

Development and Validation of a Nomogram Model for Assessing the Impact of Continuous Lumbar Drainage Volume on Prognosis in Patients with Acute Hydrocephalus After Aneurysmal Subarachnoid Hemorrhage

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Purpose: This study aimed to analyze the influence of volume during continuous lumbar drainage on the prognosis of patients with acute hydrocephalus after aneurysmal subarachnoid hemorrhage (aSAH) and to develop and validate a prognostic nomogram model.

Patients and Methods: The clinical data of patients with acute hydrocephalus after aSAH at a single center were retrospectively collected. The modified Rankin Scale score at 6 months after discharge was used as the prognostic outcome. Clinical data were included in the univariate analysis. Significant variables were incorporated into a multivariate logistic regression analysis. On the basis of the independent factors identified, an individualized prognostic nomogram was developed and internally validated.

Results: In total, 164 patients were included. Multivariate analysis revealed high World Federation of Neurological Surgeons scores (OR: 3.20), high modified Fisher grades (OR: 3.39), shunt dependence (OR: 8.05), and cerebral vasospasm (OR: 22.65) as independent risk factors for poor prognosis. Continuous lumbar drainage volume (OR: 0.61) was determined to be an independent protective factor. A nomogram model incorporating these independent factors was successfully constructed. The model demonstrated good predictive performance, with area under the receiver operating characteristic curve values greater than 0.86 in the training and test sets. Internal validation indicated high discriminative ability (C-index: 0.935) and good calibration.

Conclusion: Increasing the volume of continuous lumbar drainage within the patient's tolerance range is an independent protective factor. The nomogram effectively integrates multiple independent factors and provides a potentially effective reference tool for individualized prognosis prediction in patients with acute hydrocephalus after aSAH.

Keywords: aneurysm, subarachnoid hemorrhage, hydrocephalus, lumbar drainage, prognosis, nomogram

Introduction

Subarachnoid hemorrhage (SAH) accounts for 5% of stroke cases, and aneurysm rupture is the underlying cause in 85% of SAH cases. Hydrocephalus is a major complication among patients with spontaneous SAH.¹⁻³ Hydrocephalus can lead to a prolonged hospital stay, an increased number of days (d) in the intensive care unit (ICU), and an increased rate of shunt-dependent hydrocephalus in SAH patients.⁴ It is also a common cause of readmission after aneurysmal subarachnoid hemorrhage (aSAH). Hydrocephalus may lead to cognitive decline and neurological deterioration, even when the main cause of SAH has been treated successfully.^{5,6}

Hydrocephalus in SAH may be categorized as acute, subacute, or chronic. Acute hydrocephalus occurs within 72 hours (h) after SAH onset, subacute hydrocephalus occurs between the 3rd and 13th d after SAH onset, and chronic hydrocephalus occurs 14 d after SAH onset.⁷ The pathogenesis of post-SAH hydrocephalus is complex. Blood decomposition in the subarachnoid space triggers a strong inflammatory response, releasing cytokines such as transforming growth factor- β 1 and interleukins, which induce fibrosis of the subarachnoid space and obstruction of cerebrospinal fluid (CSF) absorption pathways.⁸ Recent studies have also suggested that glymphatic system dysfunction leads to metabolic waste accumulation and neuroinflammation, forming a vicious cycle that may contribute to the development of hydrocephalus.⁹

Pathologically, hydrocephalus can be divided into obstructive and communicating types. Obstructive hydrocephalus is caused by blockage within the ventricular system, which prevents CSF from flowing between ventricles or entering the subarachnoid space. In contrast, communicating hydrocephalus involves no mechanical obstruction in ventricular pathways; CSF can flow freely between ventricles and into the subarachnoid space, but accumulation results from impaired absorption at the arachnoid granulations or excessive CSF production.¹⁰

In clinical practice, the incidence of hydrocephalus after aSAH is approximately 40.4%, which increases the clinical burden and adversely affects patient prognosis.¹¹ Acute hydrocephalus often requires temporary drainage. Nonobstructive acute hydrocephalus is typically treated with continuous lumbar drainage of CSF, which continuously removes blood and its degradation products from the subarachnoid space, improves the brain tissue environment, and prevents brain tissue injury associated with ventricular puncture.¹² However, the effectiveness of continuous lumbar drainage has never been thoroughly investigated, and its long-term effects must be confirmed through further clinical research.¹³

Therefore, the present study focused on how defined continuous lumbar drainage volume affects the prognosis of patients with acute hydrocephalus after aSAH.

Materials and Methods

Information

The data of patients with acute hydrocephalus due to aSAH who were admitted to the Department of Neurosurgery, the First Affiliated Hospital of Chongqing Medical University between January 2014 and January 2024 were studied retrospectively. This retrospective study was approved by the Ethics Committee of the First Affiliated Hospital of Chongqing Medical University ([2023-K514], approval date: November 7, 2023).

The inclusion criteria were as follows: 1) SAH confirmed by computed tomography (CT) or lumbar puncture; intracranial aneurysms confirmed by computed tomography angiography (CTA) or digital subtraction angiography (DSA); intervention or clipping surgery for intracranial aneurysms; 2) the presence of acute hydrocephalus confirmed by preoperative or postoperative CT or magnetic resonance imaging; and (3) no death during hospitalization and a follow-up period of more than half a year post-discharge. The patients were discharged smoothly and followed up for more than 6 months after discharge.

The exclusion criteria were as follows: 1) patients with intracranial tumors and other significant organ pathologies, 2) patients for whom external ventricular drainage was needed for obstructive hydrocephalus, 3) patients who did not undergo lumbar drainage or for whom drainage data were lacking, 4) patients whose family members refused surgical treatment for intracranial aneurysms, and 5) patients with no/incomplete follow-up.

SAH Management

The patients were admitted to the neurosurgical ICU to closely monitor their vital signs and neurological symptoms, allow adequate bed rest to maintain smooth breathing, and prevent emotional overreaction. Diazepam was administered to patients with irritability. Blood pressure was controlled at 140/90 mmHg using short-acting antihypertensive drugs such as labetalol and nicardipine. All the patients were treated with nimodipine for antivasospasm. The need for surgical treatment of an aneurysm, including minimally invasive endovascular arterial embolization and aneurysm clipping, was determined on the basis of the patient's condition.

Methods

Data on patient demographic characteristics (age, body mass index (BMI), sex, history of hypertension and diabetes, and smoking habits), SAH (Hunt-Hess grade, modified Fisher (mFisher) grade, World Federation of Neurological Surgeons (WFNS) score, and location of aneurysm), surgical method, infection, cerebral vasospasm, lumbar drainage time, flow rate, height, shunt dependence, and fibrinolytic resistance treatment were collected. At the follow-up visits, a brain CT examination within 3 months after disease onset revealed progressive ventricular system expansion and a ratio greater than 0.3 of the maximum diameter of the anterior horn of the lateral ventricle and the maximum diameter of the cranial cavity at the same level. Functional outcomes were evaluated using the modified Rankin Scale (mRS) score and accordingly classified as good (mRS 0–2) or poor (mRS 3–6) at 6 months of follow-up. Symptoms such as disturbed consciousness, unsteady gait, intracranial hypertension, and urinary incontinence were evaluated. Accordingly, the requirement for permanent shunt intervention was established. Shunt dependence in patients was defined as severe stenosis of the midbrain aqueduct.¹⁴ The functional scores were evaluated by two neurosurgeons under the supervision of senior physicians. Data on lumbar drainage, including drainage duration, CSF output, and drainage pressure, were obtained from the care notes of the patients. Radiological manifestations of vasospasm were evaluated mainly through CTA. According to the CTA findings at admission, the patients were classified as mild (<30%), moderate (30–60%), or severe (>60%) depending on the degree of decrease in the inner diameter of the vessel. The vessels evaluated included the bilateral anterior and middle cerebral arteries, anterior and posterior communicating arteries, and basilar arteries.

Statistical Analysis

A statistical analysis system (version 9.4; SAS Institute, Inc., Cary, NC, USA) and R software (version 4.2.2) were used for data processing. The enumeration data are presented as the relative number composition ratio (%) or rate (%), which was adopted for the χ^2 test or mFisher's exact test. The variables meeting the normality test in the measurement data were described by means and standard deviations, and a *t*-test was used; otherwise, the median and quartile descriptions were used, and the nonparametric Wilcoxon test was applied. Factors related to adverse short-term clinical prognosis after acute hydrocephalus after SAH operation were screened by single-factor and multiple-factor stepwise logistic regression analyses ($\alpha = 0.05$ for entry, $\alpha = 0.10$ for removal). The screened risk factors were introduced into the R software to construct a nomogram. The accuracy, sensitivity, specificity, positive predictive value, negative predictive value, and area under the receiver operating characteristic (ROC) curve (AUC) were calculated using a tenfold cross-validation to evaluate model stability and prediction efficiency. The average consistency index (C index) was calculated by the bootstrap internal validation method (1000 independent repeated samples), and the degree of discrimination of the evaluation model was as follows: 1 is completely consistent, >0.90 is high, 0.71–0.90 is medium, 0.50–0.70 is low, and <0.50 is completely random. A calibration curve was drawn to evaluate the model's calibration (a good consistency between the model's prediction probability and the actual probability indicates good calibration). $P < 0.05$ was considered to indicate statistical significance.

Results

Patient Characteristics

In this study, 1578 patients with aSAH received interventional or splint treatment, 245 developed acute hydrocephalus, 52 received external ventricular drainage, 9 died, 9 gave up treatment, and 11 were lost to follow-up. A total of 164 patients were included in the final analysis (Figure 1). According to their mRS scores, 92 patients (56.1%) presented good outcomes, whereas 72 (43.9%) presented poor outcomes. Comparisons of the demographic characteristics and lumbar drainage indices of both groups are provided in Table 1. The mean age of the patients in the good prognosis group was 54.67 ± 10.14 years, and that in the poor prognosis group was 57.01 ± 8.95 years; however, the difference was not statistically significant. The good prognosis group included 32 male and 60 female patients, and the poor prognosis group included 36 male and 36 female patients; no significant difference was observed. Patient BMI, lumbar drainage pressure, history of hypertension and diabetes, smoking and drinking habits, aneurysm location, surgical method, and intracranial infection did not significantly differ between the two groups. In the good prognosis group, the WFNS score, Hunt-Hess

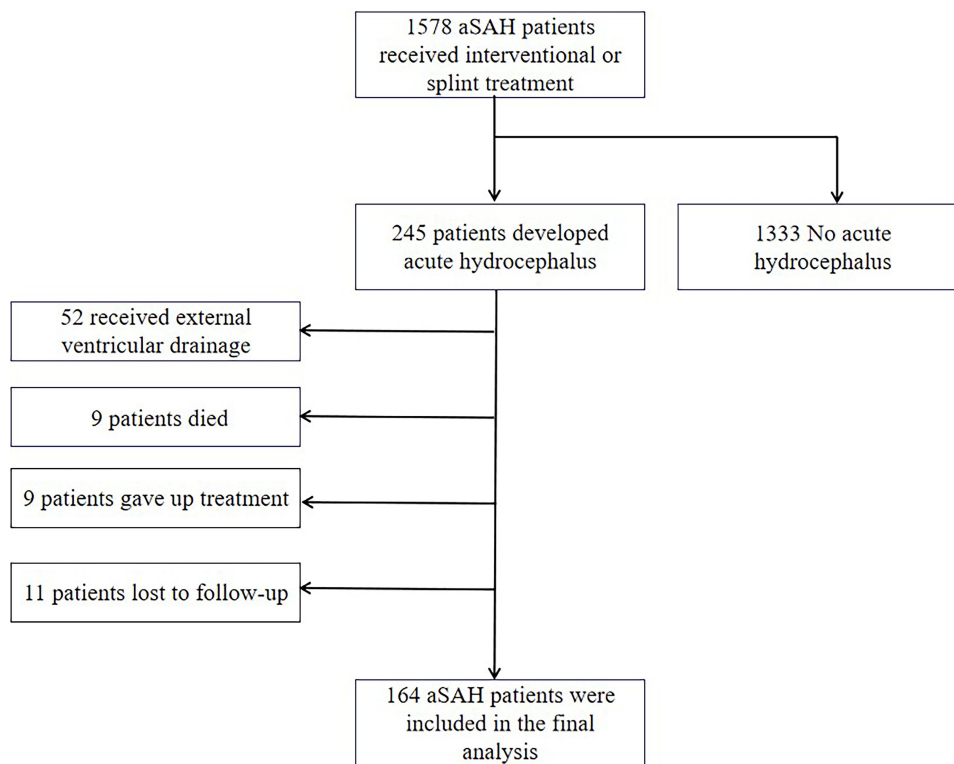


Figure 1 Flowchart of the study inclusion and exclusion criteria.
Abbreviation: aSAH, aneurysmal subarachnoid hemorrhage.

grade, and mFisher grade were low; the number of d for which lumbar drainage was performed, the number of cases of cerebral vasospasm and cerebral infarction were small; the drainage volume was large; and there was no shunt dependence. The differences between the two groups were statistically significant.

Independent Risk Factors and Protective Factors

The following variables revealed as significant in the univariate analysis were included in the multivariate analysis: WFNS score, Hunt-Hess grade, mFisher grade, lumbar drainage time and volume, shunt dependence, and cerebral vasospasm. Logistic stepwise regression was adopted to screen out the variables affecting the mRS score, and five factors were revealed to independently affect the prognosis of patients. High WFNS score (OR: 3.20; 95% CI: 1.54–6.64; $P = 0.0018$), high mFisher grade (OR: 3.39; 95% CI: 1.50–7.66; $P = 0.0033$), shunt dependence (OR: 8.05; 95% CI: 1.54–41.96; $P = 0.0133$), and cerebral vasospasm (OR: 22.65; 95% CI: 5.82–88.18; $P = 0.0001$) independently predicted the risk of mRS. Length drainage volume (OR: 0.61; 95% CI: 0.49–0.76; $P = 0.0001$) was the only factor that protected the mRS score (Table 2).

Nomogram Model Establishment and Validation

In accordance with the results of logistic regression analysis, a nomogram was constructed by taking the WFNS score, mFisher grade, shunt dependence, cerebral vasospasm, and lumbar drainage volume as predictive factors and the mRS score at 6 months after surgery as the clinical outcome (Figure 2).

The accuracy, sensitivity, specificity, positive predictive value, and negative predictive value of the model for the training and test sets were obtained through cross-validation with ten folds. The AUC was greater than 0.86, indicating that the model has good predictive ability and stability (Table 3). Verification by the bootstrapping method revealed that the nomogram model has good discrimination ability (C-index: 0.944 [95% CI: 0.910–0.977], corrected C-index is 0.935). The calibration curve revealed that in the improved model, the WFNS score, mFisher

Table 1 Comparison of the Results of Univariate Analysis Between the Good Prognosis and Poor Prognosis Groups [Mean \pm Standard Deviation, Cases (%)]

Variables	mRS 0–2 (n=92)	mRS 3–6 (n=72)	P value
Age	54.67 \pm 10.14	57.01 \pm 8.95	0.1246 ^a
Gender			
Male	32(34.78)	36(50.00)	0.0496^c
Female	60(65.22)	36(50.00)	
BMI	24.40 \pm 3.01	25.19 \pm 3.28	0.1125 ^a
WFNS score	2[2–3]	3[2.5–4]	<0.0001^b
Hunt-Hess grade	2[2–2]	3[2–3]	<0.0001^b
mFisher grade	3[1–3]	3[2–4]	0.0001^b
Drainage time of lumbar (d)	8[7–11.5]	11[8–16.5]	0.0012^b
Pressure (cmHg)	15[10–15]	15[10–15]	0.5083 ^b
Drainage volume (*10 mL)	10[6.75–13.90]	6.9[5.65–9.30]	0.0006^b
Shunt dependence	25(27.17)	37(51.39)	0.0015^c
Hypertension	42(45.65)	34(47.22)	0.8414 ^c
Smoking	30(32.61)	30(41.67)	0.2320 ^c
Drinking	24(26.09)	27(37.50)	0.1171 ^c
Diabetes	13(14.13)	9(12.50)	0.7611 ^d
Location of aneurysm			
Posterior circulation	8(8.70)	10(13.89)	0.4940 ^d
Anterior circulation	84(91.30)	62(86.11)	0.2910 ^c
Operation method			
Coil	37(40.22)	27(37.50)	0.7233 ^c
Clip	55(59.78)	45(62.50)	<0.0001^c
Complicated with intracranial infection	34(36.96)	23(31.94)	0.5036 ^c
Cerebral vasospasm	8(8.70)	40(55.56)	<0.0001^c

Notes: ^adenotes the t-test, ^bdenotes the nonparametric Wilcoxon test, ^cdenotes the chi-square test, and ^ddenotes the mFisher exact test. The bold indicates a statistically significant P value <0.05.

Abbreviations: mRS, modified Rankin Scale; BMI, body mass index; WFNS, World Federation of Neurological Surgeons; mFisher, modified Fisher.

Table 2 Results of Multivariate Logistic Stepwise Regression Analysis Conducted for the Variables Affecting the mRS Score

Variables	Estimated	Standard Deviation	χ^2	P value	OR	95% CI	
WFNS score	1.16	0.37	9.72	0.0018	3.20	1.54	6.64
mFisher grade	1.22	0.42	8.64	0.0033	3.39	1.50	7.66
Shunt dependence	2.09	0.84	6.13	0.0133	8.05	1.54	41.96
Cerebral vasospasm	3.12	0.69	20.24	<0.0001	22.65	5.82	88.18
Lumbar drainage volume	–0.50	0.11	18.67	<0.0001	0.61	0.49	0.76

Note: The bold indicates a statistically significant P value <0.05.

Abbreviations: mRS, modified Rankin Scale; WFNS, World Federation of Neurological Surgeons; mFisher, modified Fisher.

grade, shunt dependence, cerebral vasospasm, and lumbar drainage volume were highly consistent between the prediction probability of poor clinical prognosis and the actual probability (Figure 3), indicating that the model was well calibrated.

The ROC curve revealed that only the lumbar drainage volume predicted the prognosis of postoperative acute hydrocephalus, with an AUC of 0.626. The AUC of the improved model (predicted by WFNS score, mFisher grade, shunt dependence, cerebral vasospasm, and lumbar drainage volume) was 0.859 (Figure 4).

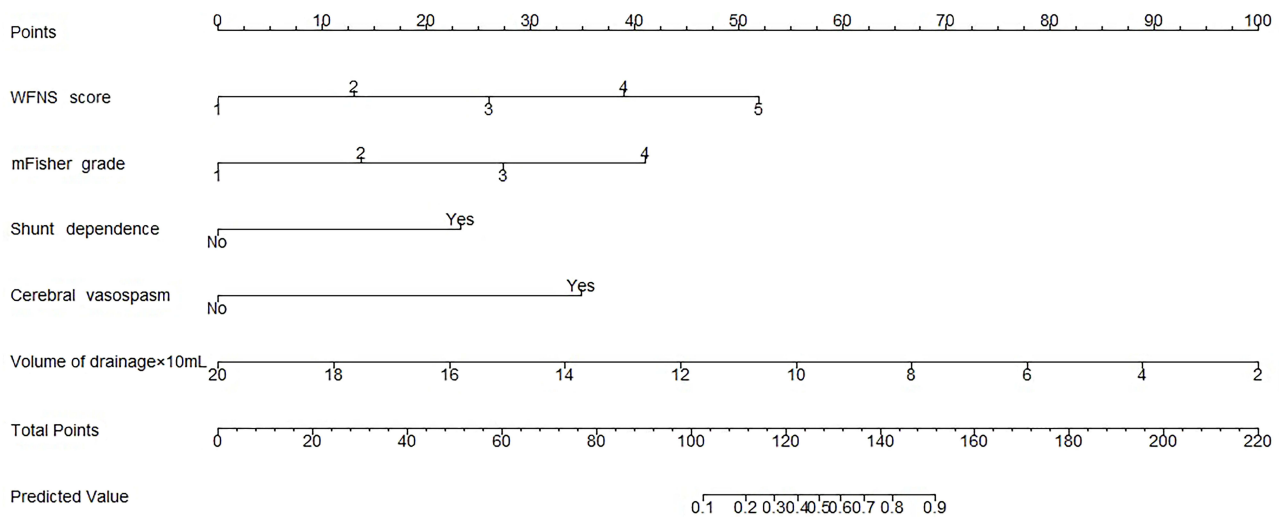


Figure 2 Illustrates the developed nomogram for predicting the prognosis of patients with acute hydrocephalus after aSAH. Find the patient's value on each variable axis and draw a line upward to assign points, sum these points, locate the total on the designated axis, and draw a line downward to the risk axes to determine the prognosis.

Abbreviations: WFNS, World Federation of Neurological Surgeons; mFisher, modified Fisher; aSAH, aneurysmal subarachnoid hemorrhage.

Discussion

aSAH is a common and severe craniocerebral disease.¹⁵ When blood vessels rupture, blood enters the subarachnoid space, which hinders the dynamics of the CSF and leads to a mass effect and eventually to abnormal intracranial pressure.¹⁶ Hydrocephalus, initially reported by Bagley in 1928, manifests as the presence of excessive CSF in the ventricular system. Accordingly, removing bloody CSF from the subarachnoid space and cisternae is crucial for managing aSAH-associated hydrocephalus.

Lumbar drainage and external ventricular drainage (EVD) remain the most extensively adopted approaches for continuous CSF drainage.¹⁷ Both lumbar drainage and EVD are controllable, enabling long-term continuous CSF drainage, effectively controlling intracranial hypertension, reducing blood accumulation, and lowering the risk of hydrocephalus. Among them, lumbar drainage is less invasive and avoids repeated lumbar punctures, resulting in greater patient acceptance. Studies have shown that the volume of CSF drainage can alter the amount of blood in the subarachnoid system, thereby influencing patients' symptoms and prognosis. Aggressive removal of bloody CSF from the basal cisterns in the early stage can significantly reduce the rate of shunt dependence. Compared with EVD, lumbar drainage clears blood from the basal cisterns more rapidly and is associated with a lower incidence of shunt dependence. CSF is less dense than blood, and ventricular drainage is easily affected by gravity, which may cause blood to remain in the basal cisterns and be difficult to eliminate. Among patients receiving both EVD and lumbar drainage after aSAH, CSF obtained from lumbar drainage was visibly more bloody or xanthochromic, with a higher hemoglobin content than that from EVD. Although both procedures carry a risk of catheter-related intracranial infection, EVD involves direct puncture of the brain parenchyma and is associated with an increased infection risk. In addition, lumbar drainage is associated with a lower incidence of intracerebral hemorrhage. Safety concerns associated with lumbar drainage should not be overlooked. Severe complications such as central brain herniation due to excessive drainage can be prevented by adjusting the height of the drainage tube, drainage rate, and total drainage volume.¹⁸

Table 3 Tenfold Cross-Validation Evaluation Indicators

Data Set	ACC	SEN	SPE	PPV	NPV	AUC
Train	86.44(85.96–86.99)	80.15(79.09–81.39)	90.97(90.36–92.45)	87.72(86.72–89.05)	85.47(84.77–86.13)	0.86(0.85–0.86)
Test	87.87(82.81–92.37)	84.52(73.02–96.43)	95.00(81.43–100)	92.86(80.83–100)	88.19(82.52–97.5)	0.87(0.82–0.92)

Note: Each indicator is expressed as the median [25%, 75%].

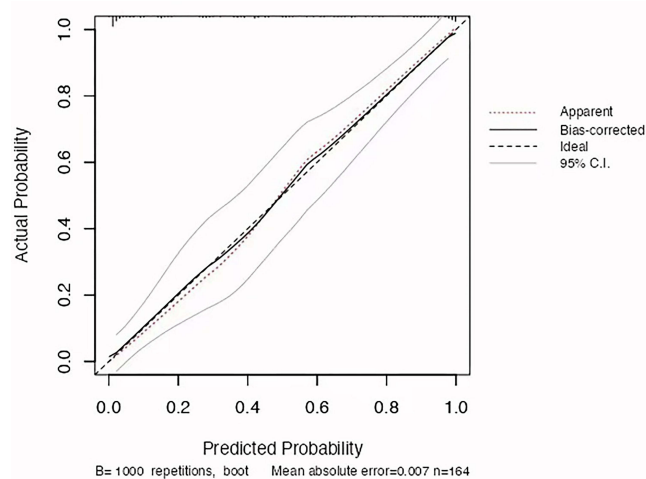


Figure 3 Calibration curve of the nomogram model. Calibration was assessed with 1000 bootstrap resamples using the rms package in R. The bias-corrected calibration curve showed excellent agreement between the predicted and actual probabilities (mean absolute error = 0.007), with 95% CI, confirming the model's strong predictive accuracy.

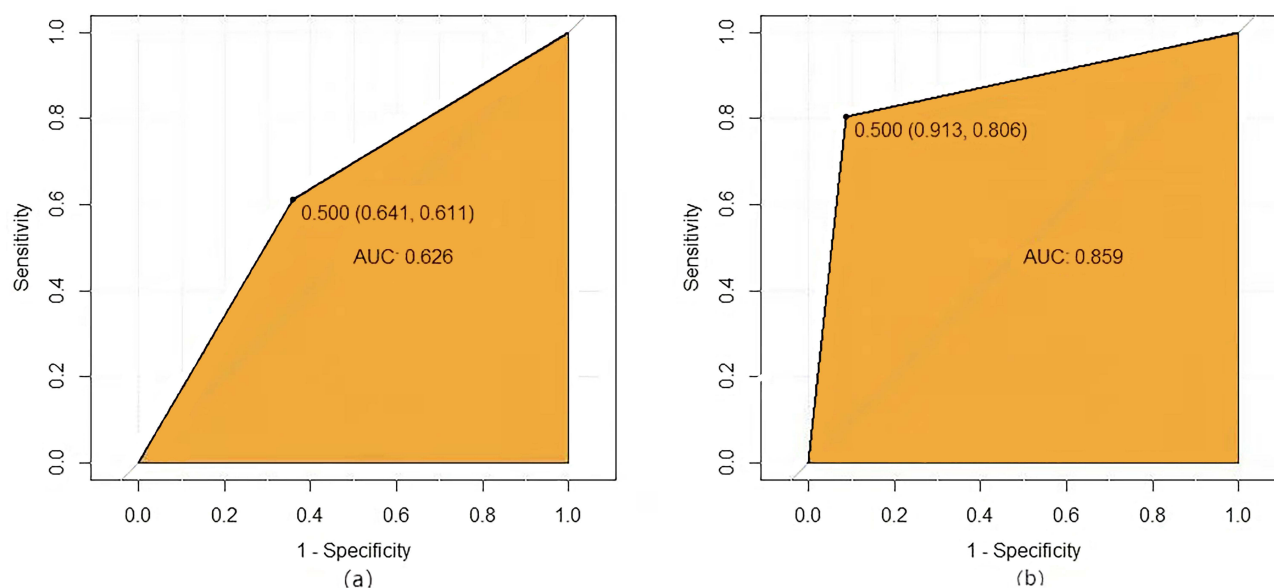


Figure 4 ROC curve of the nomogram model. (a) ROC curve using drainage volume as an indicator for predicting the prognosis of patients with acute hydrocephalus after aSAH. (b) ROC curve for predicting the prognosis of patients with acute hydrocephalus after aSAH by the modified model.

Abbreviations: ROC, receiver operating characteristic; AUC, area under the ROC curve; aSAH, aneurysmal subarachnoid hemorrhage.

Strict patient selection criteria are essential for safe and effective continuous lumbar drainage. In clinical practice, lumbar drainage is indicated in patients with nonobstructive acute communicating hydrocephalus after aSAH, without clinical or radiological evidence of brain herniation, severe intracranial mass effect, or uncorrected coagulopathy. Contraindications include obstructive hydrocephalus, impending cerebral herniation, local infection or deformity at the puncture site, and untreated bleeding disorders. A critical risk-benefit balance must be evaluated: Compared with EVD, lumbar drainage offers the benefits of rapid clearance of subarachnoid blood, reduced cerebral vasospasm, lower shunt dependency, and less invasion. However, the risks include overdrainage, rare but life-threatening brain herniation, catheter-related infection, and cerebrospinal fluid leakage. Therefore, lumbar drainage should be performed under close monitoring, with individualized adjustments of drainage pressure and volume to maximize benefits while minimizing safety risks.

The decomposition products of blood clots may trigger inflammatory cascades and cause cerebral vasospasm, which is related to cerebral infarction. Therefore, the breakdown products of blood clots are also considered to be significant predictors of poor outcomes following aSAH.^{4,19} In this context, surgical intervention is an available treatment option that prevents rebleeding by blocking the blood supply of the aneurysms and maintaining the patency of the parent artery and blood supply artery, thereby maintaining normal blood transport in brain tissues.²⁰ However, aSAH cannot be eliminated by surgery alone, and postoperative adjuvant drainage is necessary for clot removal. Lumbar puncture was previously applied extensively in this regard, but was not popular among patients because of its invasiveness and the possibility of multiple punctures being needed. Moreover, continuous lumbar drainage causes less trauma and enables controlled drainage, thereby requiring fewer repeated lumbar punctures, realizing continuous CSF drainage over a long period of time, and efficiently controlling intracranial hypertension for subsequent targeted therapy.²¹ Drainage is effective at reducing blood accumulation. The key to ensuring effective drainage is to select the appropriate drainage method. Continuous lumbar drainage offers the advantages of reduced pain due to multiple lumbar punctures, improved stimulation of the meninges by blood decomposition products, rapid control of the patient's intracranial pressure, and reduced occurrence of hydrocephalus and epilepsy.

As a consequence, the outflow speed is controlled effectively with reduced trauma to patients, leading to high acceptance of this method among patients.^{22,23} The clearance rate of extensive subarachnoid blood clots is reported to be an independent predictor of cerebral vasospasm.^{24,25} Rapid blood clot removal from the subarachnoid space is conducive to improving the prognosis of patients with aSAH.²⁶ Studies have reported that increasing the drainage volume to a level that is tolerable for patients leads to the effective removal of blood accumulation, achieving the goal of controlling vasospasm and reducing complications.²⁷ These findings are consistent with those of the present work. Here, the average drainage volume in the good prognosis group was 100 mL, which was greater than that in the poor prognosis group (69 mL). Every 10 mL increase in drainage volume significantly increased the prognosis score. According to Hoekema et al,⁷ excessive drainage may occur if the drainage volume exceeds 10 mL per h, with symptoms such as headache, an altered state of consciousness, or cranial nerve paralysis. In addition, the risk of shunt dependency may increase because of the prolonged, continuous drainage of CSF in large amounts. This phenomenon may be caused by the permanent collapse of the normal pathways for CSF drainage. We believe that under certain pressures, properly increasing the drainage volume can reduce the occurrence of shunt-dependent hydrocephalus and improve the prognosis.

Different studies may reach different conclusions. One study reported that total CSF drainage volume and mean CSF drainage volume within 72 h after aSAH were significant risk factors for shunt dependence. Their conclusions seem to be at odds with ours, but on closer analysis, both studies suggested that some aSAH patients have a greater demand for CSF drainage volume.¹³ Moreover, another study revealed a close correlation between the lumbar CSF drainage volume and the prognosis of aSAH patients and revealed that an appropriate drainage volume can improve short-term functional outcomes by alleviating oxidative stress and clearing hematoma degradation products.²²

Univariate analysis revealed that the WFNS score, Hunt-Hess grade, mFisher grade, lumbar drainage time, shunt dependence, cerebral vasospasm, and drainage volume could impact patient prognosis. Multivariate analysis was subsequently conducted to determine whether drainage volume was an independent factor. The results were affirmative. WFNS score, Hunt-Hess grade, mFisher grade, shunt dependence, and cerebral vasospasm were revealed as independent risk factors, which are consistent with the actual clinical research findings.

mFisher grade is an imaging manifestation reflecting the distribution of intracranial hematoma after aSAH. The higher the mFisher grade is, the greater the risk of cerebral vasospasm and delayed neurological impairment. It is an independent risk factor for poor prognosis. A high WFNS score is an independent risk factor that reflects the severity of brain tissue damage and cerebral vasospasm after aSAH, poor consciousness level, and poor prognosis.²⁸ Shunt-dependent hydrocephalus is a common and serious complication after aSAH. Hydrocephalus can lead to increased intracranial pressure and decreased cerebral perfusion pressure, leading to cerebral ischemia and affecting the prognosis of patients.²⁹ Approximately 20% to 30% of patients with aSAH develop cerebral vasospasm, which leads to cerebral ischemia and affects the blood supply of brain tissues, resulting in nerve function defects. It is one of the predictive factors of adverse prognosis after aSAH surgery.³⁰ In this study, a high WFNS score, high mFisher

grade, shunt-dependent hydrocephalus, and cerebral vasospasm were identified as independent risk factors for poor prognosis in patients with acute hydrocephalus after aSAH.

On the basis of the above five risk factors, a short-term clinical prognosis model for patients with aSAH was constructed, and a ROC curve and nomogram were constructed. The AUC was 0.859. The accuracy, sensitivity, specificity, positive predictive value, and negative predictive value for the training and test sets were obtained through cross-validation with ten folds. The model demonstrated high discriminatory power, stability, and calibration. These findings show that the model constructed by the lumbar drainage volume combined with the WFNS score, mFisher grade, shunt dependence, and cerebral vasospasm has good clinical value for predicting prognosis. Continuous lumbar drainage may also lead to intracranial infection, catheter occlusion, intracranial hematoma, nerve root irritation, intracranial emphysema, CSF leakage at the puncture site, and other complications. Therefore, a suitable perioperative nursing intervention is needed during continuous lumbar drainage to control such complications.³¹ Prior to surgery, the necessary drugs, including mannitol and sedatives, must be prepared. Intraoperative monitoring of vital signs is also recommended. If brain herniation is detected in a patient, then treatment must be terminated immediately, and the appropriate treatment should be given. In addition, drainage operations must be gentle, and the CSF release rate must be rigorously controlled to prevent brain protrusion. The dressing must be regularly changed, and the three-way valve must be disinfected and covered with sterile gauze to maintain hygiene. Moreover, the drainage bottle must be lifted prior to the removal and elimination of the drainage tube when the patient does not present any aberrant manifestations. After the drainage tube is removed, the puncture site must be sewn with silk suture to prevent CSF leakage.

This study adopts a single-center retrospective design; therefore, certain limitations exist. First, information bias could have occurred with missing data and during data extraction. A formal sample size calculation and power analysis were not conducted, and the sample was determined on the basis of available data. Thus, the statistical power of this study might be inadequate. Potential selection bias due to the retrospective single-center design and the exclusion of patients who died during hospitalization may introduce survival bias and affect the generalizability of the findings. Changes in CSF diversion and the duration of lumbar drainage in each patient might also be potential sources of this bias. The lower sensitivity of CTA for mild to moderate vasospasm than that of DSA partly leads to an underestimation of its true incidence and affects its OR in the model. Finally, the small sample size used in the study did not allow for the detection of intergroup differences. Therefore, large, multicenter, prospective trials are warranted for further verification of the findings of this study.

Conclusions

Continuous lumbar drainage after aSAH assists in controlling symptoms, lowering neurological dysfunction, and improving prognosis, thereby rendering drainage safe and extensive. Increasing the drainage volume within the patient's tolerance range would enable the effective removal of blood, control of vasospasm, and alleviation of complications. Continuous lumbar drainage is an independent predictor of the prognosis of these patients. The developed nomogram effectively integrates multiple independent factors and provides a potentially effective reference tool for individualized prognosis prediction in patients with acute hydrocephalus after aSAH. Before this model can be reliably applied in a wider range of clinical settings, external validation is need.

Abbreviations

SAH, subarachnoid hemorrhage; ICU, intensive care unit; aSAH, aneurysmal subarachnoid hemorrhage; CSF, cerebrospinal fluid; CT, computed tomography; CTA, computed tomography angiography; DSA, digital subtraction angiography; BMI, body mass index; mFisher, modified Fisher; WFNS, World Federation of Neurological Surgeons; mRS, modified Rankin Scale; ROC, receiver operating characteristic; AUC, area under the receiver operating characteristic curve; EVD, external ventricular drainage.

Data Sharing Statement

The data used and analyzed during the current study are available from the corresponding author upon reasonable request.

Ethics Approval and Informed Consent

This study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of the First Affiliated Hospital of Chongqing Medical University ([2023-K514], approval date: November 7, 2023). In accordance with national legislation and institutional requirements, written informed consent for participation was not required for this retrospective study. All patient data were anonymized and kept strictly confidential to protect privacy.

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Disclosure

The authors report no conflicts of interest in this work.

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