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Nomogram-Based Independent Risk Factor Analysis and Recurrence Prediction for Chronic Subdural Hematoma After Single Burr Hole Drainage

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ABSTRACT

AIM: To identify independent risk factors and propose a predictor scoring system in chronic subdural hematoma (CSDH).

MATERIAL and METHODS: Through retrospective analysis, we analyzed the data from 279 patients with CSDH from 2010 to 2020. Independent risk factors for recurrence were identified through univariate and logistic regression analyses. A risk-scoring model was developed using a nomogram, which was applied to all patients considering postoperative recurrence as a target. ROC curve analysis was done to assess the accuracy of the estimated scoring system.

RESULTS: The results revealed significant differences in Glasgow outcome scale (GOS), brain re-expansion after drainage, postoperative use of atorvastatin, side and density of hematoma, the history of trauma, hematoma separated, History of diabetes, and midline shift between patients with recurrent CSDH and non-recurrent. A scoring parameter was developed through a nomogram based on a combination of scored risk factors that were significantly higher in patients with recurrent CSDH (P-value <0.001). The sensitivity and specificity of the predictor score confirmed its efficacy in predicting the recurrence risk of CSDH (sensitivity: 70.5%, specificity: 45.9 %; cutoff: 0.74 and 95% confidence interval: 6.57-0.74).

CONCLUSION: A scoring system was finally obtained for the prediction of postoperative recurrence risk. The establishment of a predictor scoring system will help clinicians better monitor and adopt efficient management strategies for high-risk patients.

KEYWORDS: Chronic subdural hematoma, Burr hole drainage, Recurrence rate, Glasgow coma scale, Prognostic risk, Grading system.

ABBREVIATIONS: CSDH: Chronic subdural hematoma, **GOS:** Glasgow outcome scale, **GCS:** Glasgow coma scale, **ROC:** Receiver operating characteristic, **AUC:** Area under the curve, **CT:** Computed tomography, **MRI:** Magnetic resonance imaging, **SDH:** Subdural hematoma, **PreHTh:** Preoperative hematoma thickness, **PostHTh:** Postoperative hematoma thickness, **mRS:** Modified rankin scale, **MGS:** Markwalder grading scale, **IQR:** Interquartile range, **CI:** Confidence interval

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INTRODUCTION

Subdural hematoma (SDH) refers to an intracranial hemorrhage when bleeding occurs between the dura mater and arachnoid mater of the meninges (10). This condition, often due to traumatic brain injury or non-traumatic injuries caused by anticoagulant medication and spontaneous bleeding factors, can increase intracranial pressure and cause brain damage. CSDH develops over weeks or months after a brain injury and usually has a better prognosis (10).

Symptoms of a subdural hematoma are usually not specified. Patients complain of complicated manifestations such as headaches, visual and cognitive difficulties, lethargy, numbness in limbs, and sometimes nausea, vomiting, or confusion (37). The thickness of the hematoma, the degree of mass effect (such as midline shift or compression of the brain structure) on the brain, and the presence of edema are considered in imaging results (29). In subdural hematoma, the density of extra-axial fluid collection between the inner layer of the skull and the brain surface varies from hyper to hypodense in acute, subacute, and CSDH (26).

Recent studies have demonstrated that not all CSDH cases are associated with trauma, especially in older patients, with a relatively higher proportion of non-trauma-related patients. However, not all CSDH are transformed by acute subdural hematoma (5,27).

Considering global aging, it is necessary to explore the risk factors that increase the CSDH recurrence rate. Assessing the risk of postoperative recurrence of CSDH is clinically important (17,30,35,36). The recurrence rate of CSDH after burr hole drainage ranges from 4% to 38%, and the postoperative mortality rate of the cases ranges from 1.8% to 32% (8,40).

Several studies explore CSDH recurrence risk factors after hematoma drainage, including gender, age, trauma history, anticoagulant or antiplatelet use, preoperative Glasgow coma scale (GCS) which evaluates consciousness levels from 3 to 15, diabetes mellitus, hypertension, bilateral hematoma, hematoma volume, midline shift, and density (1,3,7,12,13,15, 22,23,25,34,38,39). Age is one of these factors, so some studies have reported aging as a risk factor for CSDH recurrence, while other studies have reported that aging could be a protective factor against it. The scoring system will provide clinical grounding for the perioperative management strategy of CSDH, reduce the postoperative recurrence, mortality, and morbidity rate, and improve the postoperative quality of life for patients (7).

Currently, no scoring system predicts CSDH recurrence; studies focus on risk factors without a cohesive model for unilateral and bilateral cases. This gap hinders clinicians from stratifying patients by recurrence risk and optimizing care. This study aims to develop a grading model based on independent risk factors from a retrospective analysis of patients treated with single-burr hole drainage, providing a tool to improve management and reduce recurrence rates.

MATERIAL and METHODS

Study Design

We retrospectively analyzed clinical data of all patients with CSDH admitted to the Seventh Medical Center of the PLA General Hospital from 2010 to 2020. This study was approved by the Ethics Committee of the Seventh Medical Center of the PLA General Hospital (approval number: 2021-133, approval date: November 14, 2021). All procedures were performed in accordance with the relevant guidelines and regulations of the Ethics Committee. All patients provided informed consent for participation and the use of anonymized data. Inclusion criteria were patients aged 18–96 years who underwent burr hole drainage for CSDH, with complete medical records including preoperative, intraoperative, and postoperative data, documented follow-up for recurrence, and at least one postoperative imaging study to evaluate recurrence. Exclusion criteria included age <18 years, craniotomy within the past 6 months, acute subdural hematoma, incomplete medical records, lack of follow-up, or patients undergoing other neurosurgical procedures except burr hole drainage. Postoperative imaging findings were used to confirm recurrence, which was defined based on hematoma re-accumulation on imaging combined with clinical symptoms (34).

Imaging Analysis

In patients with clinical symptoms, the diagnosis of CSDH was confirmed using documented results of cranial CT or MRI. The important finding in these two techniques included the age of the hematoma that can be estimated through T1 and T2-weighted images. In this case, hypo-, iso-, or hyper-density is noted due to the presence of blood, with CSDH typically appearing T1-hypointense compared to gray matter and showing variable T2 signal characteristics. The degree of midline shift reflects the mass effect and raised intracranial pressure associated with subdural hematomas. Brain herniation signs, such as subfalcine or uncal herniation, are also relevant. Skull fractures are assessed, along with various hemorrhage types, including intraparenchymal and epidural. Other findings include contusions, calcifications, the origin and side of the hematoma, and the presence of residual blood products post-surgery. Changes in burr hole drainage are monitored after surgery (16).

Surgical Procedure

The surgical intervention followed standard protocol. Burr hole surgery with twist-drill drainage is indicated for symptomatic patients with CSDH. Indications for burr hole drainage include: a) Clinical symptoms of subdural hematoma; b) Hematoma thickness over 10 mm and/or midline shift exceeding 5 mm; c) Midline shift from mass effect of hematoma causing consciousness disturbance, hemiplegia, paresthesia, seizures, and other neurological dysfunction; d) Progressive hematoma volume increase after conservative treatment. In bilateral subdural hematoma cases, the choice of unilateral or bilateral drainage depends on the thickness of the hematoma and associated clinical symptoms. If one side has a hemato-

ma thickness over 10 mm and causes symptoms, unilateral drainage is performed; if both sides cause symptoms, bilateral drainage is indicated (23).

Anesthesia was selected based on the patient's condition and cooperation. The patient was positioned supine, and the thickest part of the hematoma was chosen for incision based on preoperative CT/MRI. A hole was drilled into the skull, and a cross-shaped incision exposed the dura mater. The hematoma envelope was cut open for slow release, followed by irrigation with warm saline until clear. A drainage tube was placed in the hematoma cavity and connected to a closed drainage device, with the catheter entering posteriorly to the anterior part and the tip placed in the frontal region to reduce hematoma recurrence (22,38,39). The drainage tube's direction and length were considered to place the front end in the hematoma cavity, protecting the brain parenchyma from drainage damage. Closed drainage was performed slowly and continuously post-operation, with daily monitoring of drainage volume and fluid characteristics. Postoperative management included atorvastatin to potentially reduce recurrence rates at a dosage of 20 mg daily. Patients already on statin treatment preoperatively continued in the postoperative statin group for consistency and to maintain potential therapeutic benefits during the perioperative period.

CT scans confirmed brain re-expansion, leading to drainage tube removal when daily volume fell below 30 ml. Monitoring pneumocephalus post-surgery is crucial for assessing outcomes, though our study lacked precise measurement, an aspect future research should address (14,18,20,23). The brain re-expansion rate assesses treatment effectiveness and recurrence risk in subdural hematoma. It calculates brain tissue volume changes before and after surgery. Factors affecting the re-expansion rate include cerebral atrophy, age, and injury duration.

Recurrence Follow-Up

All patients were followed up for at least 6 months after discharge. During follow-up, if the patient shows aggravation of the existing symptoms or new signs of neurological dysfunction, and the CT scan shows more hematoma on the surgical side and requires a second operation, then the patient is diagnosed with CSDH recurrence. In our study, hematoma recurrence was defined as the reaccumulation of subdural blood or fluid at the original hematoma site, requiring subsequent surgical intervention within six months post-initial surgery.

Data Collection

General data included were gender, age, trauma history, past medical history (history of hypertension, hyperlipidemia, diabetes), clinical symptoms (high intracranial pressure symptoms such as headache, nausea, and vomiting, focal neurological disorders such as a decline in the muscle strength or sense of numbness, advanced neurological disorders, bladder, and bowel dysfunction, mental disorders and seizures), history of anticoagulant or antiplatelet therapy, alcoholism, the interval between onset of symptoms to operation, GCS score at admission, postoperative use of atorvastatin tablets, injection of urokinase into the hematoma cavity, drainage time, Glasgow Outcome Scale (GOS) score at discharge.

GOS is a useful tool for evaluating the outcome of patients with brain injury; categorizing ranges from 1. full recovery, 2. partial recovery, 3. no change in condition, 4. death, and 5. progressive deterioration and aggravation. GOS helps physicians predict the long-term outcomes of patients with brain injuries. A lower GOS score indicates poorer neurological function and a higher likelihood of recurrence due to factors such as increased intracranial pressure and larger subdural space, which predispose patients to hematoma reaccumulation. The imaging data include preoperative hematoma thickness (PreHTh) and postoperative hematoma thickness (PostHTh) (thickness of the thickest plane of the axial image), midline shift (measured at the level of interventricular foramen on axial image), separated and delaminated hematoma, brain atrophy, hematoma density (including hypodense, isodense, hyperdense and mixed density), hematoma (unilateral or bilateral) and the extent of brain re-expansion after drainage. The extent of brain re-expansion after drainage, based on the CT scan before the drainage tube was removed, was calculated as follows: (PreHTh-PostHTh)/ PreHTh × 100% (32).

The clinical and imaging data of all patients were independently evaluated by two neurosurgeons and one neuroimaging specialist, all of whom were blinded to the study outcomes. For patients with bilateral hematomas, hematoma density was determined based on the operative side. In cases of bilateral drainage, density was assessed according to the hematoma on the recurrent side. If recurrence occurred on both sides, the side with the thicker hematoma was considered the reference, as greater thickness and higher or mixed density are more likely to indicate bleeding tendency and risk of recurrence.

Statistical Analysis

Statistical analyses were conducted with Statistical Package for Social Sciences (SPSS, IBM SPSS Statistics Inc., Chicago, IL, Windows version 21.00). All continuous variables were assessed for normality with the Kolmogorov-Smirnov normality test. Variables with normal distribution are presented as means ± standard deviation ($x \pm s$), and variables with skewed distribution are presented as median (Interquartile range, IQR). The nominal variables and also ranked variables were expressed in terms of count (%), and the univariate analysis was performed with Fisher's Exact Chi-Square (χ^2) test. Continuous variables were expressed as mean ± standard deviation ($x \pm s$), and their differences between patients with recurrence SDH and non-recurrence were compared using the Student's *t*-test. To estimate probable confounding factors on recurrence risk, multivariable logistic regression analysis considering the aforementioned test results was performed using variables with a p-value < 0.1. A nomogram scoring system for predicting the recurrence rate was constructed using the Orange data mining toolbox (version 3.36.2) based on the ranked top important factors that were determined from the univariate analyses. Following the nomogram construction, a scoring predictor parameter was developed. Since the results of the Kolmogorov-Smirnov normality test indicated skewed distribution, the difference in predictor scores between patients with recurrence of SDH and lack of recurrence was compared

using the Student's t-test. Finally, a receiver operating characteristic (ROC) curve was created from the predictor score obtained from the nomogram. The area under the curve (AUC) and 95% confidence interval (CI) of the predictor scores were calculated. The data from the Second Affiliated Hospital of Anhui Medical University was used as external validation and not included in any analysis of nomogram development; the nomogram was finally tested on that dataset to compare the results. For all statistical analyses, the p-values less than 0.05 were considered significant.

RESULTS

General Characteristics

A total of 397 patients with CSDH were admitted to the Seventh Medical Center of the PLA General Hospital between 2010 and 2020. Ninety-six patients received medication, but no burr hole drainage was performed. Six patients died after surgery during hospitalization, and 16 patients were lost during follow-up or incomplete data collection. Therefore, these cases were excluded from the research. Finally, 279 patients (males: 233 [83.5%]; females: 46 [16.5%]) who met the inclusion criteria and all of them who received burr hole external drainage surgery were screened out for the study. The average age of all patients was 68.7±16.1 years (age range: 18-96). A total of 32 patients had CSDH recurrence after drainage, with a recurrence rate of 11.5%. There were 25 males and seven females among the recurrent patients. There were 171 cases (61.3%) of unilateral hematoma and 108 cases (38.7%) of bilateral hematoma, including 14 cases of unilateral hematoma recurrence and 18 cases of bilateral hematoma recurrence.

Univariable Analysis

The clinical and imaging data of all patients were analyzed by univariate analysis. The results of the univariate analysis of all data are shown in Table I. The patients with history of trauma and diabetes had a higher recurrence rate (p=0.01 and

Table I: Univariate Analysis of CSDH Recurrence After Drainage

Factors		Number of patients (%)		p-value
		Recurrence	No recurrence	
		32 (11.5)	**247 (88.5)**	
Gender	Male	25 (10.7)	208 (89.3)	0.655
	Female	7 (15.2)	39 (84.8)	
Age, mean±SD (years)		69.97±15.15	68.37±16.62	0.747
History of trauma	Yes	27 (13.6)	171 (86.4)	**0.010**
	No	5 (6.2)	76 (93.8)	
Hypertension	Yes	17 (12.8)	116 (87.2)	0.745
	No	15 (10.3)	131 (89.7)	
Diabetes mellitus	Yes	10 (18.5)	44 (81.5)	**0.039**
	No	22 (9.8)	203 (90.2)	
Hyperlipemia	Yes	3 (13.6)	19 (86.4)	1.00
	No	29 (11.3)	228 (88.7)	
Alcoholism	Yes	8 (14.5)	47 (85.5)	0.220
	No	24 (10.7)	200 (89.3)	
Antiplatelet or anticoagulant therapy	Yes	9 (12.9)	61 (87.1)	0848
	No	23 (11)	186 (89)	
Headache and vomiting	Yes	29 (12.1)	211 (87.9)	0.479
	No	3 (7.7)	36 (92.3)	
Advanced neurological disorder	Yes	10 (12.2)	72 (87.8)	0.637
	No	22 (11.2)	175 (88.8)	
Focal neurological disorders	Yes	23 (11.9)	171 (88.1)	1.00
	No	9 (10.6)	76 (89.4)	
Epileptic seizure	Yes	2 (18.2)	9 (81.8)	0.427
	No	30 (11.2)	238 (88.8)	

Table I: Cont.

Factors		Number of patients (%)		p-value
		Recurrence	No recurrence	
		32 (11.5)	**247 (88.5)**	
Bladder and bowel dysfunction	Yes	1 (6.7)	14 (93.3)	0.709
	No	31 (11.7)	233 (88.3)	
Mental disorders	Yes	2 (22.2)	7 (77.8)	0.303
	No	30 (11.1)	270 (88.9)	
GCS score	3-8	3 (30)	7 (70)	0.149
	9-12	2 (5.9)	32 (94.1)	
	13-15	27 (11.5)	208 (88.5)	
The interval between injury and onset of symptoms (month)	< 1	15 (12.2)	108 (87.8)	0.463
	1- 3	14 (12.7)	96 (87.3)	
	> 3	3 (6.5)	43 (93.5)	
Injection of urokinase into the hematoma cavity	Yes	2 (25)	6 (75)	0.119
	No	30 (11.1)	241 (88.9)	
Drainage time (days)		3.78±2.15	3.22±1.92	0.256
Postoperative use of atorvastatin	Yes	2 (2.4)	80 (97.6)	**< 0.001**
	No	30 (15.2)	167 (84.8)	
GOS score at discharge	5	5 (3.8)	125 (96.2)	**<0.001**
	4	19 (14.4)	113 (85.6)	
	3	4 (57.1)	3 (42.9)	
	1-2	4 (40)	6 (60)	
Hematoma thickness,mean±SD (cm)		2.31±0.67	2.16±0.73	0.212
Midline shift, mean±SD (cm)	0	3 (7.1)	39 (92.9)	0.058
	<0.5	11 (11.5)	85 (88.5)	
	0.5-1	13 (13.5)	83 (86.5)	
	1-2	4 (9.1)	40 (90.9)	
	>2	1 (100)	0 (0.0)	
Hematoma separated and delaminated	Yes	7 (30.4)	16 (69.6)	**0.029**
	No	25 (9.8)	231 (90.2)	
Brain atrophy	Yes	17 (14.3)	102 (85.7)	0.142
	No	15 (9.4)	145 (90.6)	
Hematoma density	Hypodense	0 (0.0)	26 (100)	**0.049**
	Isodense	10 (6.9)	135 (93.1)	
	Hyperdense	1 (10)	9 (90)	
	Mixed density	21 (21.4)	77 (78.6)	
Extent of brain re-expansion after drainage	>75%	4 (3.1)	123 (96.9)	**<0.001**
	50%-75%	20 (14.9)	114 (85.1)	
	25%-50%	6 (50)	6 (50)	
	<25%	2 (33.3)	4 (66.7)	
Side of hematoma	Unilateral	14 (8.2)	157 (91.8)	**0.003**
	Bilateral	18 (16.7)	90 (83.3)	

Note: Significant P-values are represented in bold type. ***GCS:*** *Glasgow Coma Scale,* ***GOS:*** *Glasgow Outcome Scale.*

Table II: Multivariate Regression Analysis of CSDH Recurrence After Drainage

Factors	Adjusted OR	95%CI	p-value
Trauma history	5.383	1.024-28.280	0.047
Diabetes mellitus	0.843	0.245-2.907	0.787
Postoperative use of atorvastatin	0.139	0.027-0.710	0.018
GOS score at discharge	0.854	0.045-1.389	0.013
Hematoma side	0.089	0.022-0.362	0.001
Midline shift	7.253	1.546-24.015	0.123
Hematoma density	0.869	0.281-2.692	0.683
Hematoma separated and delaminated	6.557	1.328-32.377	0.021
Extent of brain re-expansion after drainage	0.78	0.049-12.519	0.01

Significant p values are in bold type. ***GOS:*** *Glasgow Outcome Scale,* ***CI:*** *Confidence interval,* ***OR:*** *Odds Ratio.*

Table III: Point Assignment and Prognostic Score for Recurrence of Subdural Hematoma

Variables and prognostic scores	Score	Estimated recurrence risk (%)
GOS		
Fully recovered	-0.82	0
Partial recovered	0.3	14
Death	-	-
Unchanged condition	1.79	55
Progression and aggravation	2.89	77
Brain re-expansion after drainage		
> 75 %	- 1.42	0
50 – 75 %	0.09	14
25 – 50 %	1.28	55
< 25 %	1.65	55
Post-surgery medication		
Yes	-1.28	0
No	0.31	14
Side of hematoma		
Left	-0.74	0
Right	-0.21	0
Bilateral	0.5	14
Whether to separate		
Yes	1.03	31
No	-0.11	0
History of trauma		
Yes	0.24	14
No	-0.83	0

Variables and prognostic scores	Score	Estimated recurrence risk (%)
Density of hematoma		
Hyperdense	0.18	14
Isodense	-0.47	0
Mixed density	0.43	31
Hypodense	0.46	31
Diabetes mellitus		
Yes	0.62	31
No	-0.18	0
Midline shift		
<0.5	-0.43	0
0.5-1.5	0.06	14
1.5-2.5	0.32	14
>2.5	-0.18	0
Total predictor score*		
-1.5-0		0
0.01-0.99		14
1-1.99		31
2-2.99		55
3-3.99		77
4-4.99		90
> 5		100

**For score-recurrence estimation please refer to nomogram (Figure 1)*

p=0.039, respectively), The GOS score at discharge was significantly lower in the recurrence group than in the no recurrence group (p<0.001), midline shift was significantly higher in the recurrence group (p=0.058), hematoma separated and delaminated (p=0.029), low extent of brain re-expansion after drainage (p<0.001), bilateral hematoma (p=0.003) and no postoperative use of Atorvastatin (p=0.001) resulted in a higher recurrence rate. At last, patients with hyperdense and mixed-density hematoma had a higher recurrence rate than those with iso and hypodense hematoma (p=0.049).

Multivariate Regression Analysis

Logistic multivariate regression analysis was performed to analyze the nine recurrence risk factors, which were significantly different in the univariable analysis (Table II). The results showed that the history of trauma (p=0.047), no use of atorvastatin postoperatively (p=0.018), low GOS at discharge (p=0.013), bilateral hematoma (p=0.001), hematoma separated and delaminated (p=0.021), and low extent of brain re-expansion after drainage (p=0.01) are independent risk factors in predicting the CSDH recurrence after drainage.

Establishing a Risk Scoring System for CSDH Recurrence After Drainage

According to the outcomes of Fisher's Exact Chi-Square ($\chi 2$) test, a nomogram for scoring a predictor model was constructed to predict the probability of the recurrence of SDH (Figure 1).

In this model, a statistical scoring parameter was adjusted to each variable that had already shown a significant effect on the recurrence of SDH. The scoring predictor model is presented in Table I. Using this scoring system, a total of 279 patients were scored. The resulting grading scores and the corresponding number of recurrent patients, along with the recurrence rate, are calculated (Table III).

The results showed that the probability of recurrence rate of SDH increases in line with the predictor score. In addition, a significant difference was observed where predictor scores were compared between patients with recurrence of SDH and non-recurrence individuals, with a p<0.001 (Figure 2). The results showed that the score was -0.5±0.66 in the recurrent group and -0.91±0.63 in the non-recurrent group with p<0.001 (Table IV).

ROC Curve Analysis

The predictor score for recurrence of SDH obtained from the nomogram was applied in the ROC curve for analysis. According to the results of ROC, the area under the curve (AUC), confidence interval (CI), cutoff value, sensitivity, and specificity were calculated (Figure 3). The data from Second Affiliated Hospital of Anhui Medical University, which consisted of 64

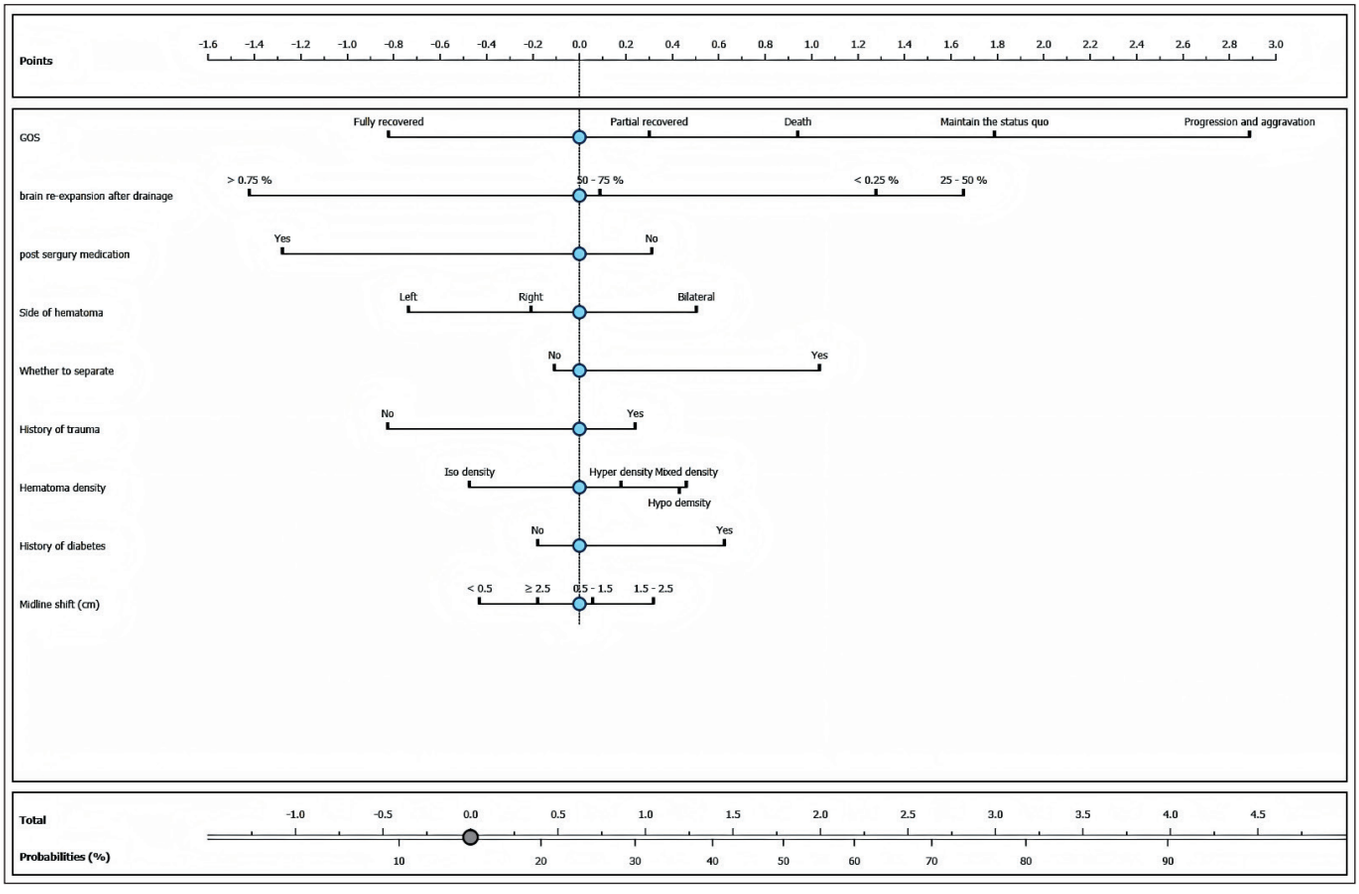

Figure 1: Nomogram for scoring the predictor mode.

Table IV: Comparisons of the Scores of Patients in Recurrent and Non-Recurrent Groups Using T-Test

Variable	Number	Average score	Standard deviation	p-value
Recurrent	32	-0.5	0.66	**<0.001**
Non-recurrent	247	- 0.91	0.63	

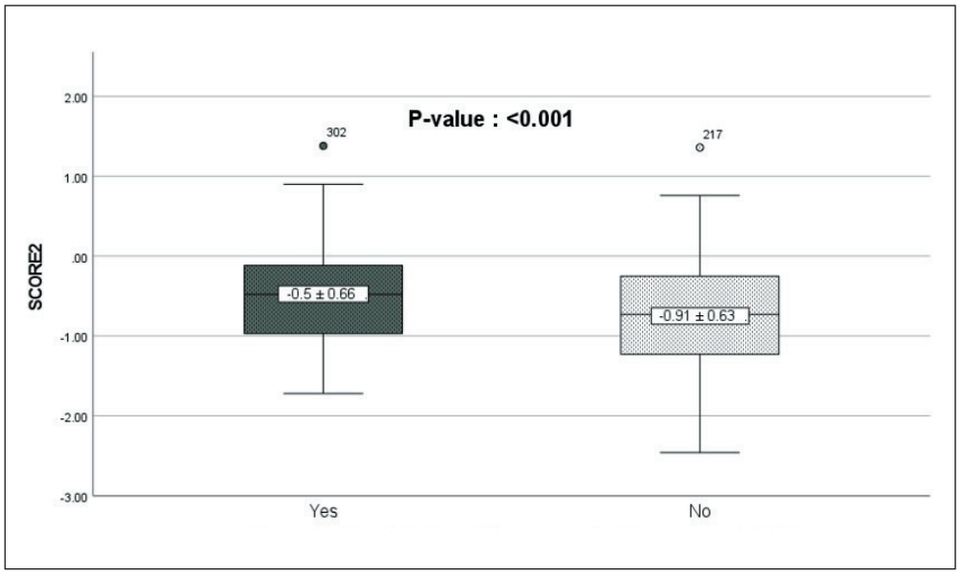

Figure 2: Boxplot of predictor scores by recurrence of SDH.

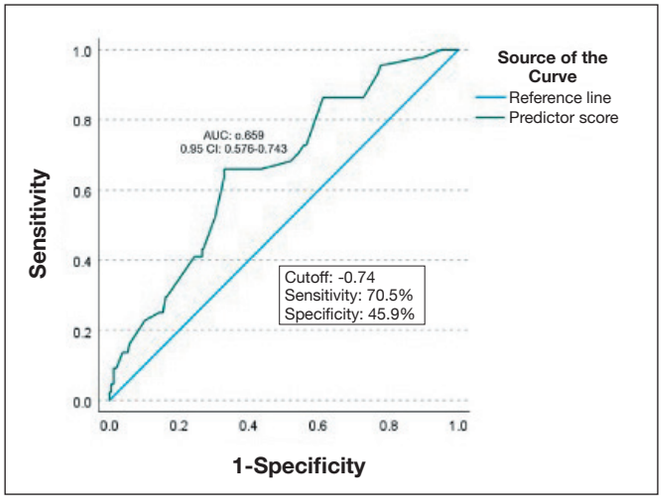

Figure 3: ROC curve analysis for the predictor score that was obtained from the nomogram.

patients, was used in this stage to assess the performance of the nomogram model. The resulting AUC was 0.618 (95% CI: 0.476 - 0.760). In the external validation set, sensitivity and specificity at the cutoff value were 0.696 and 0.561, respectively.

Image Analysis

The study identified that patients with preoperative midline shifts and hyperdense hematomas had higher recurrence rates post-surgery. This highlighted the critical nature of preoperative assessment. The study found that the absence of atorvastatin administration post-surgery significantly increased the risk of CSDH recurrence. This emphasized the need for comprehensive medical management, including the use of atorvastatin, to reduce postoperative recurrence risk.

The postoperative CT scan revealed successful drainage of the subdural hematoma. There was evident brain re-expansion, though some residual pneumocephalus was present. Effective brain re-expansion post-surgery was essential for reducing recurrence risk. The study underscored that residual pneumocephalus can impair brain re-expansion, increasing the likelihood of recurrence. Postoperatively, residual air within the cranial cavity was carefully monitored and managed to ensure optimal recovery and minimize recurrence risk. The follow-up CT scan demonstrated a significant reduction in hematoma size and improved midline shift. The brain re-expansion was satisfactory, with minimal residual subdural fluid. Follow-up imaging was crucial to assess the extent of brain re-expansion and the presence of any residual hematoma. This follow-up image showed a favorable outcome, suggesting a lower risk of recurrence due to adequate brain re-expansion and minimal residual fluid (Figure 4). Each image represents a different patient, selected to illustrate characteristic imaging features associated with recurrence risk. None of the patients depicted required repeat surgery, suggesting that meticulous follow-up can guide postoperative management without necessarily needing reoperation.

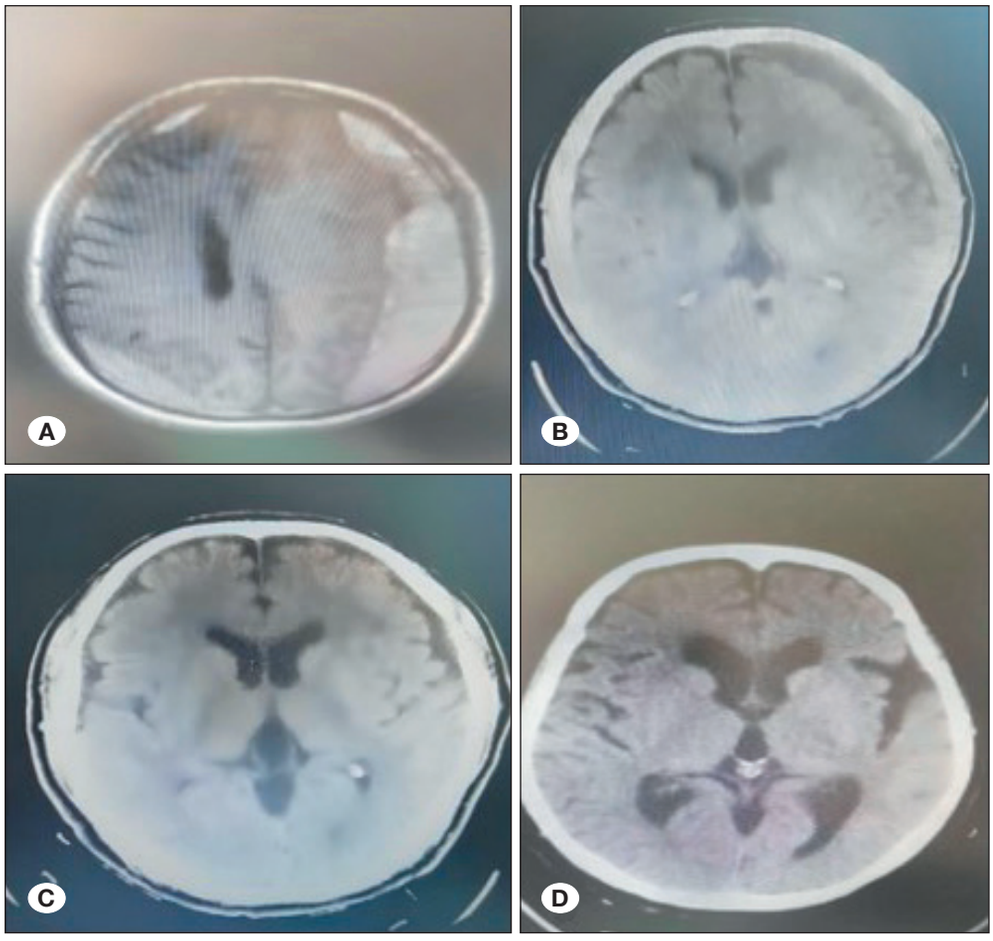

Figure 4: Follow-up CT scan image of patients. **A)** This preoperative CT scan image demonstrates chronic subdural hematoma (CSDH) with significant midline shift and mass effect. The hematoma appears hyperdense, indicating the presence of fresh blood within the subdural space. **B)** This image shows the subdural hematoma prior to the administration of atorvastatin and surgical drainage. The hematoma is still present with evident separation and layering within the subdural space. **C)** The postoperative CT scan indicates successful drainage of the subdural hematoma. The brain re-expansion is evident, though there may still be some residual pneumocephalus present. **D)** The follow-up CT scan demonstrates a significant reduction in the size of the hematoma and improved midline shift. The brain re-expansion appears satisfactory with minimal residual subdural fluid.

DISCUSSION

The present study evaluated independent risk factors for postoperative CSDH recurrence after single burr hole drainage and proposed a comprehensive predictor scoring system for postoperative recurrence risk. This proposed scoring system was constructed by applying a mixture panel of some general independent risk factors that were proposed previously. Based on our scoring system, patients with a recurrence of SDH had a higher score in comparison with those who were completely cured (i.e., no recurrence of SDH). Our proposed scoring system consists of GOS, brain re-expansion after drainage, post-operation medication, side of hematoma, history of trauma, density of hematoma, history of diabetes, and score of midline shift (stratified based on predictor importance). The findings of our study can provide a probable advancement in the prediction and management of the recurrence of SDH following single burr hole drainage (24). Although the history of diabetes, midline shift, and hematoma density were not independent predictors in multivariate analysis, they were significant in univariate tests and were therefore included in the nomogram to preserve clinically meaningful factors and improve predictive performance.

As stated before, the recurrence of SDH is one important challenge in patients who have undergone surgery. The pathophysiology of CSDH recurrence is multifactorial and may involve persistent inflammation, angiogenesis, repeated microbleeding, and impaired brain re-expansion (9). The scoring system effectively correlates with recurrence rates, demonstrating a clear increase in recurrence probability when the score rises.

The majority of the previous studies on CSDH recurrence after drainage were focused on the general characteristics and clinical symptoms of patients; some studies analyzed the imaging features, and a few studies focused on both by combining clinical and imaging traits. According to these studies, a confusing mixture of heterogenous risk factors, including old age, diabetes, anticoagulant or antiplatelet medication, aphasia, headache, neurological symptoms, the thickness of hematoma, the density of hematoma, hematoma stratification and separation, no postoperative drainage, a higher degree of midline shift, brain atrophy, and bilateral hematoma were all introduced as risk factors for recurrence of SDH. Age is one factor since some studies have reported that aging is a risk factor for SDH recurrence, whereas other studies have refuted its prognostic feature (4,13,24). We found only one published article that proposed some scoring systems based on imaging findings and not on the clinical data (6). It should be emphasized that these reported risk factors were not all statistically

significant in our multivariate analysis, and their inclusion here reflects previously published evidence rather than findings from the current study.

In this study, GOS at discharge was an independent risk factor for hematoma recurrence, which was consistent with the findings of some previous studies (13). GOS, as the most important index for patients' prognosis, shows the importance of monitoring the status of patients after surgery. A lower GOS score corresponds to poorer consciousness and neurological status and increases the likelihood of CSDH recurrence (6). GOS potentially reflects patients' consciousness and general improvement, which can better predict prognosis and recurrence than individual clinical symptoms. While GCS and GOS are widely recognized and utilized tools in the assessment of neurological status and outcomes in various conditions, we acknowledge that the modified Rankin Scale (mRS) and the Markwalder Grading Scale (MGS) are also established metrics specifically used in the context of CSDH (2,28).

Hematoma density and midline shift were also listed as risk factors for hematoma recurrence in previous studies (11). In this study, while significant differences were observed in univariate analysis, a small predictive importance was found in multivariate logistic regression analysis, and also in the nomogram result. Regarding hematoma density, the findings align with previous studies, indicating that hypodense and mixed-density hematomas are more prone to recurrence compared to hyperdense and isodense hematomas. Hypo- and mixed-density hematomas are unstable and often accompany hematoma separation, leading to incomplete liquefaction and difficulty in fully removing the hematoma and inflammatory factors through irrigation and drainage alone, potentially resulting in hematoma recurrence (31).

The complexity of the midline shift in CSDH presents differing conclusions across studies. Some studies suggest that postoperative midline shift may damage adhesion between the inner and outer membranes of the hematoma cavity, contributing to recurrence (13,15). We propose that preoperative midline shift also influences recurrence due to adhesion between newly formed membranes and impaired brain elasticity. Separated hematomas have been proposed as an additional risk factor. One probable justification is inadequate drainage, leaving residual blood and inflammatory factors that potentially result in recurrence (15).

Our study identified brain re-expansion as a key factor influencing the recurrence of SDH after drainage. Reduced brain re-expansion post-surgery correlates with a higher recurrence probability, likely due to prolonged hematoma compression that impairs brain recovery, especially in elderly patients with poor tissue elasticity. Even with effective drainage, residual compression may enlarge the subdural space, increasing recurrence risk. Postoperative pneumocephalus can hinder brain re-expansion and contribute to recurrence (21). Furthermore, postoperative pneumocephalus was present in some of our patients, but it was not measured or entered into the analysis. This should be considered for further studies.

Upon pre- and post-surgery analyses of CT or MRI images of all SDH patients, we observed a proportional relationship between the thickness of the hematoma cavity and the hematoma's long axis distance and the number of layers. This indicates that changes in hematoma layer thickness correspond to alterations in hematoma volume. Thus, hematoma thickness is a parameter used to calculate brain re-expansion.

The situation on the side of a hematoma is relatively complicated, especially for a bilateral subdural hematoma. In our study, the sides of the hematoma are considered to contribute to the scoring system for predicting hematoma recurrence. Therefore, bilateral drainage is not indicated for all patients; in addition, the side of surgery mainly depends on the maximum thickness of the hematoma, the midline shift, and the main symptoms of the hematoma. In our study, the recurrence rate of unilateral CSDH was lower than that of bilateral CSDH. This may be due to the poor brain re-expansion of bilateral CSDH compared with unilateral CSDH, which can lead to a brain shift and subsequent complications of hematoma after surgery and, therefore, a higher recurrence probability. One proposed theory is that patients with bilateral CSDH are prone to brain atrophy, which leads to poor re-expansion and a higher recurrence rate (19).

This study had some limitations. First, the study design is retrospective, which inherently carries limitations such as selection bias, incomplete data, and reliance on medical records that may not have captured all relevant variables. In addition, in the collection of imaging materials, the classification standard of hematoma density is not fine enough. Despite attempts to identify independent risk factors, there may be unaccounted confounding variables that influence CSDH recurrence, such as comorbidities, medication use, or surgical technique variations. Also, there is still a lack of quantitative indicators to determine the standard of brain atrophy in patients. The analysis is based on data from a single institution, which may limit the generalizability of the findings to other populations or healthcare settings. In the future, prospective clinical trials need to be designed in multicenter cases to verify the sensitivity and effectiveness of the risk-scoring system for CSDH recurrence after burr holes and drainage (33). Moreover, we did not perform active monitoring and measurement of post-operative pneumocephalus, which are important factors in predicting surgery outcome, brain re-expansion, and CSDH recurrence. This should be addressed in future studies. In addition to postoperative pneumocephalus the presence of which leads to residual intracranial air that can physically impede brain re-expansion, and quantitative measures from the literature have shown a direct relationship between air volume and recurrence risk and pre-existing cerebral atrophy, our study lacked the quantification of cerebral atrophy, which creates a pre-existing subdural space that can lead to poor brain re-expansion and subsequent re-accumulation of fluid.

Our study primarily focused on identifying independent risk factors for the recurrence of CSDH and developing a predictive scoring system. The data analyzed included a broad age range from 18 to 96 years, allowing for a comprehensive analysis across different age groups.

CONCLUSION

Our study identified key independent risk factors for SDH recurrence after single-burr hole drainage, including trauma history, lack of atorvastatin, low GOS score at discharge, bilateral hematoma, hematoma separation, and poor brain re-expansion. Other factors, like residual hematoma and pneumocephalus, also contribute to recurrence. Residual hematoma can act as a nidus for further bleeding, while pneumocephalus can impair brain re-expansion, leading to fluid persistence. Future studies should include these factors for a more comprehensive risk assessment. Our scoring system provides clinicians with a practical tool to predict recurrence and guide postoperative management of CSDH patients. While factors such as age, male gender, alcohol use, and anticoagulant therapy were not incorporated, future larger studies can further validate the system and refine its predictive accuracy.

Declarations

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Availability of data and materials: The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

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AUTHORSHIP CONTRIBUTION

Study conception and design: XZ, HZ

Data collection: XZ, FJ, YS, XX, PZ

Analysis and interpretation of results: XZ, FJ, YS, HZ

Draft manuscript preparation: XZ, FJ

Critical revision of the article: YS, XX, PZ, HZ

Other (study supervision, fundings, materials, etc...): HZ, XZ and FJ are co-first authors.

All authors (XZ, FJ, YS, XX, PZ, HZ) reviewed the results and approved the final version of the manuscript.

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