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Original Article

Post-operative rebleeding in patients with spontaneous supratentorial intracerebral hemorrhage: factors and clinical outcomes

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Abstract: Objective: To explore factors affecting postoperative rebleeding in patients with spontaneous supratentorial intracerebral hemorrhage (SSICH). Methods: We retrospectively analyzed data from 724 patients with SSICH treated at Renmin Hospital of Wuhan University from December 2018 to October 2021. Finally, 294 people were eligible to be included in this study. Hematoma locations were classified as basal ganglia, thalamus, subcortex, or intraventricular. Surgery was categorized as neuroendoscopic surgery, burr hole (stereotactic drilling and drainage), or open craniotomy. Postoperative rebleeding was recorded. The incidence, risk factors, and prognosis of postoperative rebleeding were evaluated. Results: All procedures were successfully completed. Postoperative rebleeding occurred in 57 patients (19.83%, 57/294). Univariate logistic regression analysis identified these risk factors for rebleeding: admission Glasgow Coma Scale (GCS) score, irregular hematoma morphology by preoperative Computed Tomography (CT), postoperative hypertension, hematoma location, surgical method ($P<0.05$), and preoperative hematoma volume ($P<0.1$). Multivariate logistic regression analysis confirmed admission GCS score, irregular hematoma morphology by preoperative CT, postoperative hypertension, hematoma location, and surgical method as significant risk factors ($P<0.05$). Burr hole surgery and basal ganglia hematomas were associated with increased odds of rebleeding, and the mortality rates in patients with rebleeding versus no rebleeding were 7.02% versus 0.84%. Conclusions: Neuroendoscopic surgery, craniotomy, and burr hole are all effective for treating SSICH, but burr hole surgery was an important risk factor for rebleeding and an adverse outcome. Admission GCS score, irregular hematoma morphology, blood pressure control, hematoma location, and surgical method are affected the risk of postoperative rebleeding. 3D Slicer-assisted neuroendoscopic surgery may be the most effective treatment for many patients with SSICH.

Keywords: Spontaneous supratentorial intracerebral hemorrhage, minimally invasive surgery, rebleeding, neuroendoscopic, 3D Slicer

Introduction

Spontaneous supratentorial intracerebral hemorrhage (SSICH) is an acute cerebrovascular disorder with high morbidity and mortality rates. It accounts for 9%-27% of all strokes and 70% of intracerebral hemorrhage (ICH). SSICH affects approximately 5 million people worldwide every year. The 30-day mortality rate is approximately 40%, which increases to 54% after 1 year [1-3], and many survivors are severely disabled, placing a substantial burden on society and families.

The main treatment options for ICH are surgical intervention or conservative medical treatment. Treatment of primary cerebral hemorrhage is controversial. Previous studies have shown that neurosurgical treatment improves outcomes after cerebral hemorrhage better than conservative treatment [4, 5]. Currently, the most commonly used surgical methods are neuroendoscopic hematoma removal, stereotactic burr hole drilling and drainage, and open craniotomy hematoma removal. Surgical hematoma removal not only reduces the local space-occupying effects of the hematoma and improves the

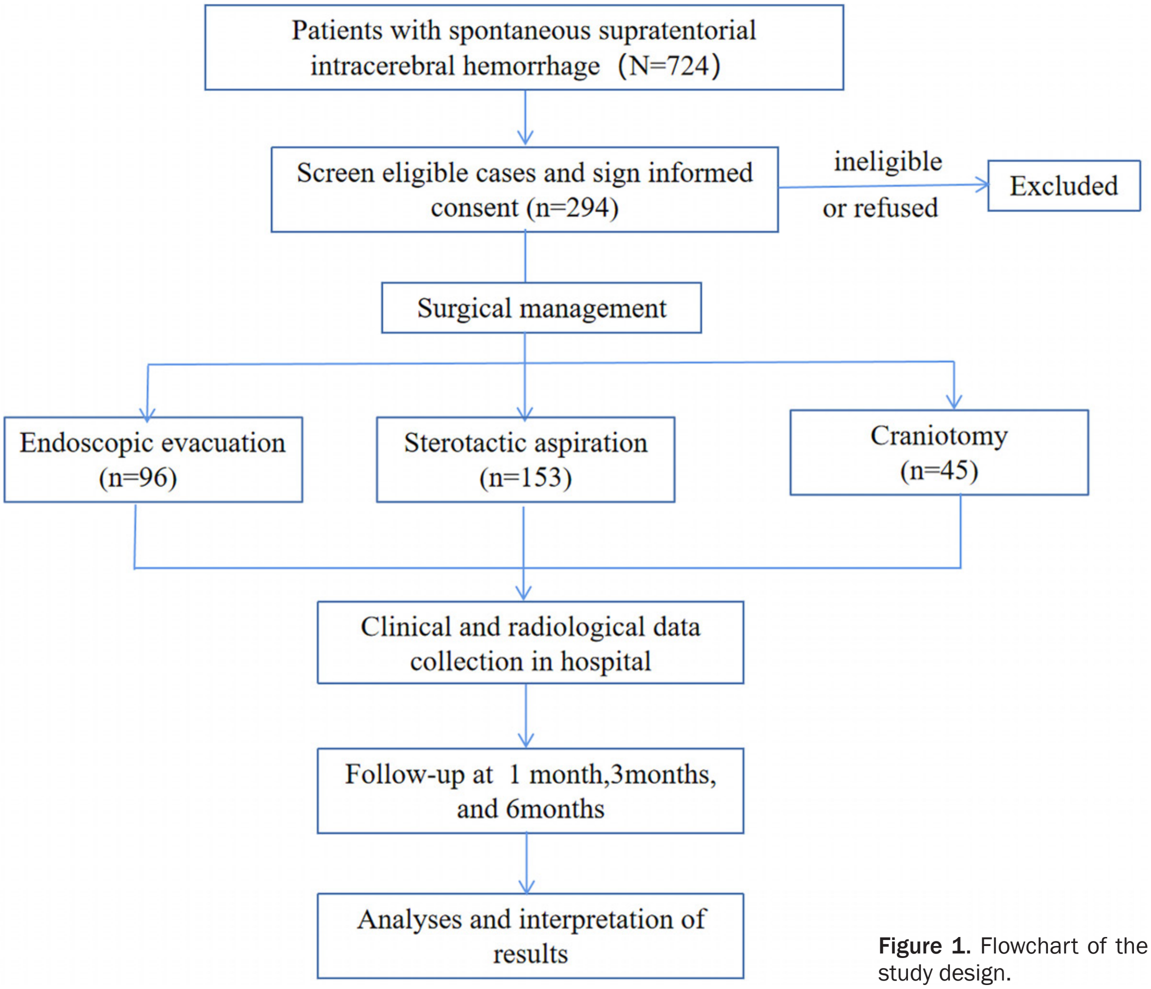

Figure 1. Flowchart of the study design.

ischemia and hypoxia of surrounding normal brain tissue, but it also decreases the release of toxic substances during hematoma decomposition, thereby reducing indirect damage to brain tissue [6, 7]. This can lead to improved survival rates, superior quality of life, and thus better overall patient prognosis [6, 8, 9]. However, postoperative rebleeding (or hematoma expansion) is a possible complication, which can result in devastating progressive neurologic deterioration and high morbidity and mortality rates [10]. Postoperative rebleeding is one of the most important reasons for the poor prognosis of patients with SSICH [10].

Materials and methods

Patient population

This study is a retrospective evaluation of prospectively collected data. Clinical data of 724 consecutive patients with SSICH treated in the Department of Neurosurgery and Neurology of Renmin Hospital of Wuhan University from December 2018 to October 2021 were reviewed for possible inclusion in the study. The final analysis included 294 patients. **Figure 1** summarizes the study design.

This study was approved by the ethics committee of Renmin Hospital of Wuhan University. All methods were performed in accordance with the relevant guidelines and regulations and the Declaration of Helsinki. Informed consent was obtained from all subjects or their family members.

Inclusion and exclusion criteria

Patient inclusion criteria were as follows: (1) diagnosed with acute SSICH, with CT showing hemorrhage in the subcortex, basal ganglia, internal capsule, or thalamus, with or without intraventricular extension; (2) hematoma volume ≥20 ml; (3) GCS score ≥5; and (4) surgical treatment performed within 72 hours of hospital admission.

The exclusion criteria were as follows: (1) hemorrhage secondary to another disorder or factor (e.g., arteriovenous malformation, aneurysm, tumor, head injury); (2) GCS score <5; (3) severe organ dysfunction (e.g. heart, liver, kidneys, lungs); (4) impaired coagulation (e.g., international normalized ratio ≥1.2, anticoagulant or antiplatelet therapy); (5) multiple intracranial hemorrhages; or (6) incomplete patient data.

Surgical management

After admission, all patients underwent head CT and CT angiography (CTA) in the emergency department to determine whether surgery or conservative treatment was appropriate. All methods were performed in accordance with the relevant guidelines and regulations, and informed consents were obtained from all subjects [7]. Patients were divided into three groups according to the type of surgery: neuroendoscopic surgery group (group A), burr hole (stereotactic drilling and catheter drainage) group (group B), and craniotomy group (group C).

Group A: neuroendoscopic surgery: Based on the results of cranial CT using 3D-Slicer combined with Mosocam/sina software to reconstruct and locate the hematoma [11], the skull over the hematoma was drilled, and the bone window was enlarged to approximately 3 cm in diameter. After suspension, a cross-shaped incision was made in the dura mater. Bipolar electrocoagulation was used to control any bleeding, and cortical vessels were avoided. A disposable self-made cannula sheath was used to dilate the surgical channel. A 0° or 30° rigid neuroendoscope (STORZ, Germany) connected to a special television surveillance/video recording system was placed through the cannula for endoscopic visualization of the hematoma. After evacuation of the hematoma and confirming hemostasis of the entire hematoma cavity wall, the dura mater was sutured, the bone flap was reset and fixed, and the scalp was closed (**Figure 2**).

Group B: burr hole group: A soft catheter was placed into the hematoma through a burr hole. The entry spot and catheter course were based on stereotactic image guidance to avoid functional domains and blood vessels. The clot was aspirated using a 10-ml syringe until fluid clot could no longer be aspirated or until resistance first occurred. The soft catheter was then connected to a 3-way stopcock and closed drainage system. Postoperative CT was performed to confirm the position of the catheter and stability of the residual hematoma. The hematoma was then liquefied by continuous infusion of a fibrinolytic agent (20,000 U-40,000 U urokinase/2-3 ml saline solution) for 2-4 days. Routine CT follow-up was performed 24 hours postoperatively and before catheter removal. The drainage tube was removed when the volume of the original hematoma was reduced by 80% or more (**Figure 3**).

Group C: open craniotomy: The surgical approach was based on the location of the hematoma shown by the head CT. A bone flap was created using a milling cutter and then removed, followed by radial incision of the dura mater. After reaching the site of the hematoma through a cortical tract, the hematoma was removed by suctioning, and necrotic brain tissue was removed under microscope visualization. Complete hemostasis was then achieved, followed by suture closure of the dura mater. The bone flap was replaced and fixed, and the muscle and scalp layers were firmly closed by suturing. Postoperative management was the same as that for group A, usually without urokinase injection (**Figure 4**).

Calculation of hematoma volume

In this study, all patients underwent brain CT scan before and at least 2 times after surgery. CT image data sets were acquired in DICOM format. The data were transferred to a personal computer (Intel Core i5 CPU, 2 × 2.5 GHz, 4 GB RAM) and then assessed with 3D Slicer software (http://www.slicer.org). The hematoma was automatically identified pixel by pixel in each slice after setting the threshold range at 50-100 Hounsfield units. A 3D model was then constructed, and the hematoma volume was calculated using the cumulative volume of each pixel. The volume obtained in this manner is more objective and accurate than that obtained by the ABC/2 method [11]. It is especially suitable for calculating irregular hematoma [12]. The hematoma evacuation rate was calculated

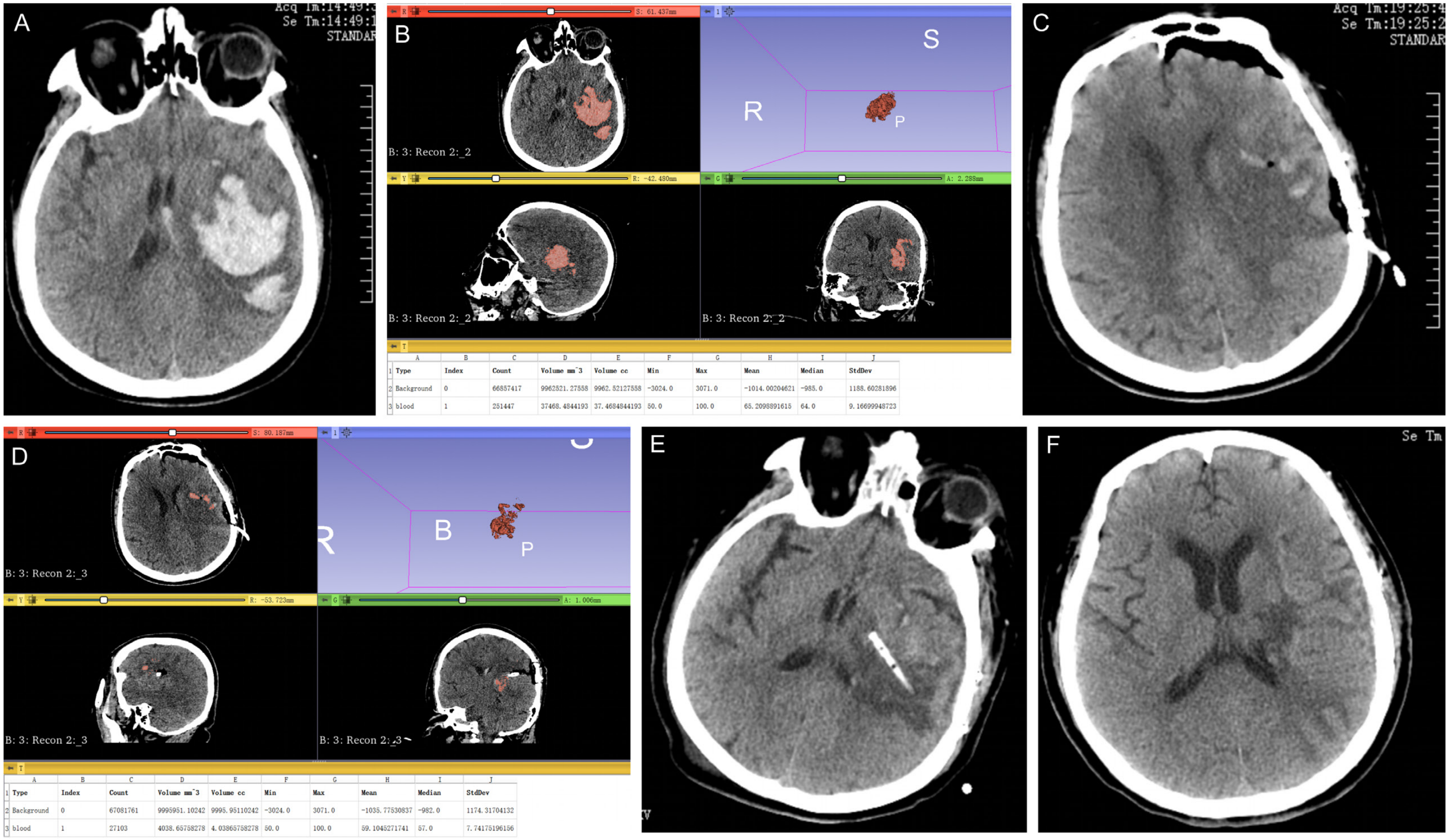

Figure 2. Neuroendoscopic surgery (ICH in the basal ganglia region). A. Preoperative head CT, cerebral hemorrhage in the left basal ganglia area. B. The hematoma volume calculated by 3D-Slicer. C. The head CT was reexamined on the day after operation, and the intracranial hematoma was cleared. D. The hematoma volume calculated by 3D-Slicer after operation, and the hematoma evacuation rate was 86.25±2.27%. E. Reexamination one week after operation CT showed that intracranial drainage tube was observed. F. CT scan one month after operation revealed that the hematoma was completely absorbed.

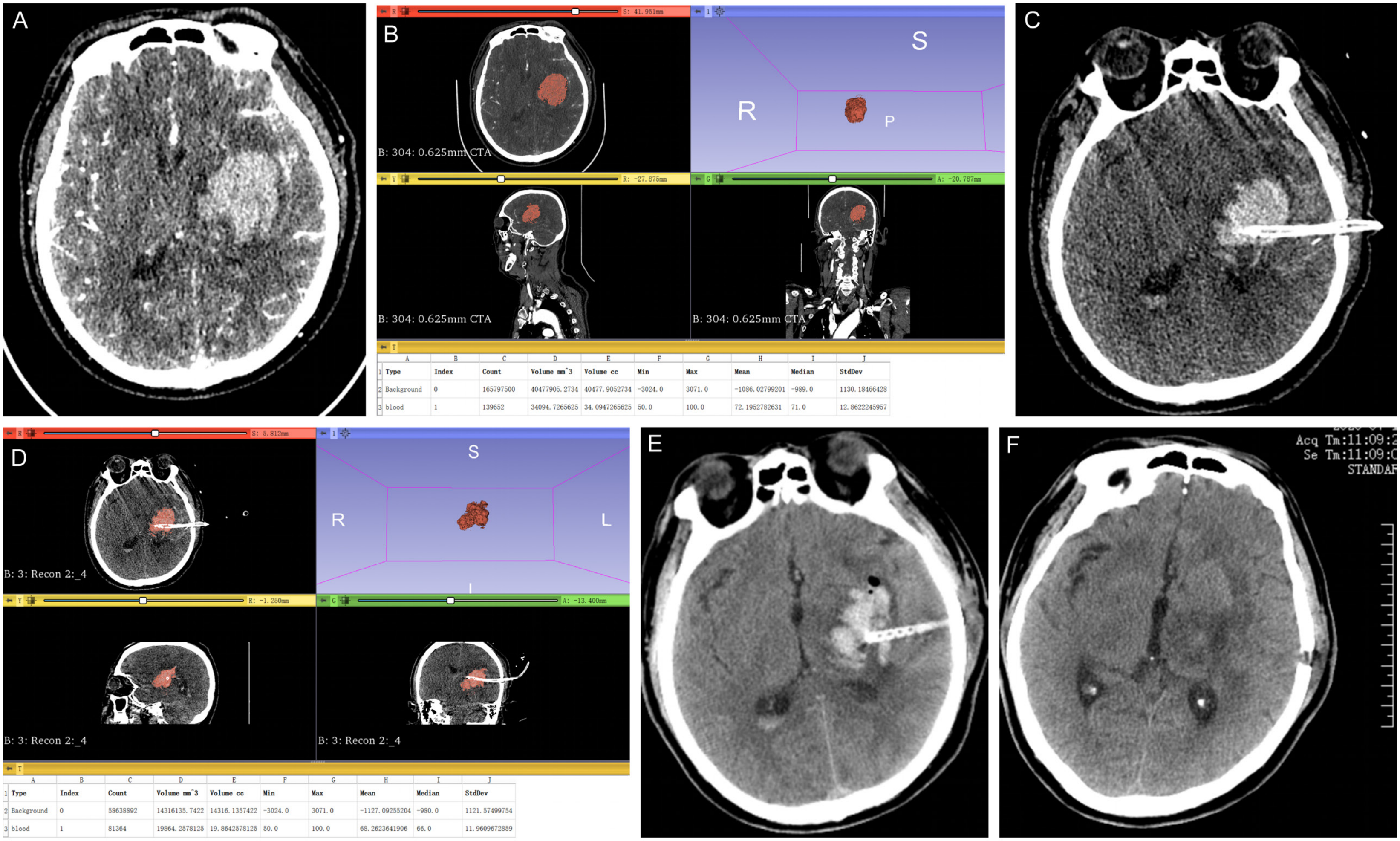

Figure 3. Burr hole group (ICH in the basal ganglia region). A. CTA of the head before operation was performed, and left basal ganglia hematoma was observed. B. The volume of hematoma calculated by 3D-Slicer before operation. C. The head CT was reexamined on the day after operation. There was still residual intracranial hematoma, and drainage was visible tube. D. The hematoma volume calculated by 3D-Slicer after operation, and the hematoma evacuation rate was 34.45±3.61%. E. CT re-examination one week after operation showed that the hematoma was partially absorbed. F. CT re-examination one month after operation suggested that the hematoma was completely absorbed.

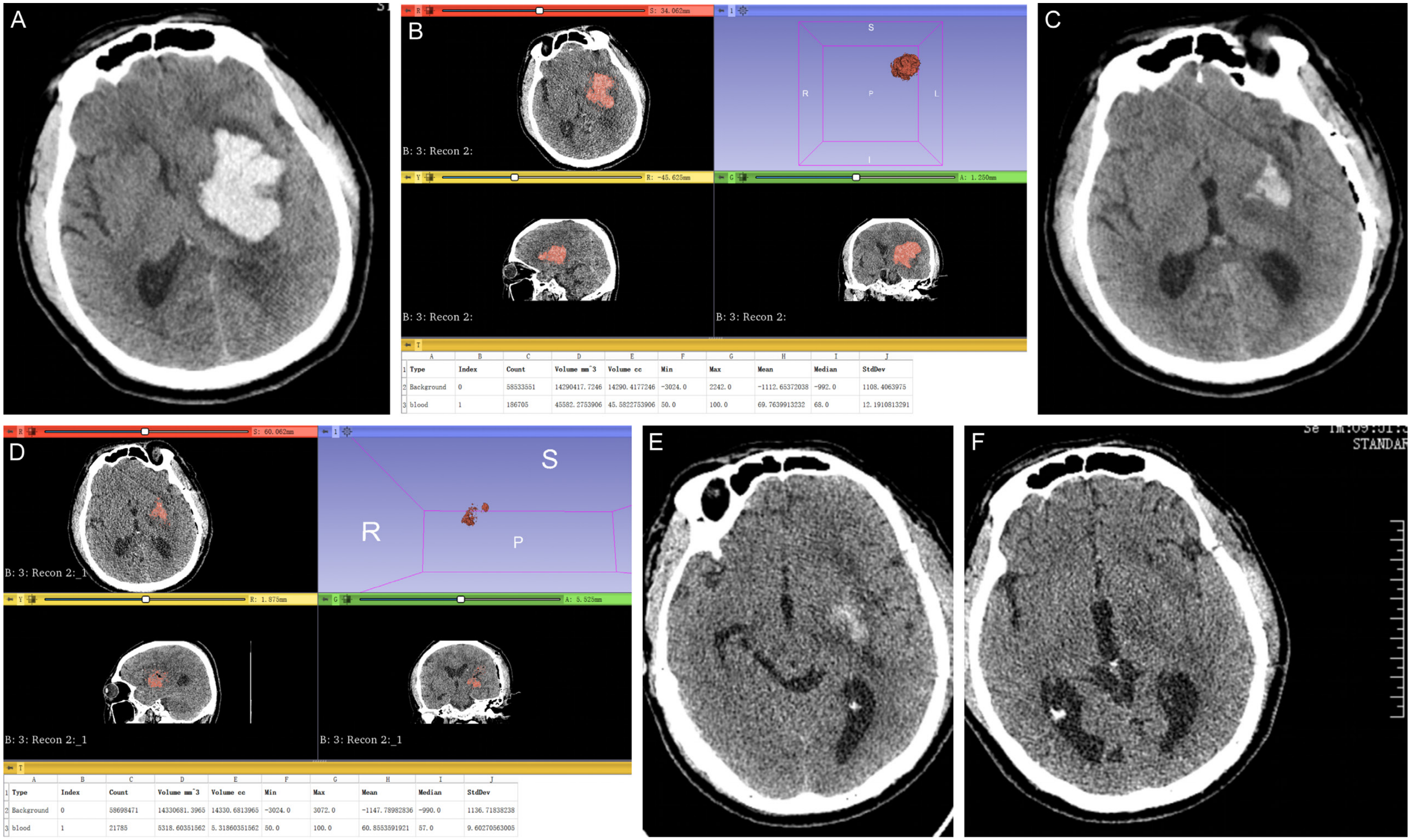

Figure 4. Craniotomy (ICH in the basal ganglia region). A. Preoperative head CT, intracerebral hemorrhage in the left basal ganglia area. B. The hematoma volume calculated by 3D-Slicer before operation. C. The head CT was reexamined on the day after operation, and the intracranial hematoma was cleared. D. The hematoma volume calculated by 3D-Slicer after operation, and the hematoma evacuation rate was 74.45±2.89%. E. Reexamination one week after operation CT revealed that most of the hematoma was absorbed. F. CT scan one month after the operation showed that the hematoma was completely absorbed.

as follows: [(preoperative volume - postoperative volume)/preoperative volume] × 100%.

Diagnostic criteria for rebleeding

All patients underwent CT preoperatively and at least two times postoperatively: immediately after surgery and at 1-3 days after surgery. Most patients also underwent a third postoperative CT scan, at 4-14 days after surgery. Postoperative rebleeding was assessed by comparing the hematoma volume on CT images. Hematoma volume was calculated by 3D Slicer software (**Figure 5**). Postoperative rebleeding was defined as postoperative hematoma volume greater than preoperative volume or postoperative hematoma volume less than preoperative volume, but the difference is less than 5 ml, or postoperative hematoma volume gradually increasing by 10 ml [13]. In addition, we distinguished residual hematoma [14-17] by reviewing the surgeon's operative report (indicating whether the hematoma was completely removed) and the hematoma shape on CT before and after surgery. Distal or subcutaneous bleeding adjacent to the surgical area was not considered rebleeding, and patients requiring reoperation for this type of bleeding were excluded from the analysis.

Postoperative management

After hematoma evacuation, the patients were managed in the neurosurgical intensive care unit. Postoperative systolic blood pressure was strictly maintained at <160 mmHg, and intravenous fluid management was strictly controlled to avoid excessive intake. All patients received standard postoperative care, including symptomatic support, early hyperbaric oxygen, and rehabilitation therapy.

Outcome measures

Study outcomes included mean surgery time, hematoma evacuation rate, visualization during surgery, decompressive effects, mortality, GCS improvement, and postoperative complications (e.g., rebleeding, pneumonia, intracranial infection). To study the effects of various factors on the risk of rebleeding, the patients were divided into four groups according to the location of hematoma: subcortical, basal ganglia, thalamus, and intraventricular groups. The patients were also divided into three groups according to preoperative hematoma volume (20-50 ml, 50-80 ml, and >80 ml) and into three groups according to preoperative GCS score: mild disturbance of consciousness (13-14), moderate disturbance of consciousness (9-12), and severe disturbance of consciousness (5-8).

All patients were followed for 3-6 months after surgery. The Glasgow Outcome Score (GOS) was used to evaluate longer-term efficacy of surgery for SSICH: excellent; good (moderately disabled but able to care for themselves); medium (conscious and unable to care for themselves); and poor (dead or vegetative state). The good-to-excellent rate was calculated as follows: [(number of excellent cases + number of good cases)/total cases] × 100%.

Statistical analysis

SPSS 26.0 (IBM Corp., Armonk, NY, USA) was used for the statistical analyses. Continuous variables with a normal distribution were expressed as mean ± standard deviation, with the independent sample t-test used for intergroup comparisons and paired sample t-test used for intragroup comparisons. Continuous variables with a non-normal distribution were expressed as median (quartile spacing), with the Mann-Whitney U test used for intergroup comparisons. Categorical data were expressed as frequency and constituent ratio, with the chi-square test or Fisher exact probability test used for intergroup comparisons. Logistic regression analysis was used to assess factors associated with rebleeding. Factors with a P value <0.1 in univariate analysis were included in the multivariate analysis. The backward likelihood ratio method was used to screen the final model.

Results

Patient characteristics

A total of 294 patients with SSICH were included in the study (**Table 1**). There were 215 males, with a mean age of 57.96±10.92 years, and 79 females, with a mean age of 58.85±12.39 years. Group A: 57.34±10.66; group B: 57.96±10.56; group C: 60.84±14.62. In accordance with the inclusion criteria, all patients had a high-density focus in the brain parenchyma on the first (within 6 hours) cranial CT after admission. There were 99 cases of

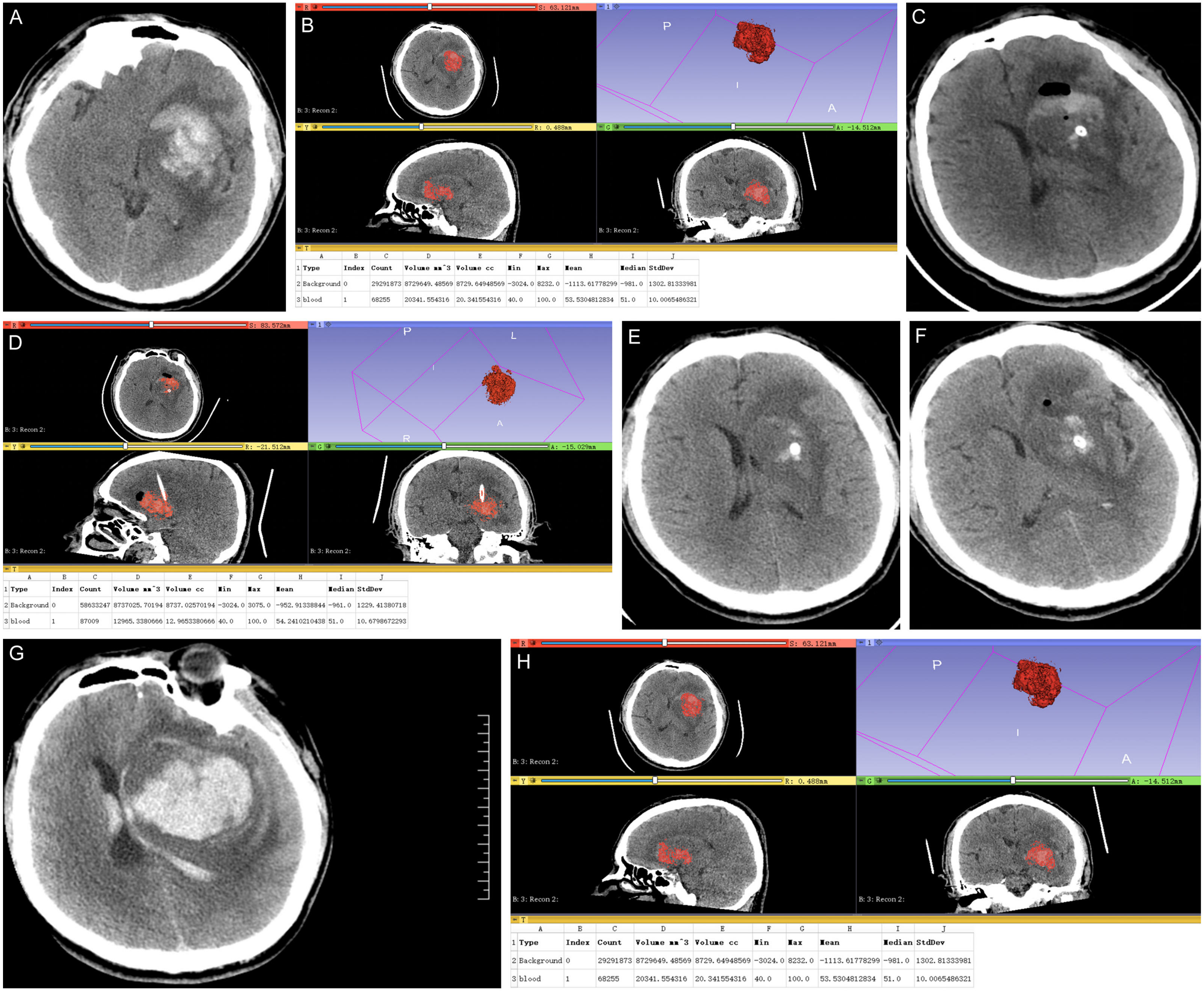
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Figure 5. Case condition of a patient with typical rebleeding. A. Preoperative head CT, intracerebral hemorrhage in the left basal ganglia area. B. The volume of hematoma calculated by 3D-Slicer before operation. C. The head CT was reexamined on the day after operation. There was still residual intracranial hematoma, and drainage was visible tube. D. The hematoma volume calculated by 3D-Slicer after operation, and the hematoma evacuation rate was 36.23%. E and F. CT re-examination 3 days and one week after operation showed that the hematoma was partially absorbed. G. Patients with left basal ganglia rebleeding. H. The hematoma volume enlargement calculated by 3D-Slicer after operation was 85.15 ml.

lobar hemorrhage, with a mean volume of 47.20 ml; 131 cases of basal ganglia hemorrhage, with a mean volume of 43.63 ml; 41 cases of thalamic hemorrhage, with a mean volume of 33.84 ml; and 23 cases of intraventricular hemorrhage, with a mean volume of 38.33 ml.

96 patients in group A had 5 patients with rebleeding, 153 patients in group B had 44 patients with rebleeding, and 45 patients in group C had 8 patients with rebleeding.

Postoperative rebleeding

Postoperative rebleeding was confirmed by repeat head CT in 57 patients, representing an overall incidence of 19.39% (57/294). Among these patients, 23 underwent reoperation, 29 received conservative treatment, and 8 received no further treatment, as the family withdrew consent for additional treatment.

Logistic regression analysis of risk factors for postoperative rebleeding

Univariate logistic regression analysis showed that admission GCS score, irregular hematoma morphology by preoperative CT, postoperative hypertension, surgical method, and hematoma location were associated with an increased risk of postoperative rebleeding (all $P<0.05$), and a preoperative hematoma volume ($P<0.1$) (**Table 2**).

Multivariate logistic regression analysis confirmed that admission GCS score, irregular hematoma morphology on preoperative CT, poor postoperative blood pressure control, hematoma location, and surgical method were significant risk factors for postoperative rebleeding ($P<0.05$) (**Table 3**). Burr hole surgery was associated with significantly higher odds of rebleeding than neuroendoscopic surgery (odds ratio [OR] 3.437, 95% confidence interval [CI] 0.93-12.702, $P<0.001$). Basal ganglia hematomas were associated with significantly higher odds of rebleeding than lobar hematoma (OR 7.18, 95% CI 2.698-19.089, $P=0.001$).

Surgical efficacy and other patient outcomes

The hematoma evacuation rate was highest in patients who underwent neuroendoscopic and lowest in those who underwent burr hole surgery. Specifically, the evacuation rate was 86.25±2.27% for group A, 34.45±3.61% for group B, and 74.45±2.89% for group C.

In addition to postoperative rebleeding, other postoperative complications included cerebral edema, pulmonary infection, intracranial infection, epilepsy, gastrointestinal bleeding, electrolyte disorder, and liver or kidney dysfunction.

At 30 days after surgery, 12.56% of all patients (n=37) remained in the hospital for continued treatment and 46.19% (n=136) remained in the hospital for further rehabilitation and other treatment. The prognosis of patients with postoperative rebleeding was worse in patients with rebleeding than in those without rebleeding. The GCS score was lower at discharge in patients with bleeding than in those without rebleeding (**Table 4**). The 30-day mortality rates of the three groups A, B, and C were respectively 1.04%, 1.96%, 2.22%. The mortality rate at 3-6 months after surgery was significantly higher in patients with rebleeding (7.02%) than in those with no rebleeding (0.84%; $P=0.017$) (**Tables 5**, **6**).

Discussion

The mortality of postoperative rebleeding is much higher than the annual average fatality rate of spontaneous intracerebral hemorrhage (ICH). Although predictors of postoperative rebleeding or secondary hematoma expansion in patients receiving conservative treatment have been studied, research on postoperative rebleeding remains limited. Previous studies [18] showed that risk factors for postoperative

Table 1. General information of the 294 SICH patients

	None (n=237)	Rebleeding (n=57)	t/chi-square	*P* value
Age	58.32±11.47	57.71±10.76	0.29	0.589
Sex				
Male	170 (79.1)	45 (20.9)	1.218	0.27
Female	67 (84.8)	12 (15.2)		
History of hypertension				
No	82 (77.4)	24 (22.6)	1.123	0.289
Yes	155 (82.4)	33 (17.6)		
History of Diabetes meuitus				
No	218 (80.7)	52 (19.3)	0.035	0.852
Yes	19 (79.2)	5 (20.8)		
Admission SBP (mmHg)	156.65±25.94	157.82±25.34	0.016	0.898
Preoperative pupil abnormality				
No	212 (81.9)	47 (18.1)	2.144	0.143
Yes	25 (71.4)	10 (28.6)		
Glasgow Coma Scale Score (point)				
5-8	80 (70.2)	34 (29.8)	13.445	0.001
9-12	110 (85.9)	18 (14.1)		
13-15	47 (90.4)	5 (9.6)		
Neuroimaging characteristics				
Hematoma volume (ml)				
20-50	174 (84.5)	32 (15.5)	7.662	0.024
50-80	46 (68.7)	21 (31.3)		
>80	17 (81.0)	4 (19.0)		
Time interval from ictus to surgery				
<6 h	116 (80.6)	28 (19.4)	0.001	0.981
≥6 h	121 (80.7)	29 (19.3)		
Irregular CT morphology				
Normal	114 (89.1)	14 (10.9)	10.358	0.001
Irregular	123 (74.1)	43 (25.9)		
Postoperative hypertension				
<160 mmHg	148 (86.5)	23 (13.5)	9.22	0.002
≥160 mmHg	89 (72.4)	34 (27.6)		
Location of hematoma				
Lobar	92 (92.9)	7 (7.1)	17.17	0.001
Basal ganglia	96 (73.3)	35 (26.7)		
Thalamus	30 (73.2)	11 (26.8)		
Intraventricular	19 (82.6)	4 (17.4)		
Surgical method				
Craniotomy	91 (94.8)	5 (5.2)	21.02	0
Neuroendoscopic surgery	109 (71.2)	44 (28.8)		
Burr hole group	37 (82.2)	8 (17.8)		

DM = Diabetes meuitus; SBP = Systolic blood pressure; CT = Computed Tomography; Group A = Neuorendoscopic surgery group; Group B = Burr hole; Group C = Craniotomy group; F = Female; M = Male; GCS = Glasgow Coma Scale; ICH = Intracerebral hemorrhage; Postop = Postoperation; Preop = Preoperation; SSICH = Spontaneous supratentorial intracerebral hemorrhage.

rebleeding included a history of hypertension, history of diabetes, use of antiplatelet drugs, coagulopathy, early craniotomy, hypertension on admission [19], midline shift, vascular amy-

Table 2. Single factor logistic regression analysis of rebleeding

Variable	B	S.E	Wald	Exp (B)	Lower	Upper	p
Sex (M/F)	0.391	0.355	1.208	1.478	0.736	2.966	0.272
Age	-0.162	0.300	0.292	0.850	0.472	1.531	0.589
History of hypertension (yes/no)	-0.318	0.301	1.118	0.727	0.403	1.321	0.290
History of DM (yes/no)	0.098	0.526	0.035	1.103	0.394	3.092	0.852
Admission SBP (≥160/<160)	-0.038	0.299	0.016	0.963	0.536	1.728	0.898
Admission GCS score	-0.791	0.234	11.436	0.453	0.287	0.717	0.001
Preoperative pupil abnormality (yes/no)	0.590	0.407	2.098	1.804	0.812	4.010	0.147
Preoperative hematoma volume	0.415	0.222	3.502	1.514	0.981	2.337	0.061
Time interval from ictus to surgery (≥6 h/<6 h)	-0.007	0.295	0.001	0.993	0.557	1.771	0.981
CT morphology	1.046	0.334	9.808	2.847	1.479	5.479	0.002
Postoperative SBP control (≥160 mmhg/<160 mmHg)	0.899	0.301	8.902	2.458	1.361	4.438	0.003
Surgical method			17.105				0.000
Neuroendoscopic/craniotomy	1.994	0.493	16.374	7.347	2.796	19.302	0.000
Burr hole group/craniotomy	1.370	0.603	5.170	3.935	1.208	12.818	0.023
Location of hematoma			13.679				0.000
Basal ganglia/Lobar	1.567	0.439	12.740	4.792	2.027	11.328	0.000
Thalamus/Lobar	1.573	0.527	8.897	4.819	1.715	13.544	0.003
Intraventricular/Lobar	1.018	0.676	2.270	2.767	0.736	10.400	0.132

Table 3. Multivariate logistic regression analysis of rebleeding

Variable	B	S.E	Wald	Exp (B)	95% CI	p
Admission GCS score	-0.940	0.274	11.760	0.391	0.228-0.669	0.001
CT morphology	1.579	0.391	16.321	4.848	2.254-10.426	0.000
Postoperative SBP control	0.864	0.350	6.073	2.372	1.193-4.714	0.014
Surgical method						
Neuroendoscopic/craniotomy	2.312	0.548	17.831	10.095	3.452-29.523	0.000
Burr hole/craniotomy	1.235	0.667	3.426	3.437	0.93-12.702	0.064
Location of hematoma						
Basal ganglia/Lobar	1.971	0.499	15.586	7.176	2.698-19.089	0.000
Thalamus/Lobar	1.330	0.585	5.168	3.780	1.201-11.894	0.023
Intraventricular/Lobar	0.544	0.737	0.544	1.722	0.406-7.302	0.461
Constant	-5.171	0.770	45.067	0.006		0.000

DM = Diabetes meuitus; SBP = Systolic blood pressure; Group A = Neuorendoscopic surgery group; Group B = Burr hole; Group C = Craniotomy group; F = Female; M = Male; GCS = Glasgow Coma Scale; ICH = Intracerebral hemorrhage; Postop = Postoperation; Preop = Preoperation; SSICH = Spontaneous supratentorial intracerebral hemorrhage.

loidosis, head CT bleeding spot sign or Blend sign, irregular hematoma shape [8, 18, 20], and preoperative plasma plasmin-α2-plasmin inhibitor complex level [17].

Surgical treatment is one of the most common and effective treatments for cerebral hemorrhage. There are a number of types of operation methods and many studies in China and elsewhere have shown that when performed according to strict surgical standards, the choice of operation method has no significant effect on short-term prognosis or rebleeding rates of cerebral hemorrhage [21]. A significant correlation between timing of surgery and postoperative rebleeding has been observed, with some studies reporting a higher rate of rebleeding in patients with early or ultra-early surgery [22].

With developments in technology and a minimally invasive concept, minimally invasive surgery, including burr hole stereotactic aspiration and neuroendoscopic surgery, has become

Table 4. Comparison of GCS score between the bleeding group and non-bleeding group

Group	Admission GCS score	Discharge GCS score	t	p
Rebleeding (n=57)	8.56±2.72	10.21±4.41	-3.446	0.001
No rebleeding (n=237)	9.97±2.97	12.56±3.33	-11.554	0.000

Table 5. GOS scores 3-6 months after surgery

Group	GOS score					Mortality rate (%)	p
	5	4	3	2	1		
No rebleeding (n=237)	49	72	84	30	2	0.84	
Rebleeding (n=57)	5	13	18	19	4	7.02	0.017

Table 6. Comparison of the efficacy of three surgical methods

Group	Median operation time (min)	Hematoma evacuation rate	Rebleeding (%)	GOS scores	Mortality (n)
Neuroendoscopic surgery (n=96)	69.54±9.25	0.863±0.023	5 (5.21)	3.52±0.95	1
Burr hole group (n=153)	47.25±9.65	0.344±0.036	44 (28.76)	3.45±1.06	3
Craniotomy (n=45)	214.65±63.68	0.755±0.029	8 (17.78)	3.33±1.09	1

widely used in the treatment of spontaneous ICH. One study reported that the incidence of rebleeding with conventional craniotomy was 15.4% and that of minimally invasive surgery was 10.0% [20].

Neuroendoscopic surgery provides multi-angle and detailed visualization and allows for direct treatment of intraoperative bleeding. Compared to burr hole stereotactic aspiration and craniotomy, neuroendoscopic surgery can be considered as soon as possible, since it can completely stop bleeding under direct vision and will not increase the incidence of rebleeding. Overall, early implementation of endoscope-assisted evacuation of cerebral hemorrhage has the lowest postoperative rebleeding rate (0-3.3%) [21, 23].

Burr hole surgery with stereotactic aspiration causes the least amount of trauma of the three main surgical procedures. Its risk of rebleeding is higher than that of other types of surgery (OR of 4.236, compared to neuroendoscopic surgery, in the current study), and urokinase injection is accompanied by an increased risk of rebleeding [1, 21, 23]. Urokinase itself has a rebleeding rate of 7% to 15% [24].

Hematoma volume is another important indicator of the severity of spontaneous ICH. Cerebral hemorrhage volume and level of consciousness are determinants of short-term prognosis [25-28]. Previous reviews have shown that minimally invasive surgery is appropriate for hematomas with a volume of 25-40 ml, while hematomas >40 ml require other forms of treatment, such as craniotomy [1, 29, 30]. It has been reported that the minimum rebleeding rate of endoscopic surgery is 0%-3.3%, and that of traditional craniotomy is 5%-10% [26]. In our study, endoscopic surgery was used not only for medium-sized hematomas but also for a number of large hematomas, with satisfactory results, reflecting expansion of its scope of application. Thus, hematoma volume may not be a limiting factor for neuroendoscopic surgery, and further research is necessary to determine the appropriate volume at which neuroendoscopy can be used for hematoma removal [21, 26].

In our univariate analysis, the hematoma volume was significant for rebleeding after surgery (P=0.061). However, the volume of the hemorrhage no longer appears as an influencing factor by multivariate analysis. Because of the limited factors we include, we consider that this is related to the mode of operation. Neuroendoscopic surgery shows many advantages, but the factor of the hematoma volume is still worthy of further consideration and study.

Some studies have reported associations between hematoma location and rebleeding rate [31]. With deep thalamic hematomas, it is difficult to remove the hematoma without damaging the surrounding brain parenchyma, resulting in a relatively low evacuation rate. Hemostasis is also more difficult to achieve in deep hematomas. CT findings of a low-density hematoma, black hole sign, and hematoma irregularity are closely related to early enlargement or rebleeding of hematomas [8, 20, 32]. The spot sign reflects extravasation of contrast medium seen on CT angiography, which is indicative of active bleeding and thus predicts expansion of the hematoma. Satellite, island, vortex, black hole, and hybrid markers differ from speckle marks in that they can all be seen on non-contrast CT scans; they also are possible risk factors associated with rebleeding [8]. Our study also suggests that irregular CT morphology are more likely to cause postoperative rebleeding.

The optimal timing of surgery for SSICH has not been determined [19]. Most studies suggest that the rebleeding rate is higher when surgery is performed within 6 hours after symptom onset [24]. Some studies have also shown that the optimal for surgical removal of hematoma is 7-24 hours after symptom onset [31, 33]. Early operation, therefore, appears to increase the risk of rebleeding: the earlier the operation time, the higher the risk of postoperative rebleeding. This may reflect reduced vascular compression after hematoma clearance. In our study, the average time from symptom onset to operation was 11.83 h, the shortest time to operation was 0.17 h, and the longest was 72 h (P=0.981). We found no increased risk of rebleeding when the operation time was shorter, although the risk of postoperative rebleeding relationship was increased as the systolic blood pressure increased.

Poor control of hypertension has been reported as the main cause of postoperative rebleeding [18, 19]. This may be attributed to effects of chronic hypertension, leading to cerebrovascular disease and necrosis. This results in weakening of the elasticity of vascular walls and continuous extravasation of blood through the ruptured vessels, interfering with achieving adequate hemostasis after ICH. Our results showed that patients with strictly controlled blood pressure had a lower rate of rebleeding.

For many years, the GCS score has been used as an important criterion for assessing the severity of acute traumatic brain injury, since it provides a comprehensive index of neurologic impairment of patients with craniocerebral injury. It is also one of the most important clinical indicators for determining the indications for surgery and predicting prognosis [25]. The GCS score has shown some correlation with rebleeding rate, especially in non-comatose patients and nonsurgical patients, and it correlates with various factors that influence rebleeding in patients with hypertensive cerebral hemorrhage, such as patient age, blood pressure, blood glucose, and hematoma volume.

Postoperative complications are an important determinant of patient prognosis. In this study, three surgical methods for treating SSICH were compared, including evaluation of rebleeding and mortality rates. All three surgical methods had good clinical effectiveness for treating SSICH. Approximately 33% of patients who underwent burr hole stereotactic aspiration required urokinase to dissolve residual hematoma, which increased the risk of rebleeding and infection [2, 28]. Neuroendoscopic surgery can be performed quickly, without increasing the rate of rebleeding. In our study focusing on rebleeding, neuroendoscopy had obvious advantages in reducing the rebleeding rate. The self-made channel sheath approach formed a natural channel, and the release of cerebrospinal fluid created additional anatomic space, which reduced brain retraction, decreased the risk of brain edema and injury, and reduced the risk of postoperative rebleeding.

Limitations and strengths

This study has some limitations. It was a retrospective single-center study conducted by more than one surgeon, and some possibly important variables (e.g., specific blood pressure control) were not controlled. In addition, the sample size was relatively small. Because assessment of postoperative rebleeding was based on CT scans performed within 14 days after surgery, and patient follow-up was relatively short, the long-term clinical results are unknown. Despite these limitations, we can draw useful clinical conclusions from our results, but a large, prospective, multicenter, randomized trial is warranted in the future.

Conclusions

Postoperative rebleeding is inevitable and a serious complication of SSICH that can result in progressive neurologic deterioration and death. A rebleeding incidence of 19.39% was found in our study population. Admission GCS score, irregular hematoma morphology on preoperative CT, poor postoperative blood pressure control, hematoma location, and surgical method, were all risk factors for postoperative rebleeding. Neuroendoscopic surgery was associated with a lower risk of rebleeding than craniotomy or stereotactic drilling and drainage surgery and it may be the safest and most effective surgical treatment for many patients with SSICH.

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The patients/participants provided their written informed consent to participate in this study.

Disclosure of conflict of interest

None.

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