoint event. After comparing clinical and surgical data from different groups, variables with $p < 0.2$ were included in the logistic regression model. Subsequently, multivariable logistic regression analyses were performed to identify independent risk factors for poor outcome in PPH patients. Use of the generalized linear model function in R software (version 4.2.2), we developed a nomogram model derived from the results of multivariable logistic regression. Receiver operating characteristic (ROC) curve analysis was employed to evaluate the reliability of the nomogram model, with particular emphasis on assessing the area under the ROC curve (AUC). Calibration was evaluated through the Hosmer–Lemeshow goodness of fit test and a calibration plot, employing 1000 bootstrap resamples for precision. Decision curve analysis (DCA) was employed to assess the clinical validity of the nomogram model.

2.7. Statistical analysis

The Kolmogorov-Smirnov test was utilized to assess the parametricity of continuous variables. Parametrically distributed variables were reported as means with standard deviations, while non-parametric variables were described using the median and interquartile range. Categorical variables were presented as percentages. To identify significant differences among the cohorts, the *t*-test, Mann–Whitney *U* test, and chi-squared test were employed for parametric, non-parametric, and categorical variables, respectively. Multicollinearity between variables was assessed using the variance inflation factor (VIF), where a VIF >10 indicates multicollinearity. The $p < 0.05$ is considered statistically significant.

3. Results

3.1. Clinical characteristics

The selection process of participants is illustrated in the flowchart (Fig. 2). The study sample consisted of 96 eligible patients in the surgical group (65.6% of whom were male) and 127 eligible patients in the control group (61.4% of whom were male). The control group included patients who received conservative treatment and only underwent EVD surgery. The demographic and clinical characteristics of participants in both the surgical and control groups are elaborated upon in Table 1. The findings reveal that individuals within the surgical group exhibited a statistically significant decrease in systolic blood pressure ($p = 0.03$), a heightened occurrence of intraventricular extension ($p = 0.02$), and an elevated prevalence of hydrocephalus ($p = 0.04$) in comparison to the control group.

3.2. Clinical outcomes

In the surgical group, the 30-day mortality rate stood at 28.1% (27/96), while in the control group, it reached 43.3% (55/127), indicating a statistically significant contrast between the cohorts ($\chi 2$, $p = 0.02$).

According to the aforementioned criteria, the postoperative poor outcome rate at 30 days in the surgical group was 72.9% (70/96), which, although lower than the control group's rate of 79.5% (101/127), exhibited no statistically significant difference between the two cohorts ($p = 0.25$). Fig. 3 illustrates the mRS scores of PPH patients for poor outcomes 30 days after onset. Compared to the control group, the surgical group exhibited notably fewer occurrences of mortality (mRS = 6) among patients experiencing poor outcomes ($p = 0.04$). While a greater percentage of individuals in the control group attained an mRS score of 5, no significant variance was observed between the two cohorts ($p = 0.44$). Furthermore, the surgical group demonstrated a notably higher count of patients with an mRS score of 4 compared to the control group, with statistical significance ($p < 0.01$).

3.3. Variable screening

In the surgical group, participants were categorized into two cohorts according to their outcomes within 30 days following surgery, with 27 cases assigned to the death group and 69 cases assigned to the survival group. Analysis revealed statistically significant distinctions between the two cohorts concerning admission GCS score ($p < 0.001$), hematoma size ($p < 0.001$), and hematoma classification ($p = 0.001$) (Table 2). Conversely, no statistically significant variances were observed between the two cohorts regarding demographic attributes, medical history, and radiological characteristics ($p > 0.05$).

Univariate logistic regression was performed to examine the association between GCS score, age, hematoma size, hematoma classification, hematoma clearance rate, and 30-day postoperative outcome in patients with PPH. The results indicated that low GCS score ($p < 0.001$), large hematoma size ($p < 0.001$), and massive hematoma classification ($p < 0.01$) were significant predictors of death within 30 days postoperatively in PPH patients (Table 3). Additionally, the presence of multicollinearity between the included variables was excluded (VIF<10).

Multivariable logistic regression analysis was performed, incorporating variables with a p-value less than 0.2. The results showed that age ($p = 0.04$), GCS score ($p = 0.01$), and hematoma size ($p = 0.04$) were significant predictors of adverse patient outcomes at 30 days postoperatively (Table 4).

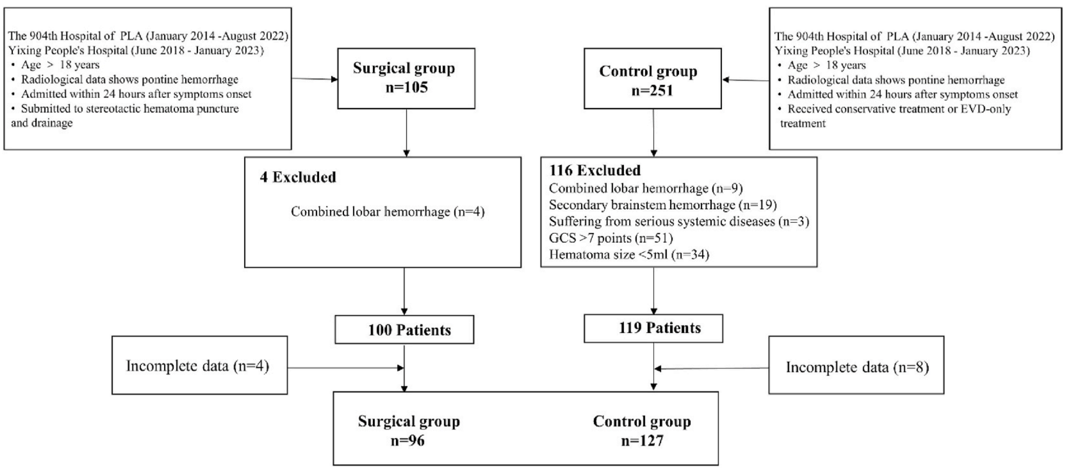

Fig. 2. Flowchart of patient selection.

Table 1
Patient's characteristics.

Variables	surgical group (n=96)	Control group (n=127)	*P* value
Age, year, median (IQR)	56(48,67)	57(51,70)	0.62
Gender, %			0.60
Male	63(65.6%)	78(61.4%)	
Female	33(34.4%)	49(38.6%)	
BMI, kg/m^2, median (IQR)	25.2(22.1,27.5)	26.4(20.7,27.9)	0.75
Drug, %			
Antiplatelet	38(39.6%)	57(44.9%)	0.43
Anticoagulant	42(43.8%)	43(33.9%)	0.13
Medical history, %			
Hypertension	87(90.6%)	112(88.2%)	0.56
Hyperlipidemia	54(56.3%)	63(49.5%)	0.33
Diabetes	27(28.1%)	43(33.9%)	0.36
Blood pressure, mmHg, median (IQR)			
Systolic pressure	168(144,203)	176(154,212)	0.03
Diastolic pressure	110(97,125)	113(105,134)	0.59
Blood glucose, mmol/L, median (IQR)	7.3(6.4,9.5)	7.5(6.2,9.8)	0.26
GCS score, median (IQR)	6(4,7)	6(4,6)	0.77
Anisocoria, %	14(14.6%)	28(22.0%)	0.16
Absence of light reflex, %	6(6.3%)	15(11.8%)	0.16
Temperature, median (IQR)	37.5(37.0,38.2)	37.8(36.8,38.4)	0.59
Mechanical ventilation, %	71(74.0%)	101(79.5%)	0.33
Hematoma size, ml, median (IQR)	10(6,16)	11(7,18)	0.18
Hematoma classification, %			0.29
Dorsal	27(28.1%)	33(26.0%)	
Ventral	37(38.5%)	39(30.7%)	
Massive	32(34.4%)	55(43.3%)	
Intraventricular extension, %	30(31.3%)	22(17.3%)	0.02
Extrapontine extension, %	49(51.0%)	59(46.5%)	0.49
Hydrocephalus, %	26(27.1%)	20(15.7%)	0.04
EVD	30(31.3%)	26(20.5%)	0.06

BMI, Body Mass Index; GCS, Glasgow Coma Scale; IQR, Interquartile Range; EVD, External Ventricular Drainage; Surgical group, submitted to stereotactic hematoma puncture and drainage; Control group, conservative treatment or EVD-only treatment

3.4. Development of the nomogram risk prediction model

A nomogram was created based on the outcomes of the multivariable logistic regression analysis, with the purpose of forecasting the mortality risk within 30 days post-stereotactic hematoma puncture and drainage in individuals with PPH. The nomogram incorporates three prominent risk factors, which are depicted in Fig. 4.

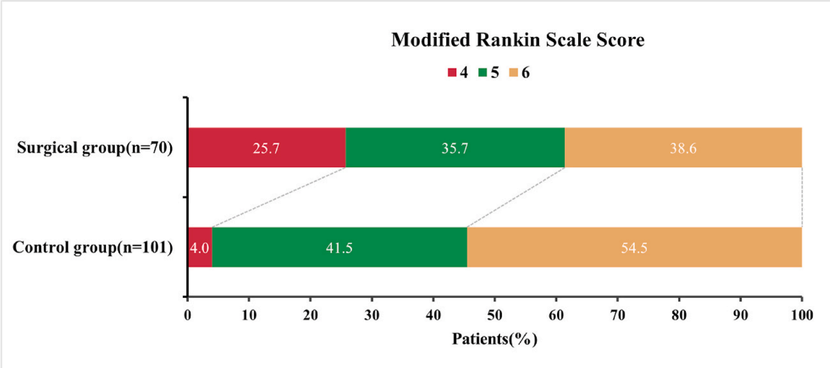

Fig. 3. Distribution of Modified Rankin Scale Scores at 30 days in patients with poor outcomes in the surgical and control groups. mRS = 4, Moderately severe disability, unable to walk without assistance and unable to attend to own bodily needs without assistance. mRS = 5, Severe disability, Bedridden, incontinent, and requires constant nursing care and attention. mRS = 6, Dead.

3.5. Validation of the nomogram risk prediction model

The discriminatory ability of the nomogram model was assessed through ROC curve analysis, revealing an area under the curve (AUC) of 0.878 (95% CI 0.80–0.95) (Fig. 5A). Internal bootstrap validation, employing repeated sampling (1000 repetitions), was utilized to validate the model. This validation approach revealed a bootstrap nomogram model with a c-index of 0.849, indicating a discriminative ability comparable to that of the initial nomogram model. This suggests that the model discriminates appropriately. The model was superior in diagnosis to age (0.616 vs. 0.878, $p < 0.001$), GSC score (0.825 vs. 0.878, $p = 0.04$), and hematoma size (0.744 vs. 0.878, $p < 0.001$) (Fig. 5B). The calibration plots exhibit notable predictive accuracy, showcasing the correlation between the predicted probabilities from the nomogram and the actual probabilities (Fig. 5C). Additionally, the Hosmer-Lemeshow goodness of fit test indicated that the observed and predicted risk values from the model did not exhibit statistically significant differences ($\chi 2 = 1.833$, df = 7, $p = 0.968$), suggesting a well-fitted nomogram model. As per the DCA, the model utilized in this study for predicting the risk of effective outcomes offers more benefits than the all-or-none scheme when the threshold probability ranges from 0.10 to 0.96 (Fig. 5D).

4. Discussion

The management of PPH remains a subject of debate among medical practitioners. Despite over a century of examination, no universal consensus has been reached [12]. The widely recognized guidelines published by the American Heart Association/American Stroke Association (AHA/ASA) and the European Stroke Organization do not provide clear specifications for the diagnosis and treatment of PPH, and the AHA/ASA guidelines specifically discourage surgical intervention [13,14]. In China, cultural beliefs have influenced families of PPH patients to prefer surgical treatment, prioritizing survival over functional outcomes [12,15,16]. Chinese surgeons have attempted surgical treatment of PPH with encouraging results [17]. Stereotactic hematoma puncture and drainage is a widely used surgical approach for the treatment of PPH. The procedure has several advantages, including simplicity, minimal invasiveness, and a short operative time. A study by Shitamichi et al. showed that CT-guided stereotactic hematoma puncture and drainage significantly improved patient prognosis in a cohort of 20 PPH patients, particularly among those with severe cases [18]. This observation was corroborated by Hara et al., who demonstrated that patients with PPH who underwent stereotactic hematoma puncture and drainage had better clinical outcomes compared to those treated conservatively [8]. The mortality rate linked with PPH has been documented to vary between 47% and 80% [19,20]. However, in our data, we observed a mortality rate of 28.1% among patients treated surgically with stereotactic hematoma puncture and drainage and 44.1% among those treated conservatively, with a statistically significant difference between the two cohorts. These results suggest that stereotactic hematoma puncture and drainage may be an effective method for reducing mortality in PPH patients.

The noteworthy point is that, according to the conventional definition in previous studies, an mRS $\geq$4 is defined as an unfavorable clinical outcome. In both the surgical and control groups of this study, the rate of poor outcomes did not exhibit a significant difference. This implies that, even with surgical intervention, a majority of patients with PPH still experienced moderate to severe disability or even death 30 days after onset, which appears to be disheartening. However, surgical treatment is not without merit. In our data, we observed that stereotactic hematoma puncture and drainage not only significantly increased the survival rate of PPH patients but also led to a notable increase in the proportion of patients with moderate to severe disability, thereby improving functional outcomes to some extent. Furthermore, with the development of various rehabilitation techniques, such as neurostimulation therapy showing tremendous potential in enhancing functional outcomes for stroke patients, surviving PPH patients, even those with moderate to severe or profound disability, may benefit from rehabilitation therapy, thereby improving the ultimate clinical outcome [21–23]. However, the selection of surgical treatment for PPH remains subjective, lacking an objective scale to predict the outcome of patients after stereotactic hematoma puncture and drainage [24].To address this, we formulated a nomogram to predict the probability of death

Table 2
Surgical group patient's characteristics.

Variables	Death group (n=27)	Survival group (n=69)	*P* value
Age, year, %			0.10
<48	5(18.6%)	19(27.5%)	
48-67	11(40.7%)	37(53.6%)	
>67	11(40.7%)	13(18.8%)	
Gender, %			0.54
Male	19(70.4%)	44(63.8%)	
Female	8(29.6%)	25(36.2%)	
BMI, kg/m^2, median (IQR)	25.4(22.5,27.7)	24.9(21.8,27.4)	0.47
Drug, %			
Antiplatelet	11(40.7%)	27(39.1%)	0.88
Anticoagulant	12(44.4%)	30(43.5%)	0.93
Medical history, %			
Hypertension	25(92.6%)	62(89.9%)	0.73
Hyperlipidemia	16(59.3%)	38(55.1%)	0.82
Diabetes	9(33.3%)	18(26.1%)	0.61
Blood pressure, mmHg, median (IQR)			
Systolic pressure	172(142,206)	164(146,197)	0.46
Diastolic pressure	114(101,129)	106(95,120)	0.54
Blood glucose, mmol/L, median (IQR)	7.6(6.3,9.7)	7.2(6.6,9.2)	0.33
GCS score, median (IQR)	4(4,5)	6(5,7)	<0.001
Anisocoria, %	6(22.2%)	8(11.6%)	0.21
Absence of light reflex, %	3(11.1%)	3(4.3%)	0.35
Temperature, ℃, median (IQR)	37.6(37.0,38.3)	37.4(36.9,38.1)	0.29
Mechanical ventilation, %	18(66.7%)	53(76.8%)	0.44
Hematoma size, ml, median (IQR)			<0.001
5-10	6(22.2%)	49(71.0%)	
>10	21(77.8%)	20(29.0%)	
Hematoma classification, %			0.001
Dorsal	4(14.8%)	23(33.4%)	
Ventral	6(22.2%)	31(44.9%)	
Massive	17(63.0%)	15(21.7%)	
Intraventricular extension, %	9(33.3%)	21(30.4%)	0.81
Extrapontine extension, %	13(48.1%)	36(52.2%)	0.82
Hydrocephalus, %	6(22.2%)	20(29.0%)	0.61
Onset to surgery time, h, median (IQR)	7(6,18)	7(6,16)	0.58
Hematoma clearance rate, %			0.07
50%-70%	17(63.0%)	29(42.0%)	
>70%	10(37.0%)	40(58.0%)	
EVD	7(25.9%)	23(33.3%)	0.63

BMI, Body Mass Index; GCS, Glasgow Coma Scale; EVD, External Ventricular Drainage; IQR, Interquartile Range

Table 3
Univariate analysis for death within 30 days of surgery in patients with PPH.

Variables	OR (95%CI)	*P* value
Age, year		
<48	Reference	
48–67	1.13(0.34,3.73)	0.84
>67	3.22(0.90,11.46)	0.07
GCS score	0.33(0.20,0.53)	<0.001
Hematoma size, ml		
5–10	Reference	
>10	8.58(3.01,24.40)	<0.001
Hematoma classification		
Dorsal	Reference	
Ventral	1.11(0.28,4.40)	0.88
Massive	6.52(1.83,23.17)	<0.01
Hematoma clearance rate		
50%–70%	Reference	
>70%	0.43(0.17,1.07)	0.07

GCS, Glasgow Coma Scale; OR, odd ratio; CI, Confidence Interval.

Table 4
Multivariable analysis for death within 30 days of surgery in patients with PPH.

Variables	OR (95%CI)	*P* value
Age, year		
<48	Reference	
48–67	3.00(0.58,15.61)	0.19
>67	6.00(1.06,34.04)	0.04
GCS score	0.44(0.24,0.81)	0.01
Hematoma size, ml		
5–10	Reference	
>10	5.12(1.30,20.15)	0.02
Hematoma classification		
Dorsal	Reference	
Ventral	0.71(0.12,4.16)	0.71
Massive	1.44(0.24,8.57)	0.69
Hematoma clearance rate		
50%–70%	Reference	
>70%	0.30(0.09,1.07)	0.16

GCS, Glasgow Coma Scale; OR, odd ratio; CI, Confidence Interval.

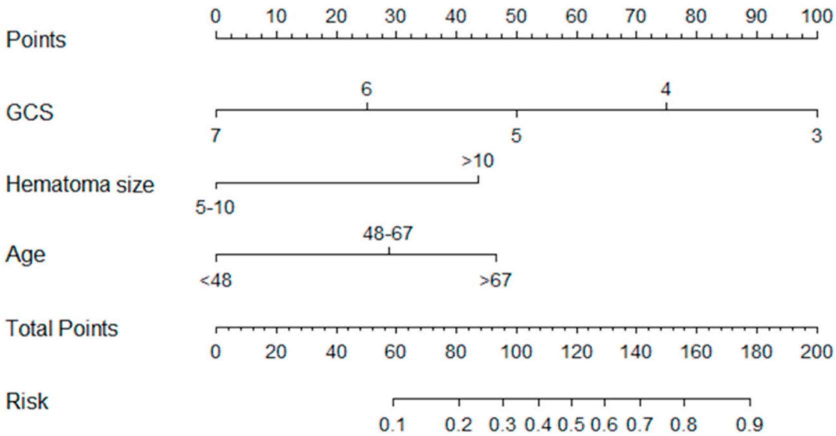

Fig. 4. A nomogram model for predicting the risk of death within 30 days of stereotactic hematoma puncture and drainage in patients with PPH. Each risk factor is assigned a numerical score on the top line, and the sum of these scores constitutes the cumulative score. The cumulative score can then be used to predict the probability of death within 30 days following stereotactic hematoma puncture and drainage for PPH patients by referencing the bottom axis.

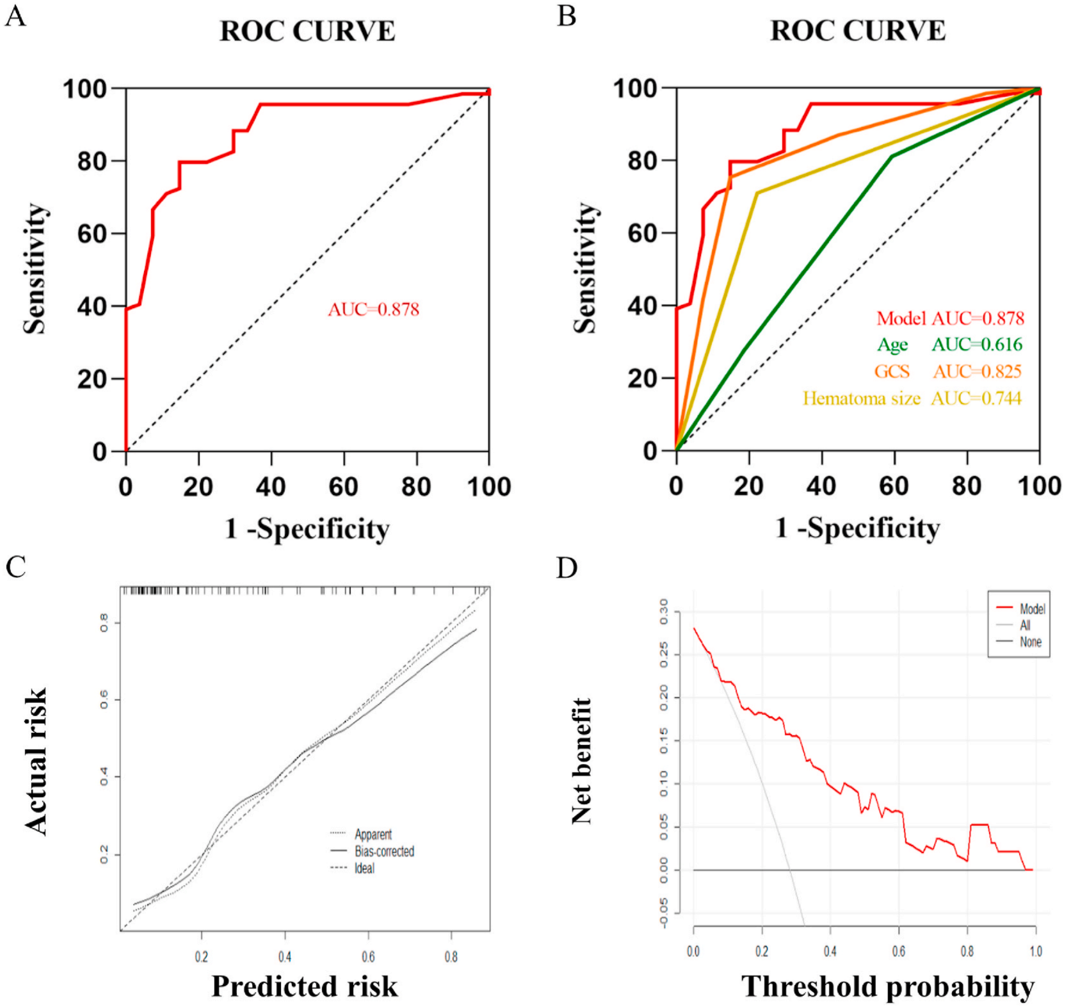

Fig. 5. The evaluation of the nomogram model. Receiver operating characteristic curve for assessing the discrimination performance of the nomogram model (A). Receiver operating characteristic curves of patients who died within 30 days of surgery predicted by age, GCS score, hematoma size, and nomogram model (B). Calibration curve of the risk nomogram for death at 30 days after surgery in patients with PPH (C). The decision curve analysis of the nomogram model (D).

within 30 days post-treatment, providing a reference for neurosurgeons to identify patients who may benefit from surgery. Additionally, the model demonstrated good discriminative and calibration abilities through internal validation.

Previous studies have identified several factors that may impact the prognosis of PPH patients, including coma on admission, hematoma location, hematoma size, hyperthermia, and hematoma extension. Dziewas et al. found that coma on admission, hematoma location, and hematoma size were independent predictors of death, while Matsukawa et al. reported that hyperthermia and hematoma extension also predicted patient death [25–27]. In general, the initial level of consciousness and radiological features are considered important indicators of prognosis in PPH patients. However, the factors that impact surgical outcomes in this patient population have received limited examination and their validity remains to be fully established.

In our study, GCS score and hematoma size were found to be independent predictors of death within 30 days following stereotactic hematoma puncture and drainage in patients with PPH. Lower GCS score and larger hematomas, greater than 10 ml, were identified as being associated with an increased risk of death. Previous studies examining the influence of level of consciousness on prognosis in conservatively managed patients have utilized either the "coma on admission" assessment or GCS threshold, with results consistently demonstrating a significant correlation [28]. Our findings reinforce the established notion that patient consciousness plays a pivotal role in prognosis. Hematoma size has similarly been shown to affect surgical outcomes, as mechanical destruction of hematomas can lead to primary and secondary brainstem injury, as well as local tissue ischemia, edema, or an inflammatory response triggered by hematoma catabolic products [24]. In addition, age was found to be a predictor of death within 30 days after stereotactic hematoma puncture and drainage in patients with PPH, a finding consistent with previous studies in conservative management by Morotti et al. [29]. This may be due to the observation that younger patients tend to possess a stronger repair capacity and immune barrier.

In our univariate analysis, hematoma classification was also determined to exert a significant impact on postoperative mortality. Research conducted by Wessels et al. and Jang et al. have indicated that ventral or massive hematomas are associated with high mortality rates, while dorsal hematomas tend to have more favorable outcomes [10,30]. Despite similar findings in our study, multivariable analysis indicated that hematoma classification was not an independent predictor of postoperative mortality. The results of our analysis suggest that hematoma clearance rate, which was also included in the multifactorial analysis, does not appear to affect the clinical outcome of patients. This may be due to our surgical strategy, which involves placing drains after removing at least 50% of the hematoma and allowing residual hematoma to drain.

The timing of surgical intervention is a critical aspect of management in cases of PPH. Lan et al. discovered that neurological recovery was better in the group operated on within 6 h than in the group operated on late in PPH patients, Consequently, they proposed that the optimal timing for surgery might involve receiving surgical intervention within 6 h of symptom onset [31]. Chen et al. concluded that the optimal timing for surgery in PPH is between 12 and 48 h after the onset of symptoms [17]. Notably, the timing of surgery in this study did not significantly impact the clinical outcomes in PPH patients. This could be attributed to the limited sample size and the fact that surgeries were mostly performed within 6–24 h of onset. Additional research is necessary to comprehensively elucidate the impact of timing on surgical outcomes for PPH patients. In our analysis, we also evaluated other factors that may influence the outcome of the procedure, and found that the presence of ventricular hematoma or hydrocephalus did not have a significant impact. This may be attributed to the utilization of EVD in this patient population. In addition, we excluded the effect of extrapontine extension from the analysis.

Acknowledging the limitations of our study is crucial. It involved a retrospective analysis with a small sample size. Furthermore, there is a possibility that some important prognostic factors may have been overlooked, although we included several important prognostic factors in the model. The validity of our findings is therefore limited, and further validation through external data is required.

5. Conclusions

In this study, stereotactic hematoma puncture and drainage procedures significantly improved the survival rate of patients with PPH and demonstrated the potential to enhance functional outcomes in PPH patients. Age, GCS score, and hematoma size emerged as independent predictors of death within 30 days following stereotactic hematoma puncture and drainage in PPH patients. A nomogram predictive model for postoperative mortality risk in PPH patients was constructed based on these factors and internally validated, exhibiting good discriminative and calibration abilities.

The model provides neurosurgeons with a reference tool for assessing the risk of postoperative death and screening ideal surgical candidates.

Ethics approval

This study was approved by the Ethics Committees of the 904th Hospital of PLA and Yixing People's Hospital (N20230276). As this study was retrospective in nature, the need for informed consent was waived.

Additional information

No additional information is available for this paper.

Funding

No funding received for this study.

Data availability Statement

Data is available on reasonable request.

CRediT authorship contribution statement

Yingying Ding: Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Ming Qi:** Formal analysis, Data curation, Conceptualization. **Xu Zhang:** Validation, Formal analysis, Data curation. **Jirong Dong:** Writing – review & editing, Validation, Conceptualization. **Da Wu:** Writing – review & editing, Validation, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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