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Original Article

Analysis of short-term efficacy and rebleeding risk in aneurysmal subarachnoid hemorrhage patients undergoing vascular intervention

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Abstract: Objective: To evaluate the short-term efficacy and rebleeding risk of vascular intervention in patients with aneurysmal subarachnoid hemorrhage (aSAH). Methods: This retrospective study included 98 aSAH patients treated between August 2020 and May 2023. Based on the treatment method, patients were divided into an interventional group (n = 50, treated with endovascular embolization) and a craniotomy group (n = 48, treated with microsurgical clipping). Surgical parameters, clinical outcomes, immune markers, prognosis scores, cognitive function, and safety were compared using t-tests or chi-square tests. Binary logistic regression identified independent risk factors for clinical outcomes and rebleeding. Results: The interventional group showed significantly less intraoperative blood loss, shorter hospital stays, and shorter operative times compared to the craniotomy group (all $P < 0.05$). Clinical outcomes and Glasgow Outcome Scale scores were better in the interventional group (all $P < 0.05$). At 3 days and 3 months post-surgery, immune markers (IgG, IgA, IgM) were significantly higher in the interventional group (all $P < 0.05$). Additionally, MMSE scores at 3 days post-surgery were higher, and the incidence of postoperative cognitive dysfunction within 3 months was lower (both $P < 0.05$). The complication rate was significantly lower in the interventional group (12.00% vs. 37.50%, $P < 0.05$). Preoperative Hunt-Hess grade, surgical approach, age, and postoperative complications were identified as independent risk factors for prognosis (all $P < 0.05$), while surgical approach, age, and Hunt-Hess grade were risk factors for rebleeding (all $P < 0.05$). Conclusion: Vascular intervention provides superior short-term efficacy in aSAH patients, with faster recovery, reduced surgical trauma, and better clinical outcomes compared to craniotomy. Monitoring should be intensified for older patients and those with higher preoperative Hunt-Hess grades to minimize the risks of poor prognosis and rebleeding.

Keywords: Aneurysmal subarachnoid hemorrhage, endovascular embolization, craniotomy and clipping, efficacy, safety, risk factor

Introduction

Aneurysmal subarachnoid hemorrhage (aSAH) is a life-threatening cerebrovascular emergency that, despite accounting for only 5% of all strokes, carries a mortality rate of 40%-50%. Nearly 30% of survivors experience permanent neurological deficits [1, 2]. This condition primarily results from the rupture of an intracranial aneurysm, leading to blood infiltrating the subarachnoid space and triggering complex pathophysiological changes, including elevated intracranial pressure, cerebral ischemia, and neuroinflammation [3]. Clinically, aSAH patients typically present with sudden, severe headaches, nausea, vomiting, light sensitivity, and neck stiffness [4]. In severe cases, patients may exhibit impaired consciousness, focal neurological deficits, or even progress to coma or sudden death [5].

The treatment strategy for aSAH focuses on preventing rebleeding, managing cerebral edema and intracranial pressure, and preventing complications such as cerebral vasospasm and delayed cerebral ischemia [6]. Early aneurysm sealing is crucial for preventing rebleeding, typically achieved through either endovascular coil embolization or conventional craniotomy clipping [7]. Craniotomy clipping in-

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volves surgically placing a metal clip at the neck of the aneurysm to sever its connection with the main vessel. While this technique is well-established and particularly effective for superficially located, wide-necked, or complex aneurysms, its invasive nature results in significant tissue disruption, prolonged recovery, and a relatively high complication rate [8]. In contrast, endovascular embolization, a minimally invasive procedure involving the insertion of detachable platinum coils to induce thrombosis, has become an essential treatment option. The technique is advantageous for elderly patients, those with multiple comorbidities, and deep aneurysms in the posterior circulation [9].

Recent studies have shown that endovascular embolization results in lower one-year mortality and severe disability rates compared to craniotomy clipping, but slightly higher rates of rebleeding and retreatment [10]. This suggests that each surgical approach has distinct advantages and limitations. However, current research presents several gaps: most studies focus on survival and overall functional outcomes, with insufficient attention to cognitive function and quality of life; while immune responses are critical in aSAH pathophysiology, few studies have investigated the effects of treatment strategies on immune function; and although prognostic risk factors for aSAH have been identified, the long-term impact of surgical methods remains unclear. Therefore, this study aims to systematically compare the short-term efficacy, immune response, neurological and cognitive recovery, and incidence of complications between endovascular embolization and craniotomy clipping in treating aSAH. Additionally, it aims to identify independent risk factors for prognosis and rebleeding, providing a comprehensive scientific foundation for individualized clinical decision-making.

Materials and methods

Research subjects

This retrospective cohort study was conducted from August 2020 to May 2023, involving 98 aSAH patients who met the inclusion and exclusion criteria based on the hospital medical record system (134 eligible cases, 36 excluded). Patients were classified into two groups: the interventional group (n = 50, treated with endovascular embolization) and the craniotomy group (n = 48, treated with microsurgical clipping). The study was approved by the Ethics Committee of the Affiliated Hospital of North Sichuan Medical College.

Inclusion criteria

(1) Diagnosis of subarachnoid hemorrhage based on clinical presentation and confirmed by cranial CT or lumbar puncture, with subsequent inpatient admission for treatment; (2) Presence of a single intracranial aneurysm confirmed by cranial CT angiography (CTA), digital subtraction angiography (DSA), or magnetic resonance angiography (MRA); (3) Availability of comprehensive patient data, including demographic information (sex, age, body mass index, comorbidities, medication history, and atherosclerosis history), disease-related details (aneurysm location, size, and preoperative Hunt-Hess grade), surgical parameters (intraoperative blood loss, postoperative hospital stay, and operative time), clinical outcomes at three months post-surgery, preoperative and postoperative immune markers (IgG, IgA, and IgM), preoperative and postoperative GOS and MMSE scores, and postoperative complications within three months.

Exclusion criteria

(1) Traumatic subarachnoid hemorrhage, pseudoaneurysms, dissecting aneurysms, or intracranial arteriovenous malformations; (2) Brainstem aneurysms, large aneurysms, or giant aneurysms; (3) Hunt-Hess grade IV or V at admission; (4) Incomplete patient data.

Outcome measures

Primary outcome measures: (1) Clinical efficacy was assessed at three months postoperatively according to the American Heart Association/American Stroke Association Guidelines for the Management of Aneurysmal Subarachnoid Hemorrhage (Part II) [11]. Outcomes were categorized as follows: good (symptoms largely resolved, independent daily self-care), moderate disability (recovery of consciousness and limb function, but dependence in daily living), severe disability (preserved consciousness but loss of limb function), or vegetative state (complete loss of consciousness). (2) Glasgow Outcome Scale (GOS) score [12]

Table 1. Comparison of general clinical data between the two groups

General clinical data		Interventional group (n = 50)	Craniotomy group (n = 48)	t/χ^2	P
Sex	Male	19	20	0.137	0.711
	Female	31	28		
Average age (years)		59.63±9.62	60.23±8.81	0.324	0.747
Average BMI (kg/m^2)		22.63±2.15	21.98±2.96	1.248	0.215
Hypertension (Yes/No)		21/29	20/28	0.001	0.973
Diabetes (Yes/No)		3/47	5/43	0.637	0.425
History of smoking (Yes/No)		12/38	10/38	0.141	0.708
History of aspirin use (Yes/No)		5/45	3/45	0.459	0.498
History of atherosclerosis (Yes/No)		26/24	23/25	0.163	0.686

BMI: body mass index.

was evaluated on the first day of admission, the third postoperative day, and three months postoperatively, ranging from 1 to 5 (1 = death, 5 = good recovery). A GOS score ≥4 was considered indicative of a favorable prognosis. (3) Mini-Mental State Examination (MMSE) score [13] was assessed on the first day of admission, the third postoperative day, and three months postoperatively. This test consists of 30 items evaluating orientation, recall, temporal and spatial perception, attention, calculation, and language, with scores ranging from 0 to 30. Higher scores reflect better cognitive function, and a score ≤23 was considered indicative of postoperative cognitive dysfunction (POCD). (4) Binary multivariable logistic regression analysis was conducted to assess clinical outcomes (favorable or unfavorable prognosis) and identify independent risk factors for rebleeding.

Secondary outcome measures: (1) Surgical parameters, including intraoperative blood loss, postoperative hospital stay, and operative time, were recorded. (2) Immunological parameters were assessed by measuring IgG, IgA, and IgM levels on the first day of admission, the third postoperative day, and three months postoperatively. (3) Complications occurring within three months postoperatively were recorded and analyzed for both groups.

Quality control

Data collectors received standardized training on data collection procedures and confidentiality protocols. After collection, the data were aggregated in Excel and reviewed by the principal investigator for accuracy and completeness.

Statistical methods

Data were analyzed using SPSS 26.0. Continuous variables with a normal distribution were expressed as mean ± standard deviation (mean ± SD), and intergroup differences were assessed using independent sample t-tests. Categorical variables were presented as rates and analyzed using chi-square or Fisher's exact tests. Binary multivariable logistic regression was used to evaluate clinical efficacy and identify risk factors for rebleeding. Statistical significance was defined as $P < 0.05$.

Results

Comparison of general clinical data between the two groups

General clinical data, including age, sex, underlying diseases, and smoking history, were collected from the hospital's information system. To ensure consistency in preoperative baseline characteristics, t-tests and chi-square tests were performed. The results showed no statistically significant differences between the two groups in these parameters (all $P > 0.05$), indicating good comparability (**Table 1**).

Since factors such as aneurysm location, size, and preoperative Hunt-Hess grade may influence surgical outcomes, these characteristics were also compared. No statistically significant differences were observed between the groups for these variables (all $P > 0.05$) (**Table 2**).

Table 2. Comparison of basic information of aneurysm patients between the two groups

General clinical data		Interventional group (n = 50)	Craniotomy group (n = 48)	t/χ^2	*P*
Aneurysm location	Anterior communicating artery aneurysms	16	15	5.236	0.165
	Posterior communicating artery aneurysms	20	19		
	Anterior cerebral artery aneurysms	3	3		
	Middle cerebral artery aneurysm	6	5		
	Posterior cerebral artery aneurysm	3	3		
	Internal carotid artery aneurysm	2	3		
Aneurysm size	Tiny aneurysms	9	6	3.226	0.098
	Small/medium aneurysms	41	42		
Hunt-Hess grade	Grade I	16	14	4.516	0.115
	Grade II	20	21		
	Grade III	14	13		

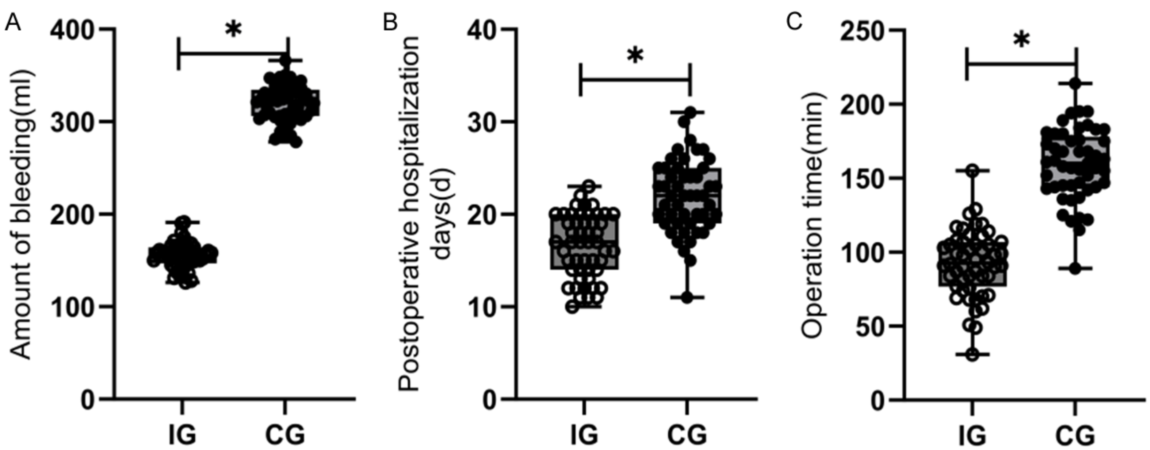

Figure 1. Comparison of surgical parameters between the two groups. A: Intraoperative blood loss; B: Postoperative hospitalization; C: Operative time. Note: IG: interventional group; CG: craniotomy group. *$P < 0.05$.

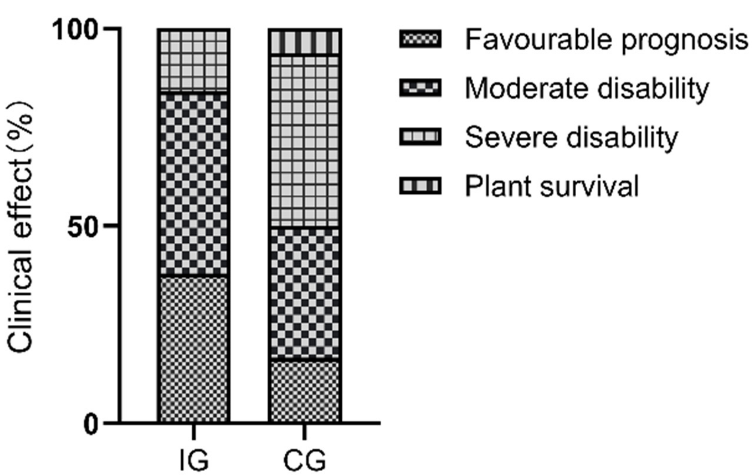

Figure 2. Comparison of clinical outcomes between the two groups. Note: IG: interventional group; CG: craniotomy group.

Comparison of surgical parameters between the two groups

Patients in the interventional group experienced significantly lower intraoperative blood loss, shorter postoperative hospital stay, and reduced operative time compared to the craniotomy group, with statistically significant differences (all P < 0.05) (**Figure 1**).

Comparison of clinical outcomes between the two groups

At the three-month postoperative follow-up, the intervention-

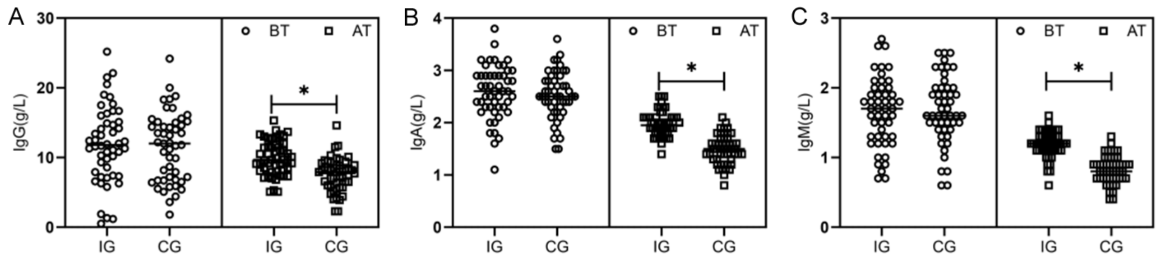

Figure 3. Comparison of preoperative and postoperative immunological markers between the two groups. A: IgG; B: IgA; C: IgM. Note: IG: interventional group; CG: craniotomy group; BT: before treatment; AT: after treatment. $^{*}P < 0.05$.

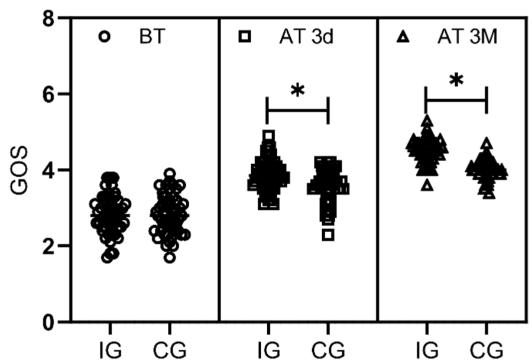

Figure 4. Comparison of preoperative and postoperative GOS scores between the two groups. Note: GOS: Glasgow Outcome Scale; IG: interventional group; CG: craniotomy group; BT: before treatment; AT 3d: 3 days after treatment; AT 3M: 3 months after treatment. $^{*}P < 0.05$.

al group demonstrated a favorable prognosis in 19 cases, moderate disability in 23 cases, and severe disability in 8 cases, with no vegetative survival cases. In contrast, the craniotomy group had 8 cases with favorable prognosis, 16 with moderate disability, 21 with severe disability, and 3 cases of vegetative survival. The difference in clinical outcomes between the two groups was statistically significant (P < 0.05) (**Figure 2**).

Comparison of preoperative and postoperative immunological markers between the two groups

Blood immunological markers (IgG, IgA, and IgM) were measured preoperatively and on postoperative day 1. The results showed no significant differences in preoperative immunological markers between the groups (all P > 0.05). However, on postoperative day 1, these markers were significantly higher in the interventional group compared to the craniotomy group (all P < 0.05) (**Figure 3**).

Comparison of preoperative and postoperative GOS scores between the two groups

Both groups were evaluated using the GOS preoperatively, on day 3 postoperatively, and at three months postoperatively. No significant differences in preoperative GOS scores were found between the two groups (both P > 0.05). However, the interventional group had significantly higher GOS scores at 3 days postoperatively and at the 3-month follow-up compared to the craniotomy group (both P < 0.05) (**Figure 4**).

Comparison of preoperative and postoperative cognitive function between the two groups

MMSE scores were collected preoperatively, on day 3 postoperatively, and at 3 months postoperatively. The interventional group had significantly higher MMSE scores than the craniotomy group on day 3 postoperatively (P < 0.05), but no significant differences were observed at other time points (both P > 0.05) (**Figure 5A**). Additionally, the incidence of POCD within 3 months postoperatively was significantly lower in the interventional group compared to the craniotomy group (P < 0.05) (**Figure 5B**).

Comparison of postoperative complications between the two groups

During the 3-month follow-up, the interventional group experienced 2 cases of intracranial infection, 1 case of hydrocephalus, 2 cases of cerebral vasospasm, and 1 case of rebleeding, with an overall complication rate of 12.00%

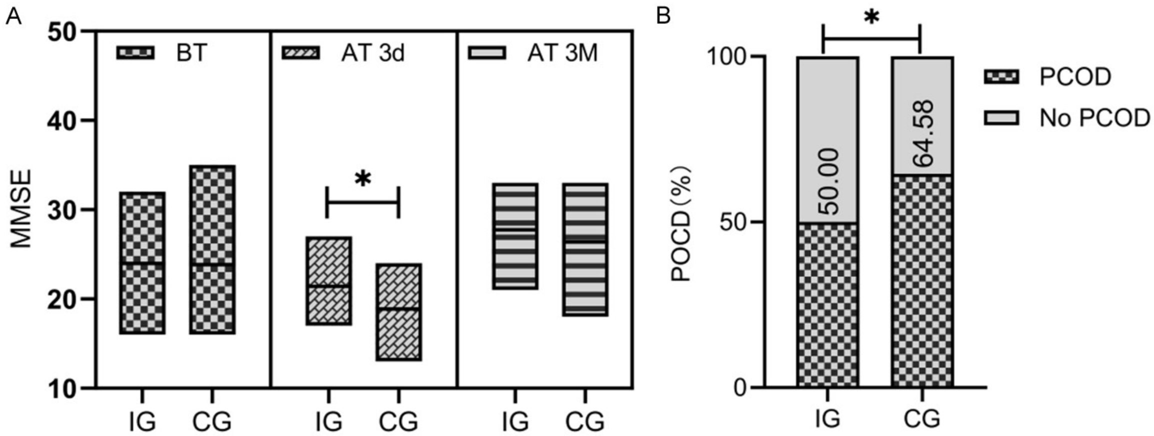

Figure 5. Assessment of preoperative and postoperative cognitive function between the two groups. A: MMSE scores; B: Incidence of POCD within 3 months postoperatively. Note: MMSE: Mini-Mental State Examination; POCD: postoperative cognitive dysfunction; IG: interventional group; CG: craniotomy group; BT: before treatment; AT 3d: 3 days after treatment; AT 3M: 3 months after treatment. $^{*}P < 0.05$.

Table 3. Comparison of postoperative complications between the two groups

Group	Number of cases	Intracranial infection	Hydrocephalus	Cerebral vasospasm	Rebleeding	Incidence
Interventional group	50	2	1	2	1	6 (12.00)
Craniotomy group	48	5	3	6	4	18 (37.50)
Fisher/χ^2	-	1.520	1.130	2.360	2.029	8.611
P	-	0.218	0.288	0.124	0.154	0.003

Table 4. Analysis of factors influencing prognosis

Risk factors	B	Wald	*P*	*OR*	95% *CI*
Preoperative Hunt-Hess grade	1.898	8.516	0.003	7.265	1.598-27.563
Age	-0.089	6.236	0.012	0.915	0.851-0.981
Surgical approach	1.216	3.269	0.049	3.526	0.926-12.063
Postoperative complications	0.315	14.516	0.000	1.681	1.151-1.698

(6/50), significantly lower than the 37.50% (18/48) in the craniotomy group (P < 0.05) (**Table 3**).

Analysis of influencing factors

A binary multivariable logistic regression analysis was performed, with prognosis at 3 months as the dependent variable (favorable prognosis = 0, unfavorable prognosis = 1), and other potential influencing factors (e.g., sex, age, postoperative complications) as independent variables. The analysis identified preoperative Hunt-Hess grade, surgical approach, age, and postoperative complications as independent risk factors affecting prognosis (all P < 0.05) (**Table 4**; **Figure 6**).

Analysis of risk factors for rebleeding

Binary multivariable logistic regression was conducted with postoperative rebleeding within 3 months as the dependent variable (bleeding = 0, no bleeding = 1) and factors such as sex, age, surgical approach, and preoperative Hunt-Hess grade as independent variables. The results indicated that surgical approach, age, and preoperative Hunt-Hess grade were independent risk factors for postoperative rebleeding (all P < 0.05) (**Table 5**; **Figure 7**).

Preoperative and postoperative imaging of typical cases

Figure 8 presents imaging for two typical patients. Patient 1, diagnosed with aSAH,

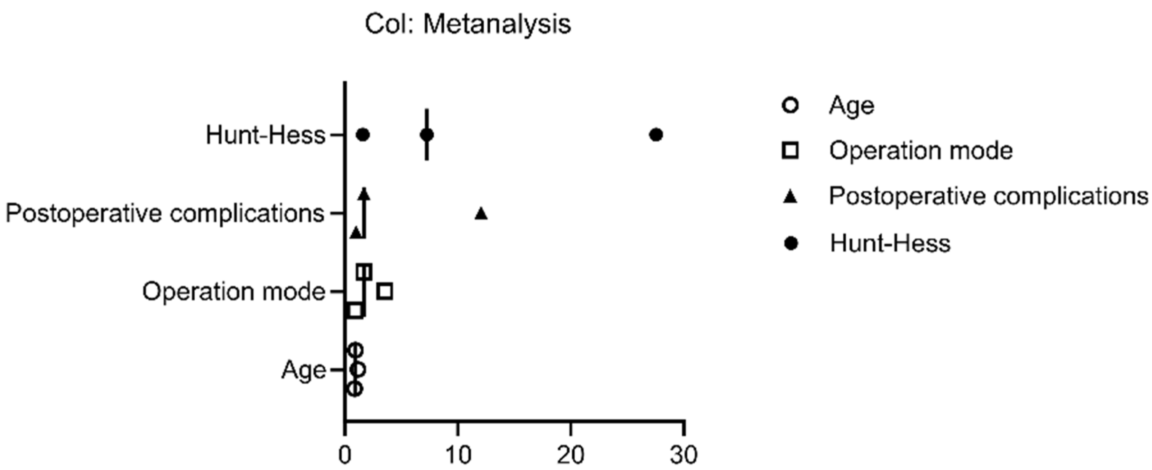

Figure 6. Analysis of factors influencing prognosis.

Table 5. Analysis of risk factors for rebleeding

Risk factors	B	Wald	*P*	*OR*	95% *CI*
Preoperative Hunt-Hess grade	1.168	8.563	0.003	3.026	1.563-6.236
Age	1.336	5.113	0.026	3.659	1.692-11.519
Surgical approach	1.635	13.263	0.000	4.516	2.165-11.051

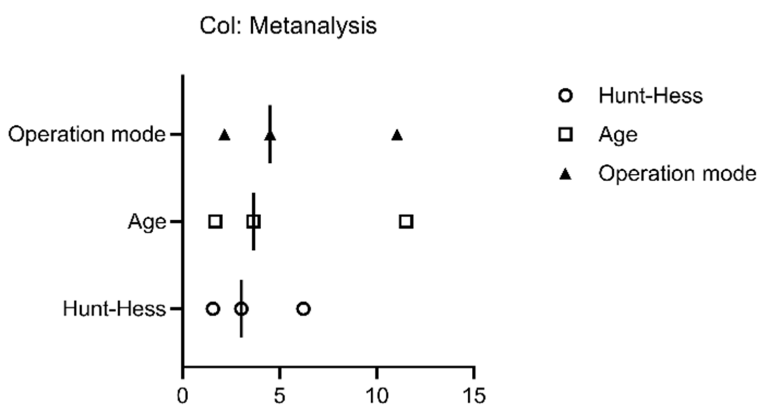

Figure 7. Analysis of risk factors for rebleeding.

underwent endovascular embolization. Postoperative imaging (**Figure 8B**) showed a significant reduction in aneurysm size compared to preoperative imaging (**Figure 8A**). Similarly, Patient 2, treated with the same procedure, exhibited comparable outcomes (**Figure 8C** and **8D**).

Discussion

This study conducted a comparative analysis to assess the clinical value of endovascular embolization in treating aSAH. The results demonstrated that, compared to patients undergoing traditional microsurgical clipping, those treated with endovascular embolization experienced significantly less trauma and faster postoperative recovery, consistent with findings from other studies. Akimoto et al. [14] reported the efficacy of endovascular embolization in 118 cases of severe aSAH, noting that, compared to traditional surgical clipping, interventional surgery provides greater safety, causes less trauma, and significantly enhances postoperative recovery. Compared to traditional craniotomy, endovascular intervention offers several advantages: (1) It eliminates the need for craniotomy, reducing the risks associated with cranial and vascular exposure and obviating the need for manual localization of the aneurysmal neck under a microscope, thus shortening procedure time [15]; (2) Advances in interventional techniques have improved the precision of instruments and imaging systems, enabling rapid vascular localization and minimizing operative time; (3) Vascular clipping often involves manip-

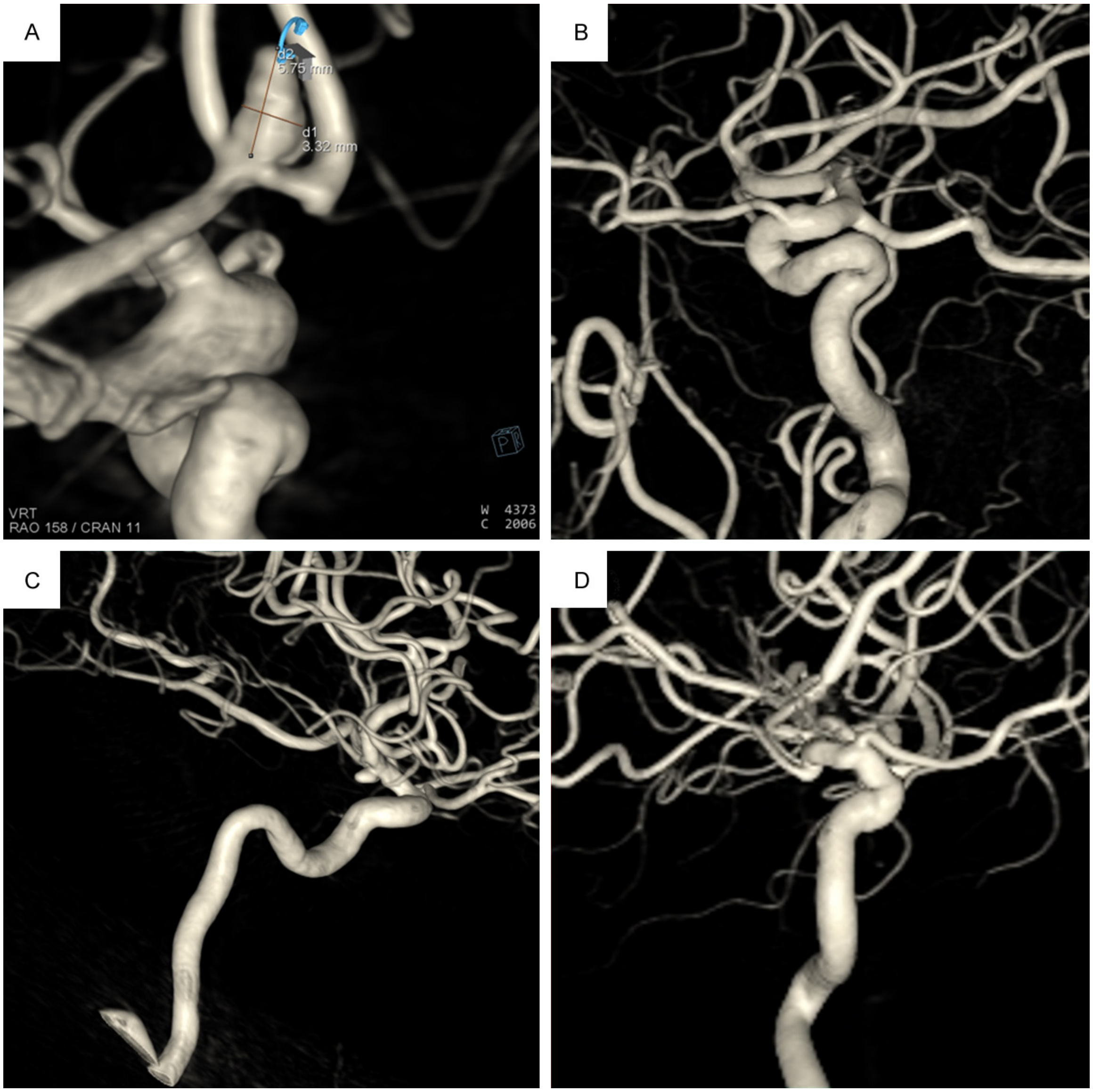

Figure 8. Preoperative and postoperative imaging of typical cases. A and C: Preoperative DSA images; B and D: Postoperative DSA images. Note: DSA: digital subtraction angiography.

ulation of vessels connected to the aneurysm, complicating the procedure, while endovascular intervention avoids this interference [16].

A comparative analysis of clinical outcomes showed that interventional surgery yielded superior efficacy compared to craniotomy clipping, leading to better patient prognoses. This advantage highlights the comprehensive benefits of interventional surgery, particularly in terms of postoperative neurological function, immune response, and complication rates.

First, regarding neurological function, the results revealed that postoperative GOS and MMSE scores in the interventional group were superior to those in the craniotomy group. Guo et al. [17] conducted a nomogram study, finding that patients who underwent vascular interventional therapy demonstrated superior neurological function postoperatively compared to those undergoing craniotomy, attributing this to the reduced surgical trauma, which aligns with our findings. Zhou et al. [18] reached similar conclusions, highlighting faster recovery and higher quality-of-life scores for patients in the interventional group. Based on the literature and clinical experience, the causes of this phenomenon are as follows: (1) Vascular interventional surgery avoids the brain structure damage associated with craniotomy [19], reducing the risk of neurological impairment; (2) It minimizes direct manipulation of cerebral vessels, thus reducing irritation to blood vessels surrounding the aneurysm and lowering the risk of postoperative cerebral vasospasm, a major cause of postoperative cerebral ischemia and neurological impairment after aSAH [20]; (3) Traditional craniotomy, due to its invasive nature, often leads to postoperative cerebral edema and hemorrhage [21], increasing the risk of neurological deficits; (4) Patients undergoing vascular interventional surgery recover more rapidly, with early ambulation and rehabilitation facilitating neurological recovery, whereas craniotomy requires a longer rehabilitation period; (5) In cases where the aneurysm is located at the base of the brain or in the posterior circulation, vascular interventional surgery avoids interference with critical neural structures, such as the oculomotor and facial nerves, reducing the risk of postoperative neurological impairment [22].

Secondly, regarding immune function, the results of this study indicated that postoperative levels of IgG, IgA, and IgM in the interventional group were significantly higher than those in the craniotomy group. This difference may be attributed to the minimally invasive nature of vascular interventional surgery, which results in less trauma, a weaker surgical stress response, and less negative impact on postoperative immune function. Immune function plays a crucial role in the recovery of patients with aSAH. Intense stress responses can trigger the release of inflammatory factors, leading to immunosuppression and increasing the risk of postoperative infections and immune dysfunction [23, 24]. Moreover, intense stress responses are closely linked to various postoperative complications in aSAH patients, including cerebral edema, infections, and seizures [25, 26]. Mitigating these stress responses provides a solid foundation for postoperative recovery. Craniotomy and clipping, by contrast, may cause further brain tissue damage, influencing systemic immune responses through the neuro-immune axis, resulting in secondary damage to the immune system [27]. This impact is reflected in the comparative complication rates between the two groups in this study.

Finally, a binary multivariable logistic regression analysis was performed to identify risk factors associated with poor prognosis and rebleeding in patients with aSAH. This represents the innovation of the study. Compared to traditional craniotomy and clipping, endovascular intervention is less invasive, exerts minimal impact on immune function, and promotes faster postoperative neurological recovery. These advantages emphasize the significant influence of surgical approach on patient prognosis. Additionally, advanced age and higher Hunt-Hess grades have been established as critical factors affecting prognosis in patients with aSAH [28, 29].

The innovation of this study lies in its comprehensive analysis of multiple quantitative indicators - such as neurological and immune functions - to elucidate the advantages of vascular interventional surgery in treating aSAH, supported by robust and reliable data. Although the study compared the clinical outcomes of two surgical approaches in several aspects, it has certain limitations. First, as a retrospective study with a relatively small sample size from a single center, the study may be subject to selection bias. Second, the follow-up period of three months did not allow for assessment of the long-term effects of the two surgical methods on neurological recovery and quality of life. Third, due to study design constraints, we were unable to systematically measure preoperative and postoperative serum inflammatory markers (e.g., IL-6, TNF-α), limiting the evaluation of differential impacts on systemic inflammatory responses. Fourth, the exclusion of patients with Hunt-Hess grades IV and V means that the conclusions may not apply to this high-risk population. Lastly, the study did not perform a stratified analysis of aneurysm location, size, and other anatomical characteristics, which are crucial factors influencing treatment selection and prognosis.

Future research should focus on the following aspects: First, large-sample, multicenter prospective studies should be conducted to comprehensively assess the differential efficacy of the two surgical approaches among various patient subgroups. Second, the follow-up period should be extended to one year or more to thoroughly investigate the long-term effects of both procedures on neurological recovery, cognitive function, rebleeding rates, and quality of life. Third, integrating radiomics, serum molecular biomarkers, and genomic data could facilitate the development of more precise prognostic models, enabling personalized treatment decisions. These efforts will allow for more precise and individualized management of aSAH, ultimately improving patient outcomes.

In conclusion, vascular intervention demonstrates superior clinical efficacy in patients with aSAH, offering advantages over traditional craniotomy, such as reduced operative time, minimized surgical trauma, accelerated recovery of immune function, and diminished neurological impact, with enhanced safety. It is recommended to intensify monitoring in elderly patients and those with higher preoperative Hunt-Hess grades to mitigate the risks of poor prognosis and rebleeding.

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Disclosure of conflict of interest

None.

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