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Original Article

Efficacy and Safety of Neuroendoscopic Surgery versus Craniotomy for Supratentorial Spontaneous Intracerebral Hemorrhage: A Systematic Review and Meta-analysis of Randomized Controlled Trials

Biwu Wu[1,2,3,4,5], Haoyue Yuan[1,2,3,4,5], Qiang Yuan[2,3,4,5,6], Gang Wu[2,3,4,5,6] and Jin Hu[2,3,4,5,6*]

[1]Department of Neurosurgical Intensive Care Unit, Huashan Hospital, Fudan University, Shanghai, China; [2]National Center for Neurological Disorders, Shanghai, China; [3]Shanghai Key Laboratory of Brain Function Restoration and Neural Regeneration, Shanghai, China; [4]Neurosurgical Institute of Fudan University, Shanghai, China; [5]Shanghai Clinical Medical Center of Neurosurgery, Shanghai, China; [6]Department of Neurosurgery, Huashan Hospital, Fudan University, Shanghai, China

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Abstract

Background and objectives: Surgical management of supratentorial spontaneous intracerebral hemorrhage (sICH) remains controversial. Craniotomy (CT) reduces mortality but offers limited functional benefits. Neuroendoscopic surgery (NE) has emerged as a viable alternative, providing improved outcomes. Recent randomized controlled trials (RCTs) strengthen ongoing comparisons between these approaches. This meta-analysis systematically evaluates the efficacy and safety of NE versus CT for supratentorial sICH.

Methods: RCTs comparing NE versus CT for supratentorial sICH were systematically identified through comprehensive searches of PubMed, Embase, Cochrane Library, and Web of Science databases. Evaluated outcomes included functional outcome (favorable or unfavorable), hematoma evacuation rate, mortality, intraoperative blood loss, operation time, rebleeding, infection (including pulmonary and intracranial), and total complications. Cochrane's Risk of Bias-2 tool was employed to assess the risk of bias across the included studies.

Results: Eight RCTs were included, comprising 1,354 patients. NE demonstrated a significant advantage in achieving a favorable functional outcome (risk ratio: 1.43; 95% confidence interval (CI) 1.22, 1.68; $p < 0.001$) and a notably higher hematoma evacuation rate (mean difference (MD): 7.60; 95% CI 3.59, 11.61; $p < 0.001$). Additionally, NE was associated with a marked reduction in intraoperative blood loss (MD: −152.95; 95% CI −261.68, −44.22; $p = 0.006$) and a substantial reduction in operative time (MD: −118.49; 95% CI −147.30, −89.67; $p < 0.001$). The incidences of unfavorable functional outcome and total complications, including pulmonary infection, were significantly lower in the NE group. However, NE did not lead to an improvement in the mortality rate, and there were no significant differences in the incidences of postoperative rebleeding or intracranial infection between the two groups.

Conclusions: These findings suggest that NE offers distinct advantages in terms of functional outcomes and surgical efficiency for patients with supratentorial sICH. Future studies should involve larger, higher-quality RCTs, and neuroendoscopic techniques should be continuously optimized.

Keywords: Neuroendoscopic surgery; Neuroendoscopy; Craniotomy; Intracerebral hemorrhage; Functional outcome; Meta-analysis.

***Correspondence to:** Jin Hu, Department of Neurosurgery, Huashan Hospital, Fudan University; National Center for Neurological Disorders; Shanghai Key Laboratory of Brain Function Restoration and Neural Regeneration; Neurosurgical Institute of Fudan University; Shanghai Clinical Medical Center of Neurosurgery, Shanghai 201107, China. ORCID: https://orcid.org/0000-0002-0504-960X. Tel: +86-021-54602470, E-mail: hujin@fudan.edu.cn

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Introduction

Spontaneous intracerebral hemorrhage (sICH) is characterized by high incidence, fatality, and disability rates.[1] Annually, around 3.5

million new cases occur globally, accounting for 20–30% of all acute strokes.[2] It represents the most lethal form of acute stroke, with a mortality rate significantly higher than that of ischemic stroke. From 1990 to 2019, sICH rose from the 9th leading cause of premature death to the 4th, and in 2019, an estimated three million people died from it.[3] Survivors often face poor functional prognosis, placing a burden on society and the economy.

Surgically removing hematoma seems beneficial, as it reduces the mass effect, perilesional edema, and toxic substances from hematoma decomposition.[4] Craniotomy (CT), long regarded as the traditional surgical option, offers a larger operative field for better control in complex cases.[4] However, previous studies have shown that, compared with medical treatment, CT increases the survival rate but does not demonstrate an advantage in improving neurological function.[5,6] With the advancement of minimally invasive techniques, new alternatives have emerged. Neuroendoscopic (NE) surgery is one such technique, aimed at achieving rapid clot removal with better access and less damage to surrounding brain tissues.[7]

Despite extensive exploration of the efficacy of surgery for supratentorial sICH in numerous randomized controlled trials (RCTs) and meta-analyses, the prognosis varies significantly among different procedures.[5,6,8–10] A previous meta-analysis demonstrated that NE (risk ratio (RR): 2.21; 95% confidence interval (CI) 1.37, 3.55) was significantly associated with a higher rate of good functional outcome, whereas CT did not show a significant difference (RR: 1.07; 95% CI 0.84, 1.37).[11] However, a subsequent meta-analysis failed to confirm the superiority of NE over CT in terms of functional outcome or mortality (RR: 2.13; 95% CI 0.01, 737; RR: 0.42; 95% CI 0.17, 1.05).[12] New studies continue to emerge, notably a recent RCT named MISICH by Xu *et al*.,[13] which has the largest sample size comparing NE and CT to date, but it has not yet been incorporated into existing meta-analyses. Therefore, a fresh comprehensive meta-analysis is urgently needed. This new analysis will integrate updated RCTs to assess the efficacy and safety of the two approaches in functional outcomes for patients with sICH, providing more reliable evidence-based support for surgical decision-making.

Materials and methods

Literature search

Two independent reviewers (BW and HY) conducted a highly systematic search from the inception of the databases up to January 31, 2025. Prominent databases, including PubMed, Cochrane Library, Embase, and Web of Science, were meticulously examined. The search strategy incorporated specific terms such as "Cerebral hemorrhage," "Intracerebral hemorrhage," "Intracranial hemorrhage," "Hypertensive intracerebral hemorrhage," "Neuroendoscopy," "Endoscopy," "Craniotomy," "Random," and "Randomized." To ensure thorough and accurate retrieval of relevant literature, a multifaceted approach was adopted, involving searches using Medical Subject Headings terms, free-text searches, and database-specific adjustments to the search terms (Appendix 1). The goal was to establish a solid evidence base for subsequent analysis. This study adhered to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) guidelines and was not registered in the PROSPERO database.[14]

Eligibility criteria

This meta-analysis included only English-language RCTs comparing NE with CT for spontaneous supratentorial ICH. Participants were required to be ≥18 years of age and suffering from lobar, basal ganglia, internal capsule, or thalamus hemorrhage, with or without concomitant intraventricular hemorrhage. The included studies were required to report at least one of the following outcomes: (1) functional outcomes (favorable or unfavorable); (2) hematoma evacuation rate; (3) mortality; (4) intraoperative blood loss; (5) operation time; (6) complications. We excluded non-randomized studies, those without surgical intervention data, and studies on ICH resulting from trauma, brain tumors, or vascular malformations.

Primary and secondary outcomes

The primary outcomes were: (1) favorable functional outcome; (2) hematoma evacuation rate. Secondary outcomes included unfavorable functional outcome, mortality, intraoperative blood loss, operation time, rebleeding, infection (including pulmonary and intracranial), and total complications such as rebleeding, infection, gastric ulcer, epilepsy, and revision surgery. A favorable functional outcome was defined as the ability to perform daily activities either independently or with minimal support. In the reviewed studies, this was typically defined by the following scores: 0–2 or 0–3 on the modified Rankin Scale (mRS), 4–5 on the Glasgow Outcome Scale, and 1–3 on the Activities of Daily Living.

Data extraction and quality assessment

Data were extracted separately by two researchers (BW and HY). Any discrepancies were resolved through discussion with a third author (GW). The data extracted encompassed the following aspects: (1) fundamental details of the included studies, such as the initial author, publication year, region, scale scores used to define favorable functional outcomes, and follow-up time; (2) demographic characteristics, including sample size, gender distribution, age range, prevalence of hypertension, preoperative Glasgow Coma Scale score, hematoma location, preoperative hematoma volume, and time to surgery; (3) data on both primary and secondary outcomes. Two researchers (BW and QY) independently assessed the methodological quality and risk of bias using the Cochrane Collaboration Risk of Bias-2 tool for RCTs.[15] When discrepant results occurred, the third author (GW) reached the final decision after discussions with the entire team.

Statistical analysis

Review Manager (Version 5.4.1, The Cochrane Collaboration, 2020) was used for the meta-analysis of the extracted data. RR and mean difference (MD) were used to report dichotomous and continuous outcome variables, respectively, with 95% CIs. For effect sizes, p-values less than 0.05 were considered statistically significant. The Cochran Q test and I^2 statistics were employed to evaluate heterogeneity. All meta-analyses were performed using random-effects models (DerSimonian-Laird method) to account for clinical heterogeneity (e.g., hematoma location, Glasgow Coma Scale score, time to surgery, and methods used to evaluate functional outcomes).

Sensitivity analysis was conducted using the leave-one-out method to assess the robustness of the results. Funnel plot analysis was employed to explore potential publication bias.

Results

Literature search and study characteristics

An initial search yielded a total of 1,664 articles. After removing duplicate records and screening titles and abstracts, 16 articles

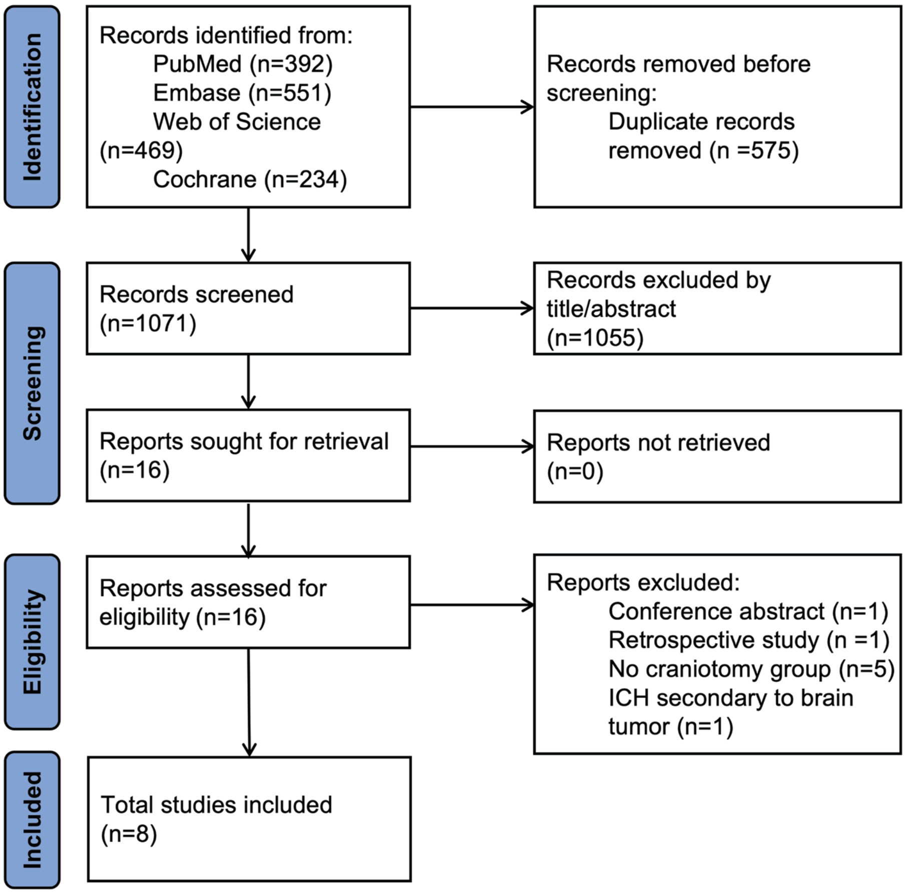

Fig. 1. Study selection process presented in the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) flow diagram. ICH, intracerebral hemorrhage.

that met the inclusion criteria were retained for in-depth review. Ultimately, eight studies were included in the meta-analysis (Fig. 1).[13,16–22] These studies were primarily from China (7/8) and included 1,354 patients, with 669 (49.4%) patients undergoing NE and 685 (50.6%) undergoing CT. The mean age of the patients was 57.06 years. The most frequently reported hematoma location was the basal ganglia. Table 1 shows the baseline characteristics of the included studies.[13,16–22]

Quality assessment and publication bias

Six studies identified risks of bias primarily related to randomization issues, intervention deviations, and selective reporting.[16–21] In contrast, the other two studies were deemed to have a low risk of bias (Fig. 2).[22] Publication bias was assessed for both the primary and secondary outcomes. Visual inspection of the funnel plot for all endpoints suggested near symmetry, indicating limited publication bias (Fig. S1).

Primary outcomes

Seven studies reported data on favorable functional outcomes.[13,17–22] In the NE group, 50.7% (324/639) of patients achieved a good outcome, compared with 35.1% (230/655) in the CT group. The NE procedure was significantly more effective than CT in improving functional outcomes (RR: 1.43; 95% CI 1.22, 1.68; $p < 0.001$; $I^2 = 40\%$; Fig. 3). In the leave-one-out analysis, the results remained robust, regardless of which individual study was excluded (Fig. S2).

The hematoma evacuation rate was reported by seven studies, involving 1,154 patients.[13,16–21] The heterogeneity among these studies was significant. However, the hematoma evacuation rate was notably higher for the NE approach than for CT (MD: 7.60; 95% CI 3.59, 11.61; $p < 0.001$; $I^2 = 94\%$; Fig. 4). The leave-one-out analysis confirmed that NE maintained an advantage over CT in terms of hematoma clearance (Fig. S3).

Secondary outcomes

For the analysis of unfavorable functional outcomes, six studies were included, comprising 1,243 patients.[13,18–22] The pooled RR was 0.69 (95% CI 0.52, 0.91; $p = 0.009$; $I^2 = 67\%$; Fig. 5), suggesting that CT was associated with more functional disability, and NE was superior to CT in terms of functional recovery. The leave-one-out analysis confirmed the robustness of this result (Fig. S4).

Seven studies were included in the mortality analysis.[13,16–18,20–22] In the NE group, the mortality rate was 10.7% (65/604), whereas in the CT group, it was 12.4% (77/620). However, NE did not show any superiority in reducing mortality (RR: 0.91; 95% CI 0.66, 1.24; $p = 0.54$; $I^2 = 0\%$; Fig. 5). The leave-one-out analysis also showed no significant difference, with low heterogeneity (Fig. S4).

Intraoperative blood loss was reported by five studies,[13,18–21] and operative time was reported by seven studies.[13,16–21] NE was

Table 1. Baseline characteristics of the included studies

Study	Region	Sample size NE/CT	Male NE/CT	Age (years) NE/CT	Fol-low-up	Location	Hyper-ten-sion (%) NE/CT	Preoperative GCS NE/CT	Preoperative hematoma volume (ml) NE/CT	Time to sur-gery (hours) NE/CT	Func-tional out-comes	Favorable functional outcome definition
Cho 2006[16]	Taiwan, China	30/30	19/21	56.67 ± 8.66/54.22 ± 10.47	6m	basal ganglia	75/80	9.26 ± 1.22/9.32 ± 1.03	55.48 ± 23.2/42.11 ± 18.43	1.12 ± 0.77/1.11 ± 0.74[&]	FIM/BI/MP	NR
Feng 2016[18]	China	93/91	56/58	66.35 ± 12.23/69.10 ± 10.26	6m	subcorticalbasal ganglia internal capsule	100/100	NR	NR	NR	ADL	Grade I–III
Gui 2019[20]	China	63/63	39/36	54.02 ± 3.74/52.33 ± 3.41	3m	supratentorial	100/100	6.01 ± 0.64/6.35 ± 0.71	52.39 ± 3.64/NR	NR	NDS/ADL	4 or 5 points
Lv 2023[21]	China	58/70	37/48	56.74 ± 13.69/54.76 ± 12.62	6m	basal ganglia	NR	7.48 ± 2.12/6.96 ± 2.49	31.35 ± 6.40/30.09 ± 5.54	10.64 ± 6.04/12.23 ± 8.01[#]	mRS	mRS 0–2
Noiphithak 2023[22]	Thailand	100/100	68/62	51(18)/50(14)[*]	6m	basal ganglia thalamus cerebral lobar	43/45	10(4)/10(6)[*]	50.1(33)/49.3(28.9)[*]	6.8(2)/6.6(2.5)[*#]	mRS	mRS 0–3
Xu 2024[13]	China	239/236	166/160	56.6 ± 11.0/55.8 ± 11.8	6m	basal ganglia lobar thalamus	NR	9.0 ± 3.1/8.9 ± 3.0	49.1 ± 20.3/49.9 ± 17.6	18(19)/17(20)[*#]	mRS	mRS 0–2
Zhang 2014[17]	China	21/30	16/22	59.90 ± 12.85/61.45 ± 9.25	6m	basal ganglia	76/73	9.19 ± 3.76/8.37 ± 2.39	58.28 ± 18.8/62.16 ± 15.62	42%/33% patients within 12 h[#]	mRS/GOS	mRS 0–3, GOS 4–5
Zhang 2018[19]	China	65/65	NR	NR	3m	lobar basal ganglia	NR	NR	39.07 ± 6.17/39.03 ± 6.14	NR	GOS/BI/mRS/SSS	GOS of Grade IV–V

Data are presented as Mean ± SD, or [*]median (IQR). [&]Time between admission to the emergency department and surgery. [#]Time from ictus to surgery. ADL, activities of daily living; BI, Barthel index score; CT, craniotomy; FIM, functional independence measure score; GOS, glasgow Outcome Scale; IQR, interquartile range; MP, muscle power; mRS, modifed Rankin scale; NDS, nerve deficiency scale; NE, neuroendoscopic surgery; NR, not reported; SD, standard deviation; SSS, Scandinavian Stroke Scale.

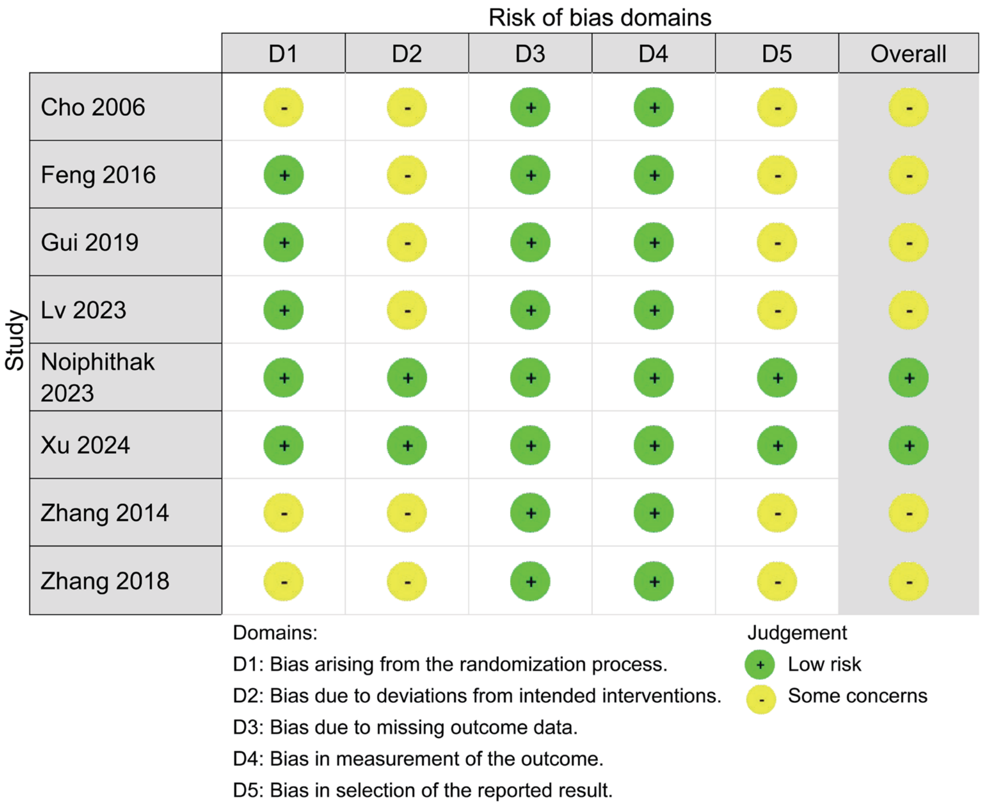

Fig. 2. Risk of bias assessment with RoB-2.

Study or Subgroup	Neuroendoscopy Events	Neuroendoscopy Total	Craniotomy Events	Craniotomy Total	Weight	Risk Ratio M-H, Random, 95% CI
Feng 2016	60	93	39	91	17.1%	1.51 [1.14, 1.99]
Gui 2019	39	63	26	63	13.0%	1.50 [1.05, 2.13]
Lv 2023	36	58	42	70	17.4%	1.03 [0.78, 1.37]
Noiphithak 2023	46	100	33	100	13.1%	1.39 [0.98, 1.98]
Xu 2024	73	239	47	236	14.8%	1.53 [1.11, 2.11]
Zhang 2014	11	21	4	30	2.3%	3.93 [1.45, 10.67]
Zhang 2018	59	65	39	65	22.3%	1.51 [1.22, 1.87]
Total (95% CI)		**639**		**655**	**100.0%**	**1.43 [1.22, 1.68]**
Total events	324		230			

Heterogeneity: $Tau^2 = 0.02$; $Chi^2 = 9.94$, df = 6 (P = 0.13); $I^2 = 40\%$
Test for overall effect: Z = 4.49 (P < 0.00001)

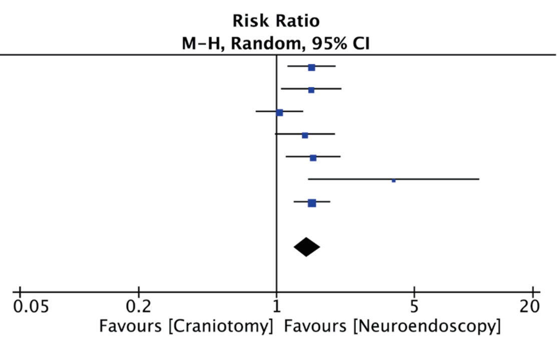

Fig. 3. Forest plot comparing the risk ratio (RR) of favorable functional outcome between neuroendoscopic surgery and craniotomy. CI, confidence interval.

Study or Subgroup	Neuroendoscopy Mean	Neuroendoscopy SD	Neuroendoscopy Total	Craniotomy Mean	Craniotomy SD	Craniotomy Total	Weight	Mean Difference IV, Random, 95% CI
Cho 2006	87	8	30	75	2	30	14.7%	12.00 [9.05, 14.95]
Feng 2016	83.52	27.51	93	77.25	13.44	91	11.5%	6.27 [0.03, 12.51]
Gui 2019	92.31	8.52	63	78.23	7.74	63	14.8%	14.08 [11.24, 16.92]
Lv 2023	94.16	1.86	58	90.87	1.89	70	15.9%	3.29 [2.64, 3.94]
Xu 2024	88.3	20.8	239	86.5	17.9	236	14.2%	1.80 [−1.69, 5.29]
Zhang 2014	90.11	7.27	21	85.37	6.78	30	13.8%	4.74 [0.80, 8.68]
Zhang 2018	83.43	4.67	65	72.78	9.35	65	15.0%	10.65 [8.11, 13.19]
Total (95% CI)			**569**			**585**	**100.0%**	**7.60 [3.59, 11.61]**

Heterogeneity: $Tau^2 = 26.25$; $Chi^2 = 106.81$, df = 6 (P < 0.00001); $I^2 = 94\%$
Test for overall effect: Z = 3.71 (P = 0.0002)

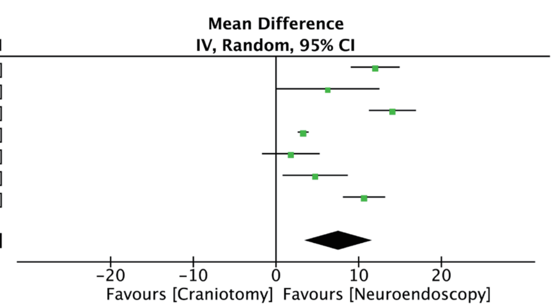

Fig. 4. Forest plot comparing the mean difference (MD) of hematoma evacuation rate between neuroendoscopic surgery and craniotomy. CI, confidence interval; SD, standard deviation.

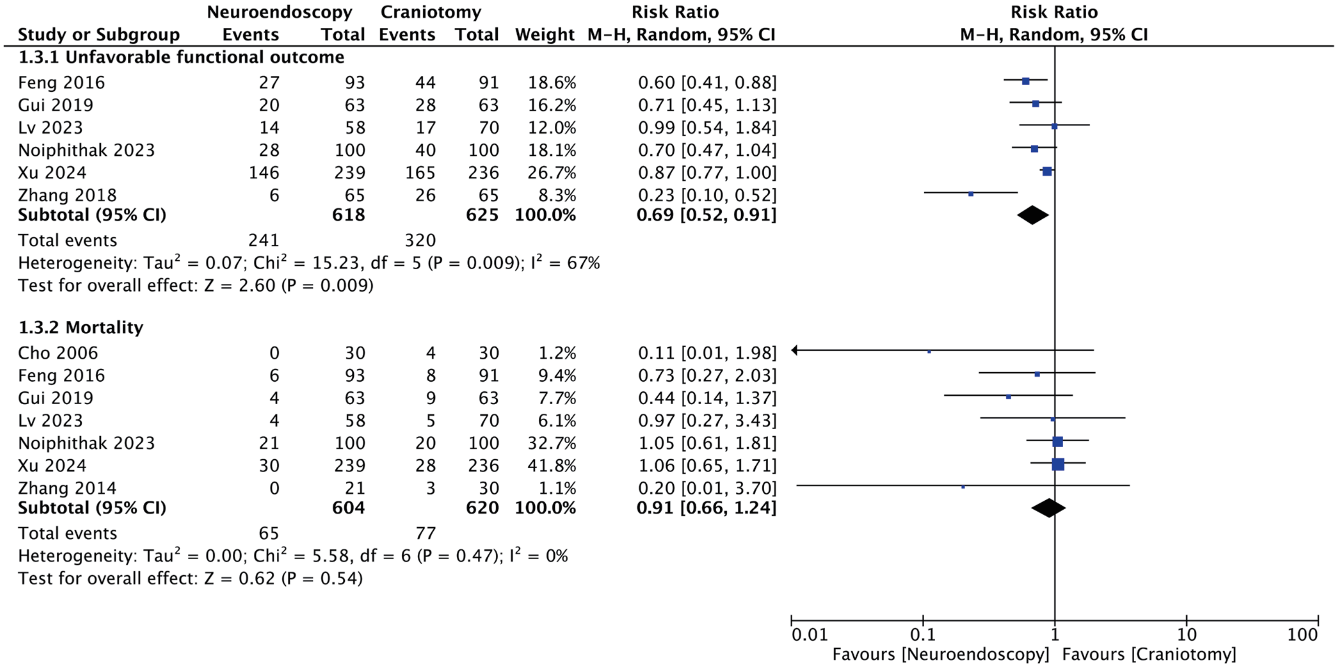

Fig. 5. Forest plot shows the risk ratio (RR) comparison for the unfavorable functional outcome (1.3.1) and mortality (1.3.2) between neuroendoscopic surgery and craniotomy. CI, confidence interval.

associated with significantly lower blood loss (MD: −152.95; 95% CI −261.68, −44.22; $p = 0.006$; $I^2 = 99\%$; Fig. 6) and shorter operative time (MD: −118.49; 95% CI −147.30, −89.67; $p < 0.001$; $I^2 = 97\%$; Fig. 6) compared with CT. Despite conducting the leave-one-out analysis, heterogeneity in intraoperative blood loss and operative time remained significantly high (Fig. S5).

Seven studies reported data on complications, including rebleeding, pulmonary infection, intracranial infection, revision surgery, digestive tract ulcers, and epilepsy.[13,16–18,20–22] The results showed that the total complication rate in the NE group was significantly lower than in the CT group (RR: 0.58; 95% CI 0.39, 0.87; $p = 0.008$; $I^2 = 68\%$; Fig. 7). In the leave-one-out analysis, significant differences were observed, except when excluding Feng *et al.*[18] (Fig. S6). Furthermore, when analyzing rebleeding (RR: 0.63; 95% CI 0.33, 1.22; $p = 0.17$; $I^2 = 0\%$), pulmonary infection (RR: 0.59; 95% CI 0.37, 0.93; $p = 0.02$; $I^2 = 51\%$), and intracranial infection (RR: 0.74; 95% CI 0.39, 1.40; $p = 0.36$; $I^2 = 0\%$) separately, a significant difference was found in pulmonary infection between NE and CT, but no differences were found for the other two (Fig. 7). The leave-one-out analysis maintained these results (Fig. S6).

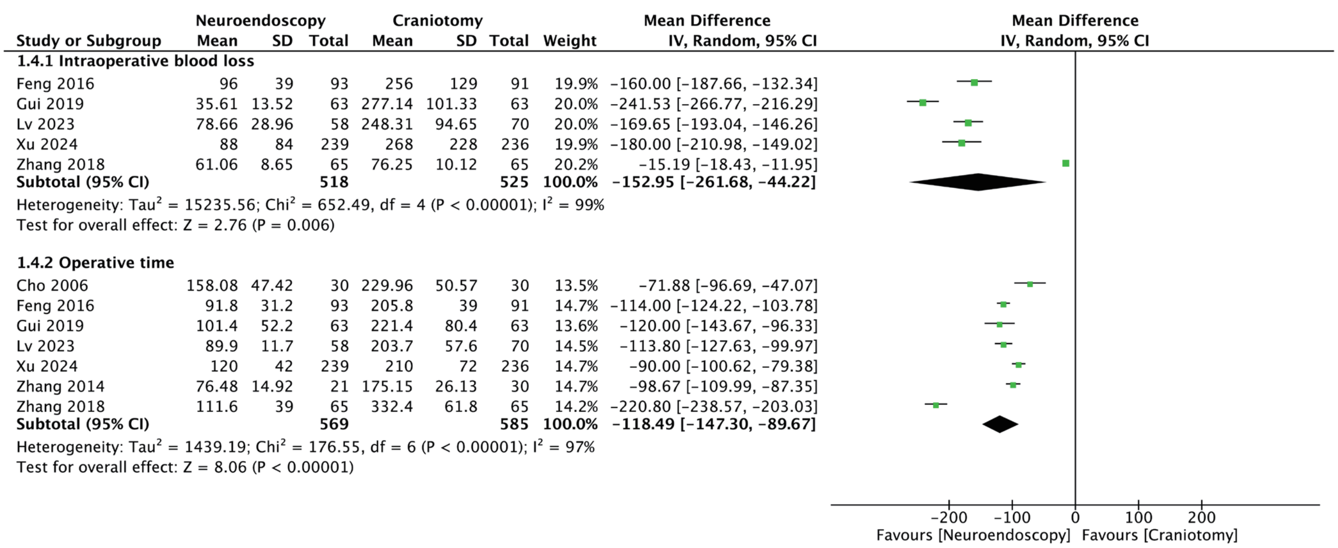

Fig. 6. Forest plot shows the mean difference (MD) comparison for intraoperative blood loss (1.4.1) and operative time (1.4.2) between neuroendoscopic surgery and craniotomy. CI, confidence interval; SD, standard deviation.

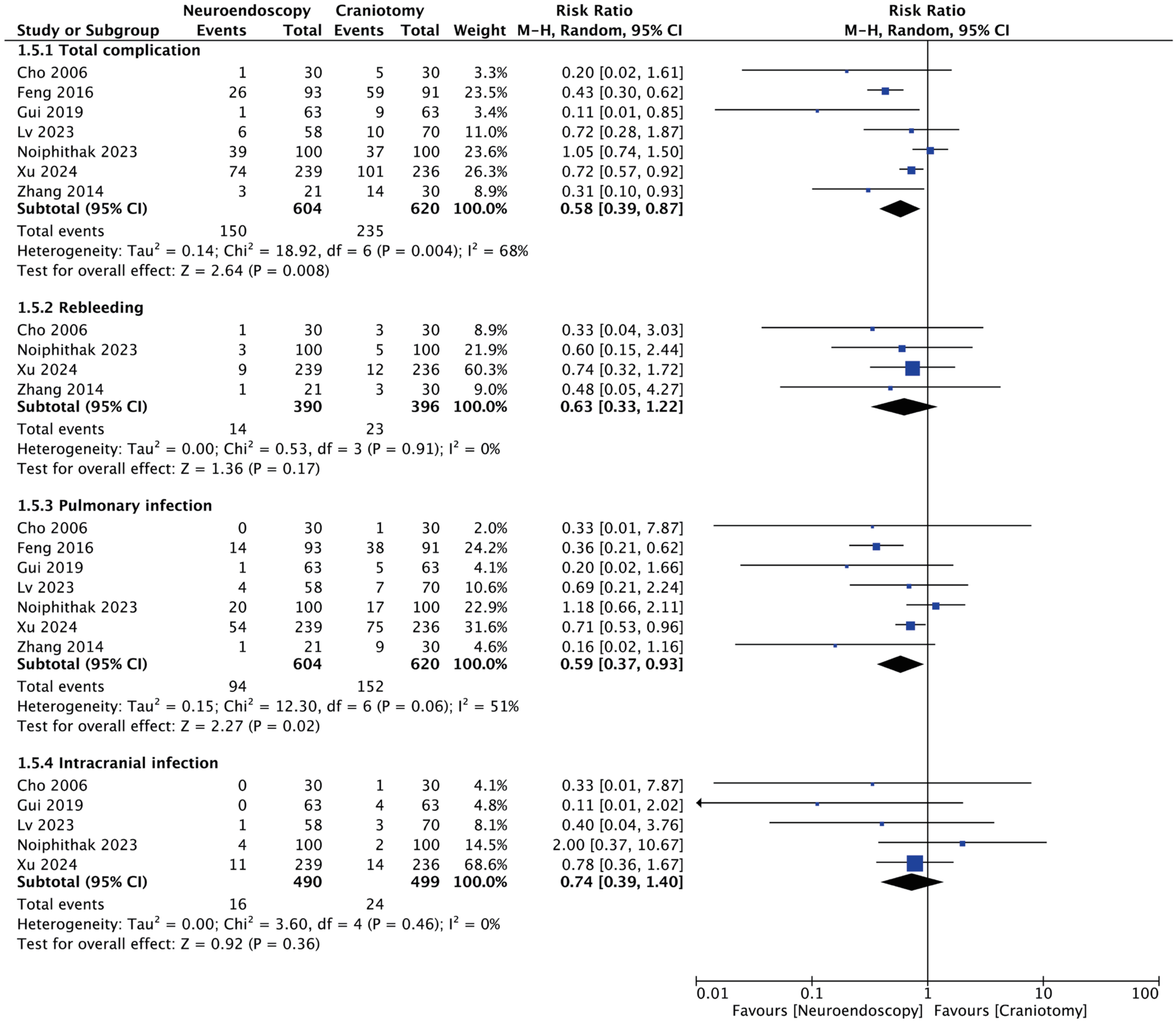

Fig. 7. Forest plot comparing the risk ratio (RR) of total complication (1.5.1), rebleeding (1.5.2), pulmonary infection (1.5.3), and intracranial infection (1.5.4) between neuroendoscopic surgery and craniotomy. CI, confidence interval.

Discussion

To our knowledge, this meta-analysis is the most up-to-date synthesis of all published RCTs comparing NE and CT in treating supratentorial sICH. Ultimately, eight RCTs were included, comprising 1,345 patients.[13,16–22] The combined analysis demonstrated that NE resulted in favorable functional outcomes, with a higher hematoma evacuation rate, less intraoperative blood loss, and a shorter operative time. NE also reduced the total complication rate and the risk of pulmonary infection. However, NE did not show an advantage in reducing mortality, postoperative rebleeding, or intracranial infection.

Traditional craniotomy has shown an improved survival rate compared with medical treatment, yet it fails to improve neurological function, as indicated by the STICH I and STICH II trials.[5,6] In recent years, there has been a paradigm shift in the evacuation of ICH towards minimally invasive surgery (MIS),[23] which can be categorized into three main techniques[24]: 1) Small Stereotactic Craniotomy and Cannulation, used in the ENRICH trial,[25] 2) Stereotactic Endoscopic ICH Evacuation under Blood Water Aspiration, employed in the MISICH trial,[13] and 3) Aspiration with Drainage and Irrigation with Thrombolysis Agent Injection, utilized in the MISTIE III trial.[8] However, the question remains whether MIS can truly improve functional outcomes in clinical practice. While the MISTIE III trial demonstrated reduced mortality and major complication rates with MIS-thrombolysis combination therapy, it failed to improve neurological outcomes.[8] Conversely, the ENRICH trial showed significant 180-day functional improvement for supratentorial lobar hemorrhage patients treated with MIS hematoma evacuation plus guideline-based medical therapy within 24 h of onset.[25] The prospective RICH-trend study validated the safety and efficacy of endoscopic evacuation in Japanese sICH patients, reporting >90% hematoma removal, <10 mL residual volume, and

35.8% favorable functional outcomes at 180 days when performed by specialized surgeons.[26] The multi-center MISICH study further confirmed the superiority of endoscopic and aspiration techniques over craniotomy in hematoma evacuation efficiency, operative time, hospitalization duration, treatment costs, and functional outcomes for supratentorial sICH.[13] These findings highlight the substantial potential of NE in the management of sICH.

Our meta-analysis showed that NE was significantly superior to CT in improving functional outcomes (RR: 1.43; 95% CI 1.22, 1.68; $p < 0.001$). During NE surgery, precise operations can be performed under direct vision, which more effectively removes hematoma and reduces damage to surrounding healthy brain tissue, creating favorable conditions for neurological recovery.[27] Zhang *et al*.[19] reported that at four weeks post-operation, the BI and SSS scores in the NE group were significantly higher than those in the CT group, while the mRS score was significantly lower. Noiphithak *et al*.[22] found that the proportion of patients with a good functional outcome (mRS 0–3) at the 180-day follow-up was significantly higher in the NE group. Cho *et al*.[16] confirmed that the FIM and BI scores of the NE group were significantly better than those of the CT group. However, another meta-analysis by Hallenberger *et al*.[12] reported no significant difference in favorable functional outcomes between NE and CT. This discrepancy was primarily attributed to the inclusion of only two RCTs in their study, where the limited sample size (NE = 114, CT = 121) compromised statistical power.

The rate of hematoma evacuation is one of the pivotal indicators for assessing surgical efficacy. This meta-analysis demonstrated that NE had a distinct superiority in evacuating hematoma (MD: 7.60; 95% CI 3.59, 11.61; $p < 0.001$). Lv *et al*.[21] reported that the proportion of hematoma cleared in the NE group reached 94.16% ± 1.86%, which was markedly higher than the 90.87% ± 1.89% in the CT group. Gui *et al*.[20] reported similar findings, with the percentage of hematoma removal in the NE group soaring to 92.31% ± 8.52%, while the CT group achieved only 78.23% ± 7.74%. Nagasaka *et al*.[28] indicated that NE not only achieved a high level of hematoma evacuation but also exerted better early recovery effects. With the good illumination and multi-angle vision provided by the endoscope, NE surgery can remove hematoma more thoroughly, especially for deep-seated hematomas, where the advantage is even more significant.

NE also performs well in terms of surgical safety. Pooled analysis showed that NE resulted in significantly less intraoperative blood loss (MD: −152.95; 95% CI −261.68, −44.22; $p = 0.006$) and a much shorter operative time (MD: −118.49; 95% CI −147.30, −89.67; $p < 0.001$). For instance, Zhang *et al*.[17] discovered that the operation time in the NE group was 76.48 ± 14.92 m, substantially shorter than the 175.15 ± 26.13 m in the CT group, and Gui *et al*.[20] revealed that intraoperative blood loss in the NE group was just 35.61 ± 13.52 mL, far lower than the 277.14 ± 101.33 mL in the CT group. Feng *et al*.[18] reached a similar conclusion after studying 184 elderly hypertensive ICH patients, finding that compared to the CT group, both anesthesia time and blood loss were significantly reduced in the endoscopic-assisted keyhole technique group. Shorter operative time and less intraoperative blood loss not only mitigate surgical risks but also reduce the incidence of postoperative complications. Moreover, the total complication rate in the NE group was significantly lower (RR: 0.58; 95% CI 0.39, 0.87; $p = 0.008$), with a particularly notable difference in pulmonary infection (RR: 0.59; 95% CI 0.37, 0.93; $p < 0.001$). This may be attributed to the minimally invasive nature of NE surgery.

However, when it comes to reducing mortality, NE did not demonstrate a significant advantage over CT (RR: 0.91; 95% CI 0.66, 1.24; $p = 0.54$), which is consistent with the findings of Hallenberger *et al*.[12] (RR: 0.42; 95% CI 0.17, 1.05). Multiple factors may account for this outcome. First, patient mortality in sICH is influenced by numerous elements, including pre-existing conditions, bleeding site, and bleeding volume. The surgical method represents only one of these factors. Second, although NE surgery minimizes trauma and complications, it may not be able to fully alter the prognosis for critically ill patients.

This study has some limitations. First, while this meta-analysis included the latest RCTs, the overall number of studies was small, and the sample size was limited. Second, some of the included studies had a risk of bias, which may have affected the accuracy of the results. Third, the included studies exhibited a high degree of heterogeneity, especially in indicators such as the hematoma evacuation rate, intraoperative blood loss, and operative time, which may have impacted the accuracy and reliability of the results. Additionally, this study had a geographical limitation, as all the included studies were from Asia, particularly China, which restricts the generalizability of the results.

Conclusions

NE is superior in terms of favorable functional outcomes, hematoma evacuation rate, intraoperative blood loss, operation time, and total complications. However, NE does not show significant advantages in reducing mortality, postoperative rebleeding, or intracranial infection. Future research should focus on high-quality studies to further verify and improve these conclusions, providing more accurate and effective guidance for clinical treatment.

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Conflict of interest

The corresponding author, Jin Hu, is an Executive Associate Editor of the journal *Neurosurgical Subspecialties*. The other authors declare no personal, financial, or institutional interests in any drugs, materials, or devices described in this article.

Author contributions

Study concept and design (BW, JH), acquisition of data (HY, QY, GW), analysis and interpretation of data (BW), drafting of the manuscript (BW, QY), critical revision of the manuscript for important intellectual content (BW, GW, JH), administrative, technical, or material support (BW, HY, QY), and study supervision (GW, JH). All authors have made significant contributions to this study and have approved the final manuscript.

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