Guo et al. BMC Neurology (2025) 25:55
https://doi.org/10.1186/s12883-025-04023-9

BMC Neurology

SYSTEMATIC REVIEW

Open Access

Long-term efficacy and safety of endoscopic surgery versus small bone window craniotomy for spontaneous supratentorial intracerebral hemorrhage: a meta-analysis and trial sequential analysis

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Abstract

Background and aims Endoscopic surgery (ES) and small bone window craniotomy (SBWC) are commonly used methods for hematoma removal in cases of intracerebral hemorrhage (ICH). However, their long-term efficacy and safety remain uncertain.

Methods A systematic search was performed in the PubMed, Embase, and Cochrane Library databases from inception to June 30, 2024. The primary outcomes assessed were the 6-month favorable functional outcome rate and the hematoma evacuation rate. Following the meta-analysis, a trial sequential analysis (TSA) was conducted to validate the findings.

Results Six randomized controlled trials were included in the meta-analysis. ES demonstrated a higher 6-month favorable functional outcome rate compared to SBWC (56.8% vs. 48.0%, relative risk [RR] 1.20, 95% confidence interval [CI] 1.05–1.38, $I^2=28\%$), with TSA supporting this result. The hematoma evacuation rate was also higher in the ES group (mean difference [MD] 6.41, 95% CI 1.83–10.99, $I^2=95\%$); however, the TSA did not support this result due to the potential false-positive. Additionally, ES was associated with shorter operation times, less blood loss during surgery, and a lower pneumonia rate compared to SBWC (MD -112.35, 95% CI -165.27 to -59.43; MD -151.22, 95% CI -279.60 to -22.84; RR 0.68, 95% CI 0.51–0.91).

Conclusions The meta-analysis and TSA indicate that ES offers better long-term efficacy, shorter operation times, less blood loss, and a lower rate of pneumonia compared to SBWC. Therefore, prioritizing ES over SBWC for treating ICH appears to be a reasonable approach.

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Keywords Spontaneous supratentorial intracerebral hemorrhage, Endoscopic surgery, Small bone window craniotomy, Meta-analysis, Trial sequential analysis

Introduction

Intracerebral hemorrhage (ICH) is a critical medical emergency with a high risk of mortality and long-term disability. Mortality rates 12 months after ICH range from 46.7 to 63.6% [1], while the proportion of patients achieving functional independence varies between 12% and 39% [2]. Hypertension stands out as the most prominent risk factor associated with ICH; other notable risk factors include cerebral amyloid angiopathy and the use of anticoagulants [3, 4]. Consequently, older adults are particularly vulnerable to ICH due to their increased likelihood of encountering these risk factors [3]. With an aging population, the incidence of ICH is expected to rise in the future.

Guidelines from multiple countries recommend supratentorial hematoma removal for patients with a Glasgow Coma Scale (GCS) score of 9 to 12 or those experiencing deteriorating conditions [5–7]. Several methods are currently available for hematoma removal, including traditional craniotomy, minimally invasive puncture surgery, and endoscopic surgery (ES), each with its advantages and considerations [8]. Traditional craniotomy provides a clear surgical view, facilitating effective reduction of hematoma volume and alleviation of perihematomal edema compared to conservative medical management [9, 10]. However, current evidence does not consistently support superior outcomes with this method [8, 11, 12], possibly due to additional damage to normal brain tissue during the procedure [13]. Minimally invasive puncture surgery is the least invasive approach but lacks direct visualization and real-time bleeding control, which may limit its effectiveness in certain cases [8]. In contrast, ES combines several advantages of the aforementioned methods: it requires only a small (2 to 3 cm diameter) bone window, allows for direct visualization of the hematoma, and provides immediate bleeding control [13–15]. Therefore, ES may be the optimal choice.

Several meta-analyses have compared the efficacy and safety of ES and traditional craniotomy [4, 8, 16]. However, significant heterogeneity—likely due to variations in bone window size, differing definitions of favorable functional outcomes, and varying follow-up periods—may limit the generalizability of these results and impact clinical decision-making. Furthermore, the traditional meta-analysis may increase the risk of Type I errors due to repeated significance testing, whereas trial sequential analysis (TSA) can overcome this limitation and offer the advantage of estimating the sample size required to draw conclusive results. Therefore, we conducted a meta-analysis and TSA to comprehensively compare the long-term efficacy and safety of small bone window craniotomy (SBWC) versus ES for spontaneous ICH.

Materials and methods

Search strategy

This meta-analysis followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and was prospectively registered on PROSPERO (Registration no. CRD42024566333) [17]. The search strategies combined MeSH Terms/Emtree terms and text words, including "intracranial hemorrhages," "intracerebral hemorrhage," "neuroendoscopy," "neuroendoscopic," "craniotomy," and "random." Two experienced physicians conducted a systematic search of the PubMed, Embase, and Cochrane Library databases from inception to June 30, 2024. The detailed search strategy is outlined in Supplementary Table 1.

Study selection

The inclusion criteria were as follows: (1) the randomized controlled trials (RCTs) comparing ES and SBWC; (2) adult patients aged 18 years or older diagnosed with ICH; (3) studies reporting either the 6-month favorable functional outcome rate or hematoma evacuation rate. Exclusion criteria included: (1) non-English language articles; (2) non-full text; (3) studies with fewer than ten patients in each treatment arm; (4) insufficient information on primary outcomes; (5) cases of supratentorial intracerebral hemorrhage associated with a head injury, cerebral tumor, aneurysm, or arteriovenous malformation; and (6) brain herniation at admission. Two independent authors screened these studies, and any discrepancies were resolved through consensus.

Outcome assessment

The primary outcomes in this meta-analysis were the 6-month favorable functional outcome rate and the hematoma evacuation rate. The 6-month favorable functional outcome rate was defined as the modified Rankin Scale (mRS) of 0–3 points at six months [4, 16]. The hematoma evacuation rate was determined as the percentage reduction in hematoma volume before and after surgery.

Secondary outcomes included: the 6-month mortality rate (all-cause mortality at six months postoperatively), the rebleeding rate (recurrent bleeding during the follow-up period), operation time, blood loss during the operation, ICU stay duration, hospital stay duration, pneumonia rate, and intracranial infection rate.

Data extraction and quality assessment

Data extracted independently by two authors from the selected studies included: the first author, publication year, enrollment period, number of participants receiving ES or SBWC, baseline characteristics of the study population, and outcomes of interest. If any studies lacked the necessary outcomes or data, corresponding authors were contacted to obtain the missing information.

The RCTs were assessed employing the Cochrane Risk of Bias 2 tool [18]. This tool assessed randomization processes, deviations from intended interventions, missing outcome data, outcome measurement, and selection of reported results, providing an overall bias assessment categorized as low risk, some concerns, or high risk.

Statistical analysis

Relative risk (RR) with a 95% confidence interval (CI) was calculated for dichotomous data, and weighted mean difference (MD) with a 95% CI was calculated for continuous outcomes [19, 20]. When only the median and first and third quartiles were available, mean values and standard deviations were estimated through transformations [19, 20]. Heterogeneity in the meta-analysis was categorized as low, moderate, or high based on I^2 thresholds of 25%, 50%, and 75%, respectively [21]. A fixed-effects model was used to create the forest plot when *P*-values exceeded 0.10 and I^2 was less than 50%; otherwise, a random-effects model was applied [22]. Publication bias was not assessed due to low test power with fewer than ten studies [23]. Subgroup and sensitivity analyses were not conducted due to the limited number of studies. A statistically significant two-sided *P*-value was defined as < 0.05. Statistical analyses were conducted using RevMan version 5.3 (The Nordic Cochrane Centre, Copenhagen, Denmark).

Trial sequential meta-analysis

The TSA could estimate the sample size that is adequate to draw conclusive results based on an anticipated prior intervention effect. Therefore, it complements conventional meta-analysis by reducing the risk of false positives (type I errors) and false negatives (type II errors) associated with small sample sizes and repeated significance testing [24]. In TSA, The Z-value is the test statistic, where $|Z| = 1.96$ corresponds to a *P*-value of 0.05. As the Z-value increases, the corresponding *P*-value decreases. The Z-value is calculated iteratively as studies are sequentially added to the meta-analysis, producing a cumulative Z-curve [25]. The stability and conclusiveness of the meta-analysis results are evaluated based on the cumulative Z-curve's position relative to several boundaries: the conventional boundary, which represents the significance level of a traditional meta-analysis ($P = 0.05$); the trial sequential monitoring boundary (TSMB), which is an adjusted benefit/harm threshold calculated based on the priori intervention effect; the futility boundary, which is an adjusted threshold for non-superiority and non-inferiority testing; and the required information size (RIS), which denotes the number of patients needed to achieve adequately powered results for assessing intervention efficacy [26]. The stability and conclusiveness of the meta-analysis results are determined when the cumulative Z-curve crosses the TSMB, reaches the RIS, or enters the futility boundary, otherwise, further research is needed [24, 27].

TSA was conducted using TSA software version 0.9.5.10 (www.ctu.dk/tsa). The significance level (type I error rate) and statistical power were set at 5% and 80%, respectively. The effect model used was consistent with the meta-analysis, and calculations for relative risk reduction and MD were based on an RCT with a low risk of bias (Xu et al. [13]). The TSMB was autogenerated by the software according to the significance level, statistical power and the relative risk reduction or MD. The adjustment of RIS for heterogeneity was conducted based on model variance.

Results

Search results and study characteristics

The flow diagram for identifying eligible studies is shown in Fig. 1. An initial search across three databases yielded 75 records after excluding 61 duplicates. Following title and abstract screening, 55 studies were excluded. The remaining 20 articles were subjected to full-text assessment based on the predefined inclusion and exclusion criteria. Of these, 14 were further excluded for the following reasons: no results posted ($n = 4$), non-RCTs ($n = 3$), unclear craniotomy method ($n = 2$), no endoscopic surgery ($n = 2$), no small bone window craniotomy ($n = 2$), and duplicate records ($n = 1$). Consequently, 6 RCTs were included in the meta-analysis. Detailed reasons for the exclusion of each study are provided in Supplementary Table 2.

Among the studies included in our analysis, one was multicenter RCT [13], while the remaining five were single-center RCTs [14, 15, 28–30]. All studies were conducted in Asia, specifically in China and Thailand. The bleeding sites varied, including the basal ganglia, thalamus, and cerebral lobes, with or without ventricular rupture. The preoperative hematoma volume ranged from 30.1 ml to 52.4 ml, and the average age of the patients

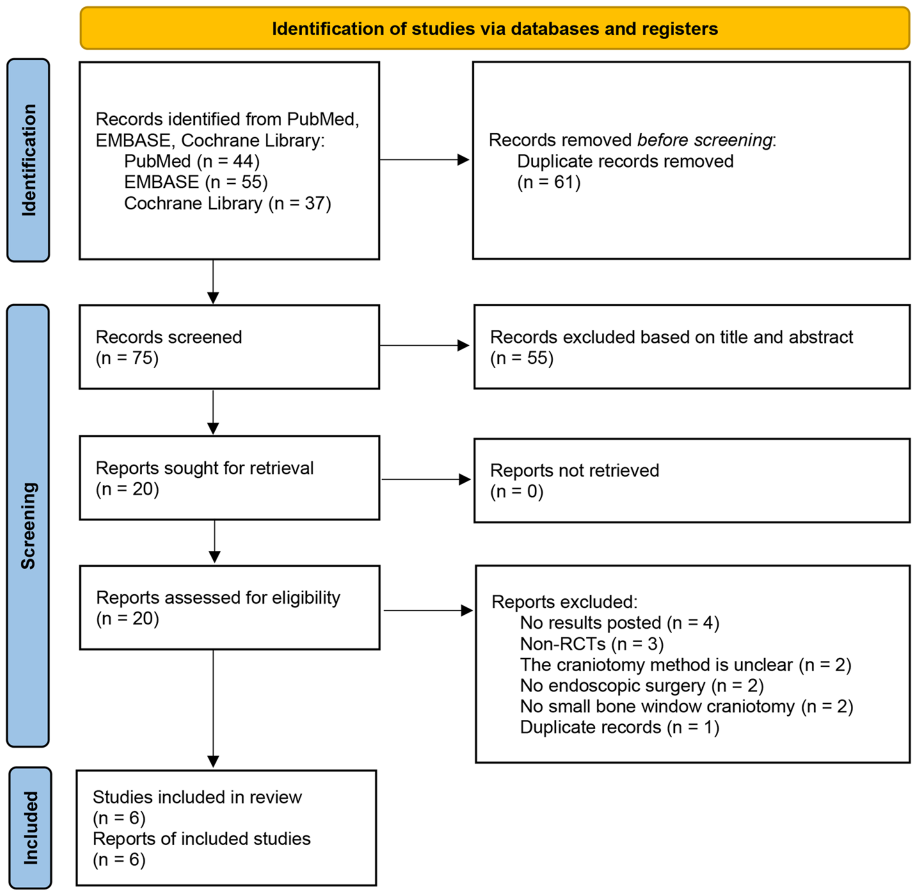

Fig. 1 Flow diagram for the identification of eligible studies. RCT, randomized controlled trial

ranged from 50 to 56.7 years. Additionally, most patients had a history of hypertension. Detailed characteristics of the included studies are provided in Table 1.

Risk of bias

The Cochrane Risk of Bias 2 tool was used to assess the included RCTs. Five RCTs were noted to have some concerns about the randomization process due to unclear sequence concealment. Four RCTs had concerns related to deviations from intended interventions and the selection of reported results, as they did not specify if deviations occurred within the trial or adhere to a pre-specified protocol. Overall, only one RCT was rated as having a low risk of bias, while the remaining five were categorized as having some concerns. Detailed results are presented in Fig. 2.

Primary outcomes

The 6-month favorable functional outcome rate

Based on the included three RCTs with 653patients, ES was superior to SBWC in achieving the 6-month favorable functional outcome rate (56.8% vs. 48.0%, RR 1.20, 95% CI 1.05–1.38), with low heterogeneity (I^2 = 28%) (Fig. 3A). To avoid false positive conclusions (type I errors), TSA was performed. The TSA indicated that the RIS was 1191 patients, and the cumulative Z-curve exceeded both the conventional boundary and the TSMB, thereby confirming the robustness of the meta-analysis findings (Fig. 3B).

The hematoma evacuation rate

The hematoma evacuation rate was reported in five RCTs, involving 919 patients. ES showed a significantly higher hematoma evacuation rate compared to SBWC (MD 6.41, 95% CI 1.83–10.99); however, the heterogeneity was considerable (I^2 = 95%) (Fig. 4A). Although the cumulative Z-curve crossed the conventional boundary in the TSA, the boundary required for the RIS was not reached due to insufficient data (Fig. 4B). Therefore, the superiority of ES cannot be definitively established due to the potential for false-positive results, highlighting the need for further research.

Table 1 Study characteristics

Author, year	Country	Study design	Enrollment period	Indication for treatment	Arms	Preoperational hematoma volume (mL)	History of hypertension (%)	Sample size	Male/female (*n*)	Age, years (mean ± SD)
Zhang, 2018 [29]	China	Single-center, RCT	2016.01–2017.04	Basal ganglia and cerebral lobe	ES	39.1 ± 6.2	100.0%	65	NA	NA
					SBWC	39.0 ± 6.1	100.0%	65	NA	NA
Gui, 2019 [28]	China	Single-center, RCT	2015.12–2017.12	Hypertensive intracerebral hemorrhage	ES	52.4 ± 3.6	100.0%	63	39/24	54.0 ± 3.7
					SBWC	NA	100.0%	63	36/27	52.3 ± 3.4
Noiphithak, 2023 [15]	Thailand	Single-center, RCT	2019.03–2022.06	Basal ganglia, thalamus, and cerebral lobe	ES	50.1 (33.0)[a]	43.2%	95	68/27	51.0 (18.0)[a]
					SBWC	49.3 (28.9)[a]	45.2%	93	62/31	50.0 (14.0)[a]
Zhu, 2022 [30]	China	Single-center, RCT	2018.01–2020.01	Intracerebral hemorrhage with ventricular rupture	ES	35.0 ± 9.4	NA	30	18/12	55.1 ± 8.3
					SBWC	35.1 ± 9.4	NA	30	19/11	55.2 ± 8.4
Lv, 2023 [14]	China	Single-center, RCT	2020.02–2022.06	Basal ganglia	ES	31.4 ± 6.4	100.0%	58	37/21	56.7 ± 13.7
					SBWC	30.1 ± 5.5	100.0%	70	48/22	54.8 ± 12.6
Xu, 2024 [13]	China	Multicenter, RCT	2016.07–2022.06	Basal ganglia, thalamus, and cerebral lobe	ES	49.1 ± 20.3	100.0%	239	166/73	56.6 ± 11.0
					SBWC	49.9 ± 17.6	100.0%	236	160/76	55.8 ± 11.8

NA not available, *ES* endoscopic surgery, *RCT* randomized controlled trial, *SBWC* small bone window craniotomy

[a] median (IQR)

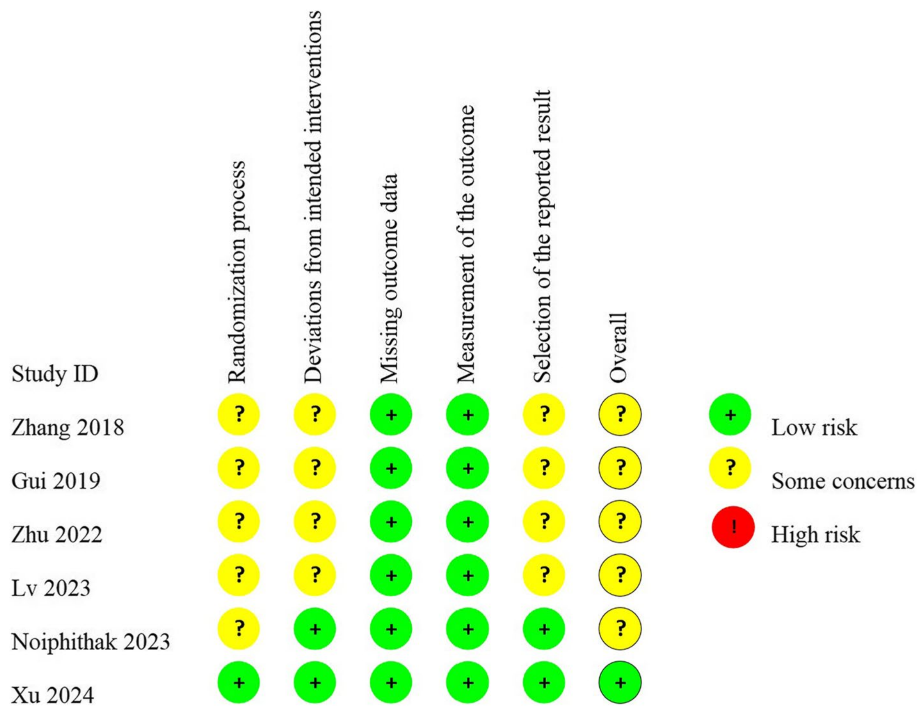

Fig. 2 Risk of bias of included RCTs. +, low risk; ?, Some concerns; !, high risk

Secondary outcomes

The 6-month mortality rate

Three RCTs involving 737 patients reported dichotomous data on the 6-month mortality rate. There was no significant difference between the ES and SBWC groups, with very low heterogeneity (14.9% vs. 14.4%, RR 1.03, 95% CI 0.73–1.45, $I^2 = 0$) (Fig. 5A).

The rebleeding rate

Only 2 RCTs, involving 663 patients, reported dichotomous data on the rebleeding rate. Analysis of the pooled data showed no significant difference in the rebleeding rate between patients treated with ES and SBWC, with very low heterogeneity (3.6% vs. 5.2%, RR 0.70, 95% CI 0.34–1.43, $I^2 = 0$) (Fig. 5B).

The operation time and the amount of blood loss during the operation

Five RCTs with 919 patients assessed operation time, and four of these RCTs evaluated the amount of blood loss during the operation with 849 patients. ES demonstrated a shorter operation time and less blood loss compared to SBWC (MD −112.35, 95% CI −165.27 to −59.43; MD −151.22, 95% CI −279.60 to −22.84). However, these comparisons exhibited substantial heterogeneity ($I^2 =$ 98% and $I^2 = 99\%$) (Fig. 5C and D).

Pneumonia rate and intracranial infection rate

There were three RCTs, comprising 729 patients, that provided pneumonia rate. The ES demonstrated a lower pneumonia rate with very low heterogeneity (16.4% vs. 23.6%, RR 0.68, 95% CI 0.51–0.91, $I^2 = 0$). Five RCTs reported the data of intracranial infection rate with 977 patients, and no significant difference was found between the ES and SBWC groups (3.3% vs. 5.3%, RR 0.63, 95% CI 0.35–1.15, $I^2 = 12\%$) (Fig. 5E and F).

ICU stay time and hospital stay time

Only two and one RCTs provided the data on ICU stay time and hospital stay time, respectively. The meta-analyses did not show significance regarding the above outcomes (MD −0.19, 95% CI −0.94–0.57, $I^2 = 34\%$; MD 0.80, 95% CI −1.97–3.57) (Fig. 5G and H).

Discussion

In the present meta-analysis, we included all related RCTs to compare ES and SBWC, providing clinical guidelines based on high-level evidence. To our knowledge, this is the first meta-analysis and TSA assessing the long-term efficacy of the ICH. Our analysis revealed that ES significantly improved the rate of favorable functional outcomes at 6 months compared to SBWC. However, the comparative effectiveness in terms of hematoma evacuation remains unclear. Additionally, ES was associated

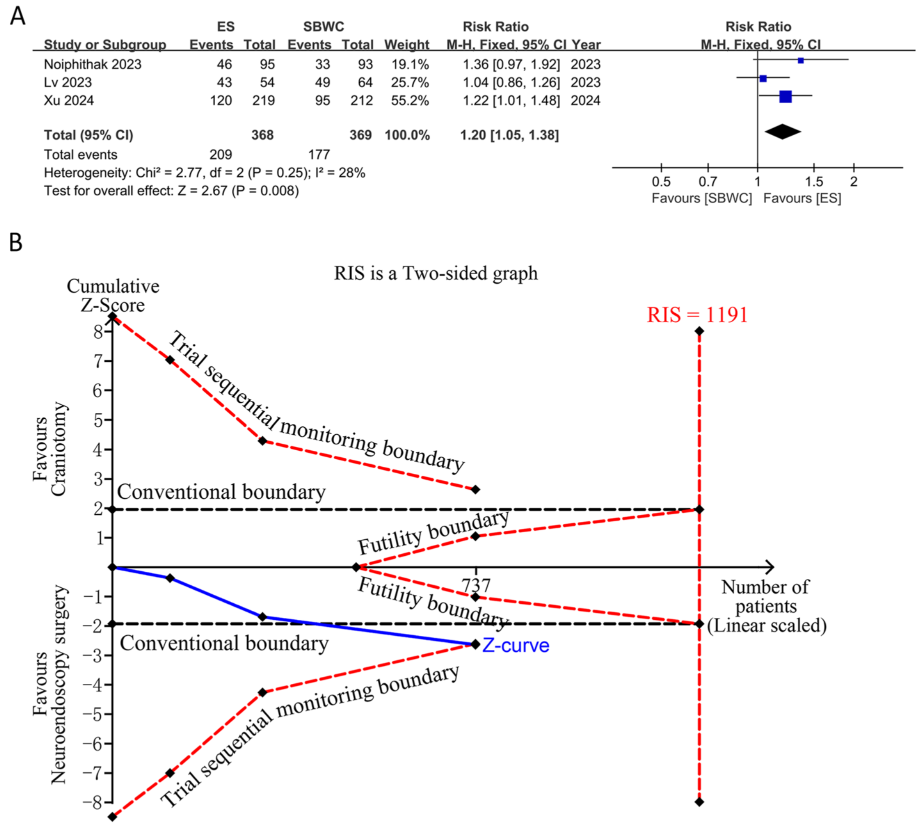

Fig. 3 Forest plot and trial sequential analysis of the 6-month favorable functional outcome rate. **A** Forest plot showing the pooled 6-month favorable functional outcome rate in patients with ES versus SBWC. ES showed a superior 6-month favorable functional outcome rate compared to SBWC. **B** The Y-axis represents the z-scores for effect sizes, and the Z-curve (blue line) along the X-axis shows the trend of cumulating evidence toward achieving maximal information. The conventional boundary (dotted black lines) represents the meta-analysis efficacy boundary ($|Z| = 1.96$, $P = 0.05$), and the trial sequential monitoring boundary (dotted red lines) and futility boundary (dotted red lines) represent the conclusive boundary in the TSA. The cumulative Z-curve crossed both the conventional boundary and the TSMB, affirming ES's superior efficacy over SBWC regarding the 6-month favorable functional outcome rate. CI, confidence interval; ES, endoscopic surgery; RIS, required information size; SBWC, small bone window craniotomy

with significantly lower operation time, blood loss during the procedure, and pneumonia rate compared to SBWC. Both ES and SBWC showed similar outcomes regarding the 6-month mortality rate, rebleeding rate, intracranial infection rate, ICU stay duration, and hospital stay duration.

The favorable functional outcome was one of the primary efficacy outcomes in the present meta-analysis, as it could reflect the neurological functions that support patients' daily activities after the intervention. The functional assessment tools vary for the ICH, including mRS, Barthel Index, Glasgow Outcome Scale score, Activity of Daily Living, and Glasgow Prognosis Scale GRADE [4, 8]. This variability complicates data pooling. Assuming these tools have similar discriminatory abilities might lead to significant heterogeneity. Moreover, the variations in follow-up periods may reflect patients' prognosis at different stages of recovery. Pooling analyses without considering these follow-up periods could also contribute to substantial heterogeneity. Although several previous meta-analyses have compared ES and SBWC [4, 8, 16], there is insufficient robust evidence to support the priority of ES, as the issues mentioned above have not been addressed. To mitigate the high heterogeneity across studies and ensure a high-quality outcome, we exclusively included RCTs reporting 6-month mRS outcomes. A previous network meta-analysis comparing conventional craniotomy, ES, minimally invasive puncture surgery, and conservative medical treatment indicated that ES was ranked first in the favorite functional outcome, consistent with our findings [8]. Furthermore, we conducted a TSA to substantiate the meta-analysis findings, thereby enhancing the robustness and reliability of our results.

Another primary outcome was the hematoma evacuation rate, as the removal of the hemorrhage is crucial for improving neurological function and saving lives, as

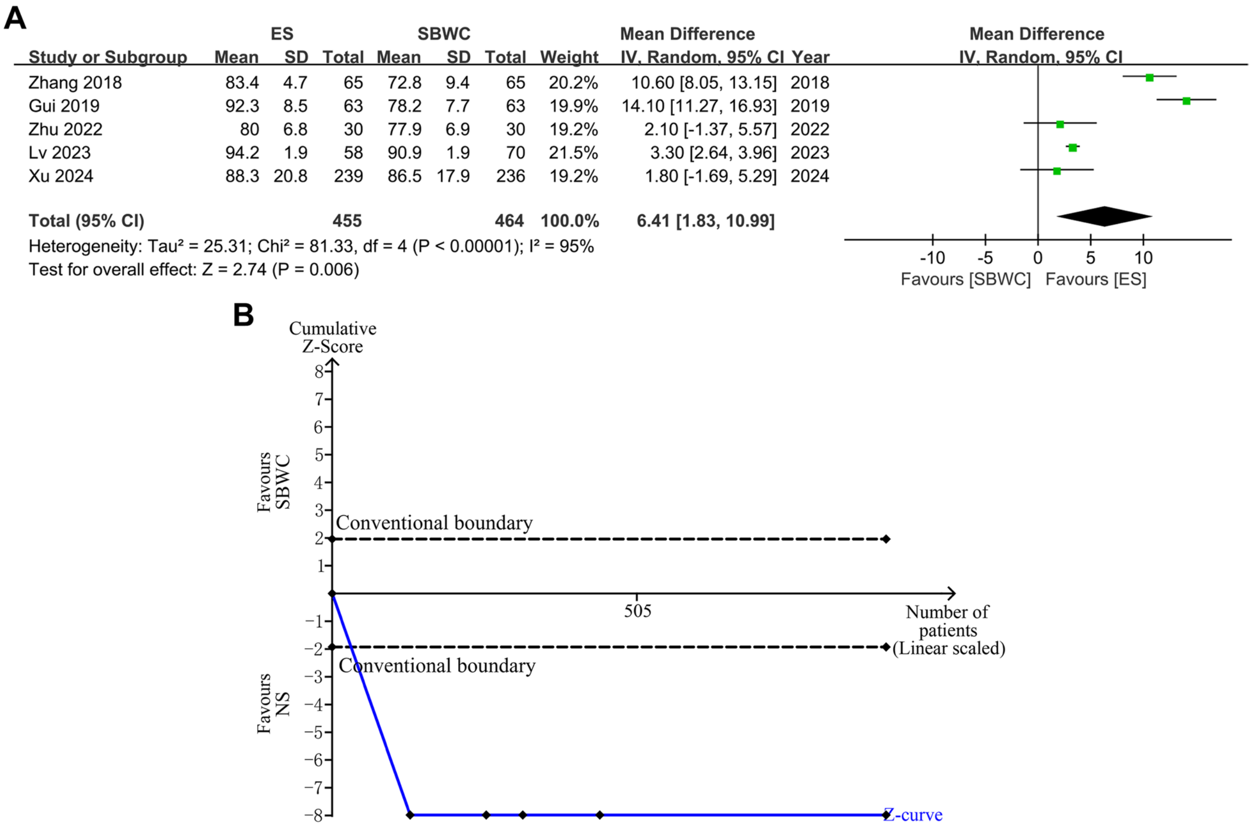

Fig. 4 Forest plot and trial sequential analysis of the hematoma evacuation rate. **A** Forest plot showing the hematoma evacuation rate in patients with ES versus SBWC. ES showed a superior hematoma evacuation rate compared to SBWC. **B** The Y-axis represents the z-scores for effect sizes, and the Z-curve (blue line) along the X-axis shows the trend of cumulating evidence toward achieving maximal information. The conventional boundary (dotted black lines) represents the meta-analysis efficacy boundary ($|Z| = 1.96$, $P = 0.05$) in the TSA. The cumulative Z-curve crossed the conventional boundary, but the boundary RIS was ignored due to too little information, meaning that the hematoma evacuation rate comparison between ES and SBWC remained inconclusive. CI, confidence interval; ES, endoscopic surgery; RIS, required information size; SBWC, small bone window craniotomy

demonstrated by a recent multicenter RCT [13]. Therefore, the hematoma evacuation rate may be a key indicator associated with the patient's prognosis. It is typically advised to remove the hematoma until the remaining volume is less than 15 ml [7, 12, 31, 32]. A prior meta-analysis has shown that the ES could improve the hematoma evacuation rate compared with SBWC [4], and the present meta-analysis confirmed this finding. Unfortunately, the significant heterogeneity and the results from the TSA prevent us from generalizing this conclusion. Therefore, further TSA is needed as more relevant studies are published to resolve this uncertainty in the future.

Interestingly, we observed that patients in the ES group had a lower incidence of pneumonia than those in the SBWC group, which contrasts with a previous meta-analysis [4]. One possible explanation is that patients in the ES group may resume out-of-bed activities and daily life sooner, potentially reducing pneumonia risk. However, there is currently a lack of relevant data to support this hypothesis, and further research is needed to confirm our results. For the 6-month mortality rate and the rebleeding rate, SBWC exhibited similar efficacy to ES, consistent with the previous four meta-analyses [4, 8, 16, 33]. ES does not appear to improve mortality or reduce the rebleeding rate compared to SBWC, likely due to the limited number of included RCTs; therefore, further research is needed.

Compared to large trauma craniotomy, SBWC can help maintain intracranial pressure and reduce wound size, potentially aiding in hematoma removal and facilitating faster recovery [34]. However, limited exposure to SBWC can hinder clear visualization of the hematoma, particularly in deep locations, increasing the risk of inadvertently damaging surrounding brain tissue [14]. In contrast, the ES has a clearer surgical field of view, which can minimize brain tissue retraction and enhance surgical precision [14]. These advantages likely contribute to the superior long-term efficacy observed with

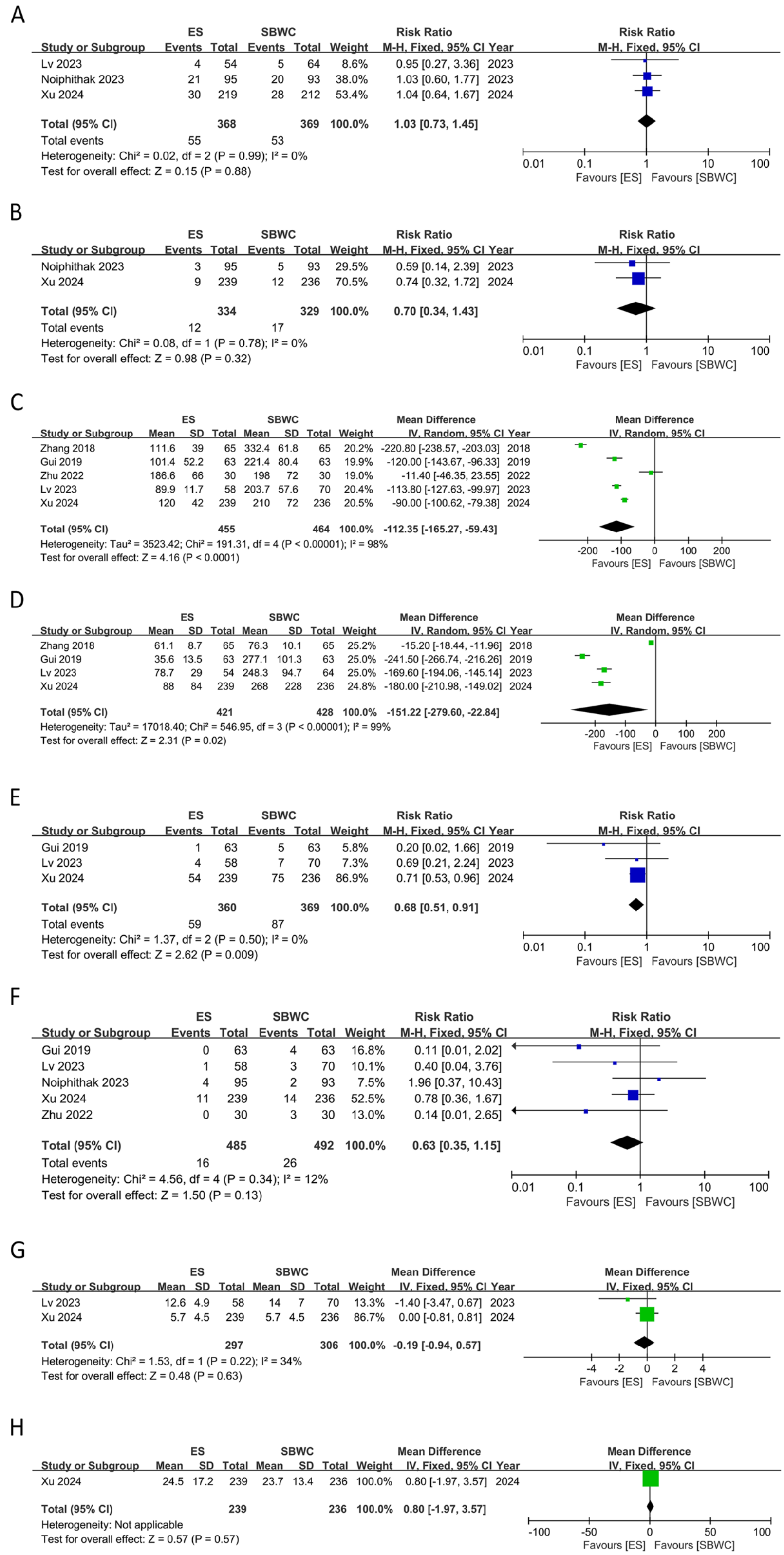

Fig. 5 Forest plot of the secondary outcomes. **A** the 6-month mortality rate; **B** the rebleeding rate; **C** the operation time; **D** the amount of blood loss during the operation; **E** the pneumonia rate; **F** the intracranial infection rate. **G** the ICU stay time; **H** the hospital stay time; ES, endoscopic surgery; SBWC, small bone window craniotomy

ES. Clear visualization also enables more efficient and accurate procedures, leading to shorter operation times and less blood loss, as evidenced in the present meta-analysis. Similar findings have been reported in previous studies [35–37]. Nonetheless, substantial heterogeneity remains, and the pooled results should be interpreted with caution. Variations in surgical habits and surgeon proficiency may account for some of this heterogeneity. Further research is needed to identify the exact sources of variability and to validate the findings of this study.

It's noteworthy that the majority of patients included in the study were under 60 years old. Consequently, based on the current evidence, ES may still be prioritized in the treatment of younger individuals with ICH. Future RCTs are required to evaluate the efficacy of ES versus SBWC in older patients and to explore the optimal treatment approach.

It also is important to note that while this study demonstrates that ES can significantly improve patient prognosis, the surgeon's experience and the choice of specific instruments can also have a substantial impact on patient outcomes [33, 38]. Advanced suction and coagulation systems may help simplify the surgical procedure, enhancing hemostasis and reducing the risk of complications. Furthermore, factors such as the location of the hematoma and the patient's coagulation status can influence prognosis [33, 38, 39]. Therefore, in clinical practice, it is essential to comprehensively consider the patient's condition, the surgeon's expertise, and the choice of instruments to select the most appropriate treatment approach.

This meta-analysis has several strengths. Firstly, we compared the long-term efficacy and safety of ES and SBWC, offering valuable insights for clinical practice. Secondly, considering the limited number of eligible studies and participants, we used TSA to further evaluate the validity and reliability of the meta-analysis outcomes, which enhanced the robustness of the meta-analysis. Finally, the rigorous inclusion and exclusion criteria, coupled with the assessment of favorable functional outcomes exclusively using mRS at six months, ensured low heterogeneity of the primary outcomes and robust conclusions.

There are several limitations to our study. Firstly, the number of the included RCTs is limited, though TSA has affirmed the robustness of the meta-analysis. Secondly, there is considerable heterogeneity in some outcomes, which may originate from the hemorrhage location, time since the onset of the hemorrhage, patient age, and preoperational hematoma volume. However, we were unable to conduct subgroup or sensitivity analyses to explore sources of heterogeneity and the efficacy of ES within specific patient groups due to the small number of studies and the unavailability of corresponding subgroup results; thus, future high-quality research is needed to address this limitation. Thirdly, publication bias could not be assessed because fewer than ten studies were available. It is also important to note that recovery from intracerebral hemorrhage (ICH) is a prolonged process; the present meta-analysis only demonstrated outcomes at the 6-month mark, leaving long-term outcomes uncertain. Future studies should focus on evaluating outcomes beyond this 6-month period. Lastly, most of the included studies are from China, and only English-language studies were considered, which may limit the generalizability of the results and introduce potential selection biases. RCTs from diverse locations will be necessary to validate our findings globally.

Conclusion

In conclusion, the meta-analysis and TSA demonstrated that ES has better long-term efficacy, shorter operation time, less blood loss during the operation, and lower pneumonia rate compared to SBWC. Therefore, prioritizing ES over SBWC in treating ICH could be reasonable. Additionally, the hematoma evacuation rate of ES compared to SBWC for ICH remains unclear, so larger, higher-quality RCTs are needed.

Abbreviations

CI	Confidence interval
ES	Endoscopic surgery
GCS	Glasgow Coma Scale
ICH	Intracerebral hemorrhage
MD	Weighted mean difference
mRS	Modified Rankin Scale
NA	Not available
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analysis statement
RCT	Randomized controlled trial
RR	Relative risk
RIS	Requisite sample sizes
SBWC	Small bone window craniotomy
TSA	Trial sequential analysis
TSMB	Trial sequential monitoring boundary

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12883-025-04023-9.

Supplementary Material 1: Supplementary Table 1. Search strategies for literature review. Supplementary Table 2. Exclusion reasons for each study. RCT, randomized controlled trial.

Acknowledgements

We thank the National Natural Science Foundation of China (No.82101318) for supporting this paper.

Authors' contributions

Guarantor of the integrity of the study: D.F. Study concepts: D.F., S.H. and C.G. Study design: C.G., Y.B. Literature research: XB.Z, G.C. Literature selection: Y.B., PJ.Z. Data acquisition and quality assessment: C.G., S.H. Data statistical analysis： C.G. Manuscript preparation: C.G.; Y.B. Manuscript editing: C.G., Y.B., XB.Z., PJ.Z, S.H., D.F.

Funding
This research was supported by the National Natural Science Foundation of China (grant No. 82101318 to YB).

Data availability
Data is provided within the manuscript or supplementary information files. If you need to go further, data can be made available upon reasonable request to the corresponding author.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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Received: 11 September 2024 Accepted: 3 January 2025
Published online: 08 February 2025

References

1. van Asch CJ, Luitse MJ, Rinkel GJ, van der Tweel I, Algra A, Klijn CJ. Incidence, case fatality, and functional outcome of intracerebral haemorrhage over time, according to age, sex, and ethnic origin: a systematic review and meta-analysis. Lancet Neurol. 2010;9(2):167–76. https://doi.org/10.1016/S1474-4422(09)70340-0.
2. Yeager CE, Garg RK. Advances and future trends in the diagnosis and management of Intracerebral Hemorrhage. Neurol Clin. 2024;42 3:689–703. https://doi.org/10.1016/j.ncl.2024.03.004.
3. Sheth KN. Spontaneous intracerebral hemorrhage. N Engl J Med. 2022;387 17:1589–96. https://doi.org/10.1056/NEJMra2201449.
4. Monteiro GA, Marinheiro G, Mutarelli A, Araujo B, Cavalcante-Neto JF, Batista S, et al. Efficacy and safety of neuroendoscopy surgery versus craniotomy for supratentorial intracerebral hemorrhage: an updated meta-analysis of randomized controlled trials. Neurosurg Rev. 2024;47(1:255). https://doi.org/10.1007/s10143-024-02492-z.
5. Steiner T, Al-Shahi Salman R, Beer R, Christensen H, Cordonnier C, Csiba L, et al. European Stroke Organisation (ESO) guidelines for the management of spontaneous intracerebral hemorrhage. Int J Stroke. 2014;9 7:840–55. https://doi.org/10.1111/ijs.12309.
6. Cao Y, Yu S, Zhang Q, Yu T, Liu Y, Sun Z, et al. Chinese Stroke Association guidelines for clinical management of cerebrovascular disorders: executive summary and 2019 update of clinical management of intracerebral haemorrhage. Stroke Vasc Neurol. 2020;5 4:396–402. https://doi.org/10.1136/svn-2020-000433.
7. Hemphill JC 3rd, Greenberg SM, Anderson CS, Becker K, Bendok BR, Cushman M, et al. Guidelines for the management of spontaneous intracerebral hemorrhage: a Guideline for Healthcare professionals from the American Heart Association/American Stroke Association. Stroke. 2015;46(7):2032–60. https://doi.org/10.1161/str.0000000000000069.
8. Guo G, Pan C, Guo W, Bai S, Nie H, Feng Y, et al. Efficacy and safety of four interventions for spontaneous supratentorial intracerebral hemorrhage: a network meta-analysis. J Neurointerv Surg. 2020;12 6:598–604. https://doi.org/10.1136/neurintsurg-2019-015362.
9. Vespa PM, Martin N, Zuccarello M, Awad I, Hanley DF. Surgical trials in intracerebral hemorrhage. Stroke. 2013;44(6 Suppl 1):S79–82. https://doi.org/10.1161/STROKEAHA.113.001494.
10. Xi G, Keep RF, Hoff JT. Mechanisms of brain injury after intracerebral haemorrhage. Lancet Neurol. 2006;5 1:53–63. https://doi.org/10.1016/S1474-4422(05)70283-0.
11. Mendelow AD, Gregson BA, Fernandes HM, Murray GD, Teasdale GM, Hope DT, et al. Early surgery versus initial conservative treatment in patients with spontaneous supratentorial intracerebral haematomas in the International Surgical Trial in Intracerebral Haemorrhage (STICH): a randomised trial. Lancet (London England). 2005;365(9457):387–97. https://doi.org/10.1016/s0140-6736(05)17826-x.
12. Mendelow AD, Gregson BA, Rowan EN, Murray GD, Gholkar A, Mitchell PM. Early surgery versus initial conservative treatment in patients with spontaneous supratentorial lobar intracerebral haematomas (STICH II): a randomised trial. Lancet (London England). 2013;382 9890:397–408. https://doi.org/10.1016/s0140-6736(13)60986-1.
13. Xu X, Zhang H, Zhang J, Luo M, Wang Q, Zhao Y, et al. Minimally invasive surgeries for spontaneous hypertensive intracerebral hemorrhage (MIS-ICH): a multicenter randomized controlled trial. BMC Med. 2024;22(1):244. https://doi.org/10.1186/s12916-024-03468-y.
14. Lv K, Wang Y, Chao H, Cao S, Cao W. Comparison of the efficacy of Subosseous Window Neuro-Endoscopy and minimally invasive craniotomy in the treatment of basal ganglia hypertensive intracerebral hemorrhage. J Craniofac Surg. 2023;34:8. https://doi.org/10.1097/scs.0000000000009461.
15. Noiphithak R, Yindeedej V, Ratanavinitkul W, Duangprasert G, Nimmannitya P, Yodwisithsak P. Treatment outcomes between endoscopic surgery and conventional craniotomy for spontaneous supratentorial intracerebral hemorrhage: a randomized controlled trial. Neurosurg Rev. 2023;46(1):136. https://doi.org/10.1007/s10143-023-02035-y.
16. Hallenberger TJ, Guzman R, Bonati LH, Greuter L, Soleman J. Endoscopic surgery for spontaneous supratentorial intracerebral haemorrhage: a systematic review and meta-analysis. Front Neurol. 2022;13: 1054106. https://doi.org/10.3389/fneur.2022.1054106.
17. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ (Clinical Res ed). 2021;372: n71. https://doi.org/10.1136/bmj.n71.
18. Cumpston M, Li T, Page MJ, Chandler J, Welch VA, Higgins JP, et al. Updated guidance for trusted systematic reviews: a new edition of the Cochrane Handbook for Systematic Reviews of Interventions. Cochrane Database Syst Rev. 2019;10(10):Ed000142. https://doi.org/10.1002/14651858.Ed000142.
19. Luo D, Wan X, Liu J, Tong T. Optimally estimating the sample mean from the sample size, median, mid-range, and/or mid-quartile range. Stat Methods Med Res. 2018;27 6:1785–805. https://doi.org/10.1177/0962280216669183.
20. Wan X, Wang W, Liu J, Tong T. Estimating the sample mean and standard deviation from the sample size, median, range and/or interquartile range. BMC Med Res Methodol. 2014;14:135. https://doi.org/10.1186/1471-2288-14-135.
21. Kumarapuram S, Elmogazy O, Mokhtari P, Goldstein I, Tayebi Meybodi A. Do overlapping neurosurgical procedures affect patient outcomes? A systematic review and meta-analysis. Neurosurg Rev. 2023;46(1:92). https://doi.org/10.1007/s10143-023-01993-7.
22. Tian B, He Y, Han Z, Liu T, Zhang X. Effect of powdered Vancomycin on stopping surgical site wound infections in neurosurgery: a meta-analysis. Int Wound J. 2023;20 4:1139–50. https://doi.org/10.1111/iwj.13973.
23. Higgins JPT, Thomas J, Chandler J, Miranda C, Tianjing L, Matthew P et al. Cochrane handbook for systematic reviews of interventions version 6.4 (updated August 2023). Available from www.training.cochrane.org/handbook: Cochrane; 2023.
24. Wetterslev J, Jakobsen JC, Gluud C. Trial Sequential Analysis in systematic reviews with meta-analysis. BMC Med Res Methodol. 2017;17 1:39. https://doi.org/10.1186/s12874-017-0315-7.
25. Cucchetti A, Binda C, Dajti E, Sbrancia M, Ercolani G, Fabbri C. Trial sequential analysis of EUS-guided gallbladder drainage versus percutaneous cholecystostomy in patients with acute cholecystitis. Gastrointest Endosc. 2022;95(3):399–406. https://doi.org/10.1016/j.gie.2021.09.028.
26. Claire R, Gluud C, Berlin I, Coleman T, Leonardi-Bee J. Using Trial Sequential Analysis for estimating the sample sizes of further trials: example using smoking cessation intervention. BMC Med Res Methodol. 2020;20(1):284. https://doi.org/10.1186/s12874-020-01169-7.

27. Liu K, Zhang W, Gao L, Bai J, Dong X, Wang Y, et al. Efficacy of hemostatic powder monotherapy versus conventional endoscopic treatment for nonvariceal GI bleeding: a meta-analysis and trial sequential analysis. Gastrointest Endosc. 2024. https://doi.org/10.1016/j.gie.2024.08.042.
28. Gui C, Gao Y, Hu D, Yang X. Neuroendoscopic minimally invasive surgery and small bone window craniotomy hematoma clearance in the treatment of hypertensive cerebral hemorrhage. Pakistan J Med Sci. 2019;35(2):377–82. https://doi.org/10.12669/pjms.35.2.463.
29. Zhang J, Lu S, Wang S, Zhou N, Li G. Comparison and analysis of the efficacy and safety of minimally invasive surgery and craniotomy in the treatment of hypertensive intracerebral hemorrhage. Pakistan J Med Sci. 2018;34(3):578–82. https://doi.org/10.12669/pjms.343.14625.
30. Zhu Y, Su J, Lin S, Liao W, Zhao D, Li L. Clinical, efficacy of neuroendoscopic haematoma removal in patients with acute cerebral haemorrhage with ventricular rupture. Acta Med Mediterranea. 2022;38(5):3107–13. https://doi.org/10.19193/0393-6384_2022_5_458.
31. Hanley DF, Thompson RE, Rosenblum M, Yenokyan G, Lane K, McBee N, et al. Efficacy and safety of minimally invasive surgery with thrombolysis in intracerebral haemorrhage evacuation (MISTIE III): a randomised, controlled, open-label, blinded endpoint phase 3 trial. Lancet (London England). 2019;393(10175):1021–32. https://doi.org/10.1016/s0140-6736(19)30195-3.
32. Greenberg SM, Ziai WC, Cordonnier C, Dowlatshahi D, Francis B, Goldstein JN, et al. 2022 Guideline for the management of patients with spontaneous intracerebral hemorrhage: a Guideline from the American Heart Association/American Stroke Association. Stroke. 2022;53(7):e282–361. https://doi.org/10.1161/str.0000000000000407.
33. Yao Z, Hu X, You C, He M. Effect and feasibility of endoscopic surgery in spontaneous intracerebral hemorrhage: a systematic review and meta-analysis. World Neurosurg. 2018;113:348–56 e2. https://doi.org/10.1016/j.wneu.2018.02.022.
34. Sun G, Fu T, Liu Z, Zhang Y, Chen X, Jin S, et al. The rule of brain hematoma pressure gradient and its influence on hypertensive cerebral hemorrhage operation. Sci Rep. 2021;11(1):4599. https://doi.org/10.1038/s41598-021-84108-w.
35. Zhang Z, Li Z. Application of neuroendoscopic surgery in treatment of hypertensive basal ganglia hemorrhage. Revista De Neurologia. 2022;75 5:109–16. https://doi.org/10.33588/rn.7505.2021445.
36. Lu W, Wang H, Feng K, He B, Jia D. Neuroendoscopic-assisted versus mini-open craniotomy for hypertensive intracerebral hemorrhage: a retrospective analysis. BMC Surg. 2022;22(1:188). https://doi.org/10.1186/s12893-022-01642-8.
37. Cai Q, Zhang H, Zhao D, Yang Z, Hu K, Wang L, et al. Analysis of three surgical treatments for spontaneous supratentorial intracerebral hemorrhage. Medicine. 2017;96 43:e8435. https://doi.org/10.1097/md.0000000000008435.
38. Kobata H, Ikeda N. Recent updates in neurosurgical interventions for spontaneous intracerebral hemorrhage: minimally invasive surgery to improve Surgical Performance. Front Neurol. 2021;12: 703189. https://doi.org/10.3389/fneur.2021.703189.
39. Kishida K, Maruyama D, Kotani S, Murakami N, Hashimoto N. Clinical significance of stiffness during endoscopic surgery for Intracerebral Hemorrhage: a retrospective study. Neurol Med Chir (Tokyo). 2023;63 12:563–70. https://doi.org/10.2176/jns-nmc.2023-0043.

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