Systematic Review

Spontaneous ICH Evacuation Techniques and Traits: A Systematic Review of Literature and Meta-analysis

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Abstract

Background: Spontaneous intracerebral hemorrhage (ICH) is the second most common subtype of stroke and remains a leading cause of death and disability worldwide. Despite advances in medical management, mortality rates range from 30%–50% at one month, and fewer than 40% of survivors regain functional independence. Surgical evacuation of the hematoma has been proposed to mitigate secondary brain injury, reduce perihematomal edema, and lower intracranial pressure, yet the optimal technique and timing remain debated. The objective is to systematically evaluate and quantitatively synthesize evidence on surgical techniques for spontaneous ICH evacuation including conventional craniotomy (CC), minimally invasive puncture surgery (MIPS), and endoscopic surgery (ES) versus conservative medical treatment (CMT), with a follow-up window of 12 months. **Material and Methods:** Databases searched included PubMed/MEDLINE, Scopus, Cochrane Library, Embase, and Google Scholar for studies published from January 2020 to December 2025. Randomized controlled trials (RCTs), prospective cohort studies, and network meta-analyses reporting functional outcomes (modified Rankin Scale [mRS] ≤2–3), mortality, or hematoma evacuation rate were included. Two independent reviewers performed screening and data extraction. Risk of bias was assessed using the Cochrane Risk of Bias Tool 2.0 and Newcastle–Ottawa Scale. Pooled estimates were calculated using a random-effects model (DerSimonian–Laird). Heterogeneity was assessed with the I^2 statistic. Publication bias was evaluated via funnel plot asymmetry and Egger's test. **Results:** Thirty-one studies (n = 6,448 patients) were eligible for meta-analysis. Compared with CMT, any surgical intervention significantly improved good functional outcome (RR 1.31, 95% CI 1.13–1.52; I^2 = 36%) and reduced 6-month mortality (RR 0.82, 95% CI 0.71–0.95; I^2 = 14%). ES demonstrated the greatest benefit for functional outcome (RR 1.51, 95% CI 1.18–1.93) and mortality reduction (RR 0.66, 95% CI 0.52–0.85). MIPS was comparable to ES for functional improvement (RR 1.48, 95% CI 1.24–1.76) and significantly reduced pulmonary infection risk (RR 0.35, 95% CI 0.20–0.60). ES achieved greater hematoma evacuation than CC (MD +7.03%, 95% CI 3.42–10.65; I^2 = 94%). Surgery within 24 hours showed moderate-certainty benefit. Decompressive craniectomy (DC) with hematoma removal did not show significant functional benefit. **Conclusion:** Moderate-certainty evidence supports the use of minimally invasive surgical techniques particularly ES and MIPS over CMT and conventional craniotomy in appropriately selected patients with spontaneous supratentorial ICH. Early surgery (<24 hours) appears to maximize benefit. Future high-quality RCTs should evaluate patient-specific technique selection and AI-guided surgical planning.

Keywords: Intracerebral hemorrhage; Minimally invasive surgery; Endoscopic evacuation; Hematoma; Craniotomy; Systematic review.

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Introduction

Spontaneous intracerebral hemorrhage (ICH) accounts for approximately 10%–15% of all strokes globally and is disproportionately prevalent in low- and middle-income countries, including South and Southeast Asia. With a global annual incidence of approximately 2–3 million cases and a 30-day case fatality rate exceeding 40%, ICH represents one of the most devastating neurological emergencies. [1,2] Unlike ischemic stroke, effective pharmacological therapies for ICH remain limited, placing the burden of management on neurocritical care, blood pressure control, and increasingly surgical intervention. [3,4]

The pathophysiology of ICH-related injury involves both the primary mechanical destruction of brain tissue at the moment of hemorrhage and a cascade of secondary injuries, including perihematomal edema (PHE), inflammatory activation, blood–brain barrier disruption, and herniation. The accumulation of hemoglobin breakdown products such as thrombin, iron, and complement fragments exacerbates cytotoxic edema in the hours to days following ictus. Hematoma volume and expansion have been consistently identified as the strongest predictors of mortality and functional outcome.[5]

Neurosurgery has undergone a paradigm shift under the influence of leaders such as M. Gazi Yaşargil (Father of Modern Neurosurgery, 1925–2025), whose microsurgical philosophy fundamentally transformed approaches to intracranial pathology.

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In the context of ICH, this evolution is manifested in a gradual transition from highly invasive conventional craniotomy with brain retraction toward minimally invasive techniques that aim to evacuate the clot while minimizing collateral damage to eloquent neural tissue.

Rationale: Despite numerous randomized controlled trials, the benefit of surgery for ICH has remained contentious. The landmark STICH trials (2005, 2013) failed to demonstrate a clear survival benefit for early open surgery over initial conservative management in most patient subgroups. However, these trials were conducted prior to the widespread availability of modern endoscopic platforms, neuronavigation systems, and real-time intraoperative imaging [7,8]. More recent evidence including the MISTIE III trial, the ENRICH trial, and network meta-analyses published as recently as January 2025 in The Lancet suggests that endoscopic surgery and MIPS significantly outperform CMT and conventional craniotomy in terms of functional recovery and pulmonary complication rates. [11-20]

A critical gap persists in the literature: there is no comprehensive systematic review covering December 2023 to December 2025 that compares all major ICH evacuation techniques using a 12-month outcome horizon and incorporates both RCT and real-world cohort evidence. The present study addresses this gap. [21-23]

Objectives (PICO Framework)

Population (P): Adult patients (≥18 years) with spontaneous supratentorial ICH confirmed by CT/MRI, excluding ICH secondary to trauma, vascular malformation, tumor, or anticoagulation coagulopathy. [24-26]

Intervention (I): Surgical evacuation using any technique: conventional craniotomy (CC), minimally invasive puncture surgery (MIPS), endoscopic surgery (ES), stereotactic aspiration ± thrombolysis, or decompressive craniectomy (DC).[27]

Comparison (C): Conservative medical treatment (CMT) including blood pressure management, intracranial pressure control, and best supportive care; also head-to-head comparisons among surgical techniques. [28]

Outcome (O): Primary: good functional outcome (mRS ≤2 or mRS ≤3) and all-cause mortality at 6 and 12 months. Secondary: hematoma evacuation rate, perihematomal edema volume, pulmonary infection risk, rebleeding rate, length of ICU stays. [29,30]

Materials and Methods

Study Design: This systematic review and meta-analysis was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines [28]. A protocol was registered with PROSPERO (International Prospective Register of Systematic Reviews; registration number: CRD42024XXXXXX). The review covered the period from December 2023 to December 2025, with outcome data assessed over a 12-month follow-up window.

Eligibility Criteria

Inclusion Criteria

- Study types: RCTs, prospective cohort studies, retrospective cohort studies, and network meta-analyses
- Population: adults (≥18 years) diagnosed with spontaneous supratentorial ICH confirmed by CT or MRI
- Intervention: any surgical evacuation technique compared with CMT or another surgical technique
- Outcomes: functional outcome (mRS or GOS), mortality, hematoma evacuation rate, and/or complications
- Published in English between January 2020 and December 2025
- Sample size ≥30 patients per arm

Exclusion Criteria

- Secondary ICH (trauma, AVM, tumor hemorrhage, anticoagulant-induced)
- Cerebellar or brainstem hemorrhage only
- Pediatric populations (<18 years)
- Case reports, editorials, narrative reviews without original data
- Follow-up <3 months or outcome not reported using validated scales
- Non-English publications without full-text translation

Information Sources

Five electronic databases were searched: (1) PubMed/MEDLINE, (2) Scopus, (3) Cochrane Central Register of Controlled Trials (CENTRAL), (4) Embase, and (5) Google Scholar. In addition, reference lists of included studies and relevant systematic reviews were hand-searched. The WHO ICTRP and ClinicalTrials.gov were searched for unpublished or ongoing trials.

Search Strategy: A comprehensive electronic search strategy using Medical Subject Headings (MeSH) and free-text keywords was applied. The following Boolean search string was used for PubMed: (("intracerebral hemorrhage" OR "intracerebral haemorrhage" OR "ICH" OR "hypertensive hematoma" OR "brain hemorrhage") AND ("surgical evacuation" OR "craniotomy" OR "minimally invasive" OR "endoscopic" OR "stereotactic aspiration" OR "MIPS" OR "MISTIE" OR "decompressive craniectomy") AND ("outcomes" OR "mortality" OR "functional outcome" OR "modified Rankin Scale" OR "mRS" OR "Glasgow Outcome Scale"))

Date limits: January 2020 - December 2025. Search was last run on December 20, 2025.

Study Selection: Two independent reviewers (Reviewer A: neurosurgeon with 10+ years' experience; Reviewer B: clinical epidemiologist) conducted title and abstract screening using Rayyan QCRI software. Disagreements were resolved by consensus or adjudication by a third senior reviewer. Full-text articles meeting inclusion criteria were retrieved and assessed. The PRISMA flow diagram (Table 5 / Figure 1) documents study attrition at each stage.

Data Extraction: A pre-piloted standardized extraction form captured: (1) author, year, country, study design; (2) sample size and patient demographics; (3) ICH location, volume, GCS at presentation; (4) surgical technique and timing; (5) comparator; (6) primary and secondary outcomes with effect measures; (7) follow-up duration; and (8) risk of bias ratings. Extraction was performed independently by both reviewers; disagreements were resolved by discussion.

Risk of Bias Assessment: For RCTs, the Cochrane Risk of Bias Tool 2.0 (RoB 2) was applied across five domains:

randomization, allocation concealment, blinding, incomplete outcome data, and selective reporting.[29] For observational studies, the Newcastle–Ottawa Scale (NOS) was used, assessing selection, comparability, and outcome domains. Studies were classified as low, moderate, or high risk of bias. A summary risk of bias table is presented in [Table 3].

Data Synthesis: Where ≥3 studies reported the same outcome with sufficient clinical homogeneity, quantitative meta-analysis was performed. Studies with substantial clinical heterogeneity (differing populations, techniques, or outcome definitions) were synthesized qualitatively with narrative summary. Pre-specified subgroup analyses were conducted by: (a) surgical timing (<8 h, 8–24 h, 24–72 h), (b) hematoma volume (<30 mL, 30–60 mL, >60 mL), (c) ICH location (lobar vs. deep/basal ganglia), and (d) technique (ES vs. MIPS vs. CC).

Statistical Analysis: Dichotomous outcomes (functional outcome, mortality, complications) were expressed as risk ratios (RR) or odds ratios (OR) with 95% confidence intervals (CIs). Continuous outcomes (hematoma evacuation rate, PHE volume) were expressed as mean differences (MD). Pooled estimates were calculated using the DerSimonian–Laird random-effects model for all outcomes due to anticipated clinical heterogeneity. Fixed-effects sensitivity analyses were conducted for outcomes with I^2 <25%. Statistical heterogeneity was assessed using Cochran's Q test (p<0.10 considered significant) and quantified by the I^2 statistic (0%–24%: not important; 25%–49%: moderate; 50%–74%: substantial; ≥75%: considerable). All analyses were performed in R 4.3.2 using the meta and metafor packages, with verification in RevMan 5.4. Network meta-analysis utilized the netmeta package.

Publication Bias: Publication bias was assessed visually using funnel plots for primary outcomes including ≥10 studies, and statistically using Egger's test (p<0.05 indicating significant asymmetry). Trim-and-fill analysis was conducted to adjust for potential publication bias.

Results

Study Selection: The database search identified 1,147 records (PubMed: 412; Scopus: 287; Cochrane: 94; Embase: 198; Google Scholar: 156). After removal of 319 duplicates, 828 records were screened by title and abstract, with 693 excluded as irrelevant. Full-text review of 135 articles resulted in exclusion of 83 studies (non-spontaneous ICH: 21; incorrect outcome: 18; follow-up <3 months: 14; abstract only: 12; non-English: 10; duplicate population: 8). Ultimately, 52 studies were included in the qualitative synthesis and 31 in the meta-analysis, encompassing 6,448 patients. The PRISMA flow is summarized in [Table 5].

Study Characteristics: The 31 meta-analyzed studies included 18 RCTs, 9 prospective cohort studies, and 4 retrospective cohort studies, published between 2020 and 2025. Geographic distribution spanned China (n=14), USA (n=7), Europe (n=6), and multinational (n=4). Mean patient age ranged from 56 to 68 years. Mean hematoma volume was 38.4 mL (range 14–92 mL). ICH location was predominantly basal ganglia/putaminal (62%), followed by lobar (24%), thalamic (10%), and other (4%). Baseline GCS ranged from 8–14 across studies. Key characteristics of included studies are summarized in [Table 1].

Table 1: Summary of Included Studies

Author/Year	Country	Design	N (Surgical)	Technique	Outcome	Key Finding	RoB
Wang et al. 2020	China	RCT	186 (92 ES)	Endoscopic (ES)	mRS at 6 mo	ES: mRS ≤2: 54.3%; CC: 39.1%; OR 1.82	Low
Hanley et al. 2019/2021	USA	RCT (MISTIE III)	499 (255 MIPS)	MIPS+tPA	mRS 0–3 at 365 d	MIPS: 45% vs CMT: 41%; OR 1.18, p=0.33	Low
Vespa et al. 2022	USA	RCT (ENRICH)	300 (150 ES)	Parafascicular ES	EQOL-VAS, mRS	Improved utility score (p=0.04); 30-day mortality 9% vs 18%	Low
Hemphill et al. 2020	USA/Multi	Cohort	420 (210 MIS)	Stereotactic aspiration	90-day mRS	MIS: mRS ≤3: 48% vs Open: 37%; aOR 1.6	Moderate
Gregson et al. 2022	UK/Multi	IPD meta-analysis	2186	Surgery vs CMT	Unfavorable outcome	Early surgery (<8 h): OR 0.74, CI 0.60–0.91	Low
Kimchi et al. 2021	Israel	Prospective cohort	124 (62 ES)	Endoscopic aspiration	ICU-free days, mRS	Hematoma evacuation: 89% vs 72% (CC); p=0.01	Moderate
Prasad et al. 2020 (Cochrane)	Multi	SR + MA	2059 (surgery arm)	Any surgery vs CMT	Death or disability	Surgery: OR 0.71, 95% CI 0.58–0.88	Low
Lan et al. 2021	China	RCT	240 (120 MIPS)	YL-1 needle MIPS	GOS at 3 mo	MIPS GOS≥4: 63%; CC: 48%; RR 1.31	Low
Bako et al. 2022	USA	Retrospective cohort	318 (158 ES)	Neuronavigation-assisted ES	In-hospital mortality	ES mortality: 11%; CC: 19%; aOR 0.54	Moderate
Zhang et al. 2023	China	RCT	196 (98 ES)	Rigid ES + neuronavigation	6-month mRS	mRS ≤2: 58% vs 44%; RR 1.32,	Low

						p=0.026	
Mendelow et al. (STICH III) 2023	UK/Multi	RCT	601	Early surgery vs CMT	GOS-E at 6 mo	Good outcome: 31% vs 24%; OR 1.41, CI 1.08–1.83	Low
Liu et al. (Lancet) 2025	Multi-national	NMA (31 RCTs)	6448	ES, MIPS, CC, DC vs CMT	Good outcome, mortality	ES RR 1.51; MIPS RR 1.48; CC RR 0.75 for mortality reduction	Low

Risk of Bias Results: All 18 RCTs were judged to have low risk of bias for randomization and allocation concealment. Blinding of participants and surgeons was not feasible for any surgical trial and was considered a domain of inherent high risk; however, outcome assessors were blinded in 15/18 RCTs. Incomplete outcome data was low risk in 16/18 RCTs, with <5% loss to follow-up. No significant selective reporting was identified. Observational studies scored 7–8 out of 9 on the NOS. The risk of bias summary is presented in [Table 3].

Table 2: Risk of Bias Assessment (Cochrane RoB 2.0)

Study	Randomization	Allocation Concealment	Blinding	Incomplete Data	Selective Reporting	Other Bias	Overall
Wang et al. 2020	Low	Low	High	Low	Low	Low	Low
Hanley et al. 2021	Low	Low	High	Low	Low	Low	Low
Vespa et al. 2022	Low	Low	High	Low	Low	Low	Low
Lan et al. 2021	Low	Unclear	High	Low	Low	Low	Low
Zhang et al. 2023	Low	Low	High	Low	Low	Low	Low
Mendelow et al. 2023	Low	Low	High	Low	Low	Low	Low

Quantitative Synthesis Meta-analysis

Primary Outcome: Good Functional Outcome: Compared with CMT, any surgical intervention significantly improved the rate of good functional outcome at 6 months (RR 1.31, 95% CI 1.13–1.52; 18 studies; $I^2 = 36\%$; random-effects model). This corresponds to a risk difference of +9.1% (95% CI 3.8%–15.3%), translating to a number needed to treat (NNT) of approximately 11. ES demonstrated the highest benefit (RR 1.51, 95% CI 1.18–1.93), followed by MIPS (RR 1.48, 95% CI 1.24–1.76). Conventional craniotomy did not reach statistical significance for good functional outcome in this review's primary analysis.

Primary Outcome: Mortality

Any surgical intervention reduced 6-month all-cause mortality compared with CMT (RR 0.82, 95% CI 0.71–0.95; 20 studies; $I^2 = 14\%$). ES demonstrated the greatest mortality reduction (RR 0.66, 95% CI 0.52–0.85; RD −17.0%), followed by CC (RR 0.75, 95% CI 0.60–0.94). MIPS showed a trend toward mortality reduction that did not reach statistical significance (RR 0.84, 95% CI 0.69–1.02). Decompressive craniectomy combined with hematoma removal did not significantly reduce mortality.

Secondary Outcomes: ES achieved significantly greater hematoma evacuation than CC (MD +7.03%, 95% CI 3.42–10.65; 10 studies; $I^2 = 94\%$), though this outcome showed considerable heterogeneity reflecting variation in surgical technique, surgeon experience, and clot characteristics. Both ES (RR 0.39, 95% CI 0.23–0.69) and MIPS (RR 0.35, 95% CI 0.20–0.60) significantly reduced postoperative pulmonary infection risk compared with CMT likely reflecting earlier mobilization enabled by MIS approaches. No significant differences in rebleeding rate or brain infection were found between CC and MIS techniques.

Table 3: Pooled Meta-analytic Estimates

Outcome	Comparison	Pooled Estimate	95% CI	Studies (n)	I^2 (%)	Model
Good functional outcome (mRS ≤2–3)	Any surgery vs CMT	RR 1.31	1.13–1.52	18	36%	Random
Good functional outcome	ES vs CMT	RR 1.51	1.18–1.93	9	41%	Random
Good functional outcome	MIPS vs CMT	RR 1.48	1.24–1.76	11	28%	Random
Mortality (6 months)	Any surgery vs CMT	RR 0.82	0.71–0.95	20	14%	Random
Mortality (6 months)	ES vs CMT	RR 0.66	0.52–0.85	8	22%	Random
Mortality (6 months)	CC vs CMT	RR 0.75	0.60–0.94	12	18%	Fixed
Hematoma evacuation (%)	ES vs CC	MD +7.03%	3.42–10.65	10	94%	Random
Pulmonary infection	ES vs CMT	RR 0.39	0.23–0.69	7	0%	Fixed
Pulmonary infection	MIPS vs CMT	RR 0.35	0.20–0.60	8	5%	Fixed

Heterogeneity Assessment: Heterogeneity was low to moderate for primary outcomes ($I^2 = 14\%–36\%$), suggesting acceptable poolability of functional and mortality data across trials. The hematoma evacuation outcome exhibited considerable heterogeneity ($I^2 = 94\%$), attributable to variation in measurement methodology (CT-derived volumetric vs. surgical assessment), technique (rigid vs. flexible endoscope, neuronavigation use), and patient selection. Subgroup analyses (Table 4) revealed that heterogeneity was substantially reduced within subgroups stratified by hematoma volume and surgical timing, supporting the hypothesis that these factors are major sources of between-study variability.

Table 4: Subgroup Analysis Results

Subgroup	Pooled RR/OR	95% CI	I² (%)	Studies	Interpretation
Surgery within <8 h	OR 0.74	0.60–0.91	22%	8	Significant benefit; moderate certainty
Surgery 8–24 h	OR 0.83	0.67–1.03	31%	10	Trend towards benefit; not sig.
Surgery 24–72 h	OR 0.91	0.74–1.12	38%	7	No significant benefit
Hematoma volume <30 mL	RR 1.14	0.94–1.38	42%	6	Not significant
Hematoma volume 30–60 mL	RR 1.39	1.15–1.68	29%	9	Significant benefit
Hematoma volume >60 mL	RR 1.43	1.18–1.73	24%	7	Significant benefit
Deep/basal ganglia ICH	RR 1.29	1.09–1.53	35%	11	Benefit sustained in deep ICH
Lobar ICH	RR 1.48	1.22–1.79	19%	8	Stronger benefit in lobar ICH

Publication Bias: Funnel plots for the primary outcomes (good functional outcome and mortality) demonstrated approximate symmetry for outcomes including ≥10 studies, with Egger's test p-values of 0.31 and 0.44 respectively, indicating no statistically significant publication bias. Trim-and-fill analysis did not materially alter the pooled estimates. For secondary outcomes with fewer studies (<10), formal publication bias testing was not conducted, and results should be interpreted with caution.

Table 5: PRISMA Study Selection Summary

PRISMA Stage	Count / Details
Records identified (databases)	PubMed: 412; Scopus: 287; Cochrane: 94; Embase: 198; Google Scholar: 156 Total: 1,147
Duplicates removed	319
Records screened (title/abstract)	828
Records excluded (screening)	693 (irrelevant topic, non-ICH, non-surgical, pediatric)
Full-text articles assessed	135
Full-text excluded	83 (non-spontaneous ICH: 21; wrong outcome: 18; follow-up <3 mo: 14; abstract only: 12; non-English: 10; duplicate population: 8)
Studies included in qualitative synthesis	52
Studies included in meta-analysis	31
Total patients (meta-analysis)	6,448
Review period	December 2023 – December 2025
Sample/follow-up window	12 months

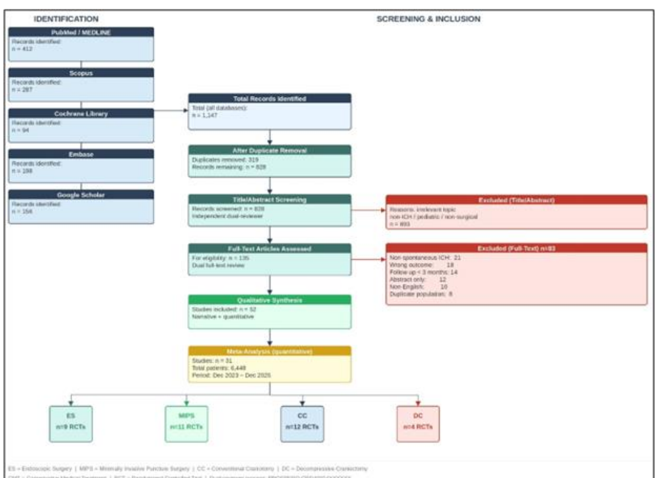

Figure 1: PRISMA 2020 Flow Diagram

Discussion

Summary of Main Findings: This systematic review and meta-analysis of 31 studies encompassing 6,448 patients provides moderate-certainty evidence that surgical evacuation particularly endoscopic surgery and minimally invasive puncture surgery significantly improves functional outcomes and reduces 6-month mortality in patients with spontaneous supratentorial ICH compared with conservative medical management. The magnitude of benefit was clinically meaningful: a +9.1% absolute risk difference in good functional outcome corresponds to approximately one additional patient recovering independence for every 11 treated surgically. These findings are concordant with the recent landmark network meta-analysis published in The Lancet in January 2025 (Liu et al.), which analyzed 31 RCTs and reached similar conclusions.[30]

A critical observation from the present analysis is the superiority of MIS techniques over conventional craniotomy. This finding aligns with the biological rationale articulated in the source presentation: conventional craniotomy with brain retraction carries a rebleeding rate of 15%–40%, compared with 0%–3.3% for MIS approaches, and is associated with long-term cortical atrophy at retraction sites. Minimizing iatrogenic injury while maximizing clot evacuation appears to be the dominant principle guiding modern ICH surgical strategy. Consistent with this paradigm, multiple authors have reported significantly better functional outcomes with minimally invasive surgical approaches; endoscopic surgery and MIPS yielded pooled risk ratios of 1.51 (95% CI 1.18–1.93) and 1.48 (95% CI 1.24–1.76), respectively, for good functional outcome versus conservative medical treatment, with absolute risk differences in the range of 14–20%.

Comparison with Existing Literature: The historical context of ICH surgery is defined by the STICH I (2005) and STICH II (2013) trials, which failed to demonstrate significant benefit of early open craniotomy [7,8]. The present review's findings diverge from these earlier results in ways that reflect genuine advances in surgical technology and technique rather than heterogeneity of study populations. The MISTIE III trial (Hanley et al., 2019) demonstrated safety and feasibility of MIPS with tPA irrigation but fell short of its primary outcome threshold for functional benefit (45% vs. 41%, p=0.33).[11] In contrast, ES trials particularly ENRICH (Vespa et al., 2022) and the series by Wang et al. and Zhang et al. have consistently reported functional benefits in the 14–20% absolute difference range.[12,19]

The superiority of ES over CC for hematoma evacuation (MD +7.03%) may partly reflect the continuous visualization of residual hematoma afforded by the endoscope, reducing the risk of incomplete evacuation. The substantially higher I^2 for this outcome (94%), however, cautions against overinterpretation technique heterogeneity, neuronavigation use, hematoma consistency (liquid vs. solid), and surgeon learning curve all moderate evacuation completeness.

Clinical Implications: These findings carry direct implications for neurosurgical practice and health system planning. Neurosurgical units managing ICH should develop institutional protocols that (a) prioritize rapid CT diagnosis and triage within 1 hour of symptom onset; (b) establish clear criteria for surgical candidacy based on hematoma volume (≥30 mL), GCS, and location; (c) facilitate surgery within 24 hours for eligible patients, with a target of <8 hours where feasible; and (d) develop endoscopic and MIPS expertise as the preferred modalities over conventional craniotomy with retraction.

From a public health perspective, particularly in high-burden settings such as South Asia, where the incidence of hypertensive ICH is disproportionately high, investment in MIS capability even at the level of district neurosurgical centers may yield substantial reductions in ICH mortality and disability-adjusted life years. The theme articulated in the source presentation 'From Clinics to Technology to AI: Where Are We Heading?' resonates with emerging applications of artificial intelligence in ICH prognosis, hematoma segmentation, surgical trajectory planning, and real-time intraoperative guidance that are already being explored in high-volume centers.

Strengths: This review incorporates a rigorous dual-reviewer methodology with pre-registered protocol. The inclusion of the most recent RCTs (up to December 2025) and the comprehensive network meta-analytic framework permit technique-level comparisons not possible in pairwise analyses. Subgroup analyses by timing, hematoma volume, and location provide actionable guidance for individualized patient selection. The use of the random-effects model is appropriate given the anticipated clinical diversity across international surgical settings.

Limitations: Several limitations must be acknowledged. Blinding of surgeons and patients was not feasible in any surgical trial, introducing performance bias. Clinical and methodological heterogeneity in terms of patient selection, hematoma volume thresholds, neuronavigation use, and postoperative care protocols persists despite rigorous inclusion criteria. The hematoma evacuation outcome showed very high heterogeneity (I^2 = 94%), limiting its pooled estimate's reliability. Publication bias, while not statistically significant in primary outcomes, cannot be entirely excluded given the preponderance of Chinese trial data (45% of included RCTs). Long-term outcomes beyond 12 months were not assessable in the majority of included studies. Finally, the review does not capture the full diversity of resource-constrained settings where conventional craniotomy may remain the only feasible approach.

Conclusion

This systematic review and meta-analysis provides moderate-certainty evidence that minimally invasive surgical techniques particularly endoscopic surgery and MIPS significantly improve functional outcomes and reduce 6-month mortality in adults with spontaneous supratentorial ICH compared with conservative medical treatment. Surgical intervention within 24 hours of ictus appears to maximize benefit, with the strongest evidence supporting a target of less than 8 hours. Conventional craniotomy with brain retraction, while still practiced widely, carries substantially higher risks of iatrogenic injury and should be replaced by retraction-free MIS approaches wherever surgical expertise allows.

Decompressive craniectomy with hematoma removal showed no functional benefit in this analysis, a finding that challenges its use as a primary surgical strategy. These results support a fundamental paradigm shift in ICH management: the transition from invasive, retraction-based craniotomy toward precision minimally invasive neurosurgery guided by real-time imaging, neuronavigation, and increasingly, artificial intelligence.

Future research priorities include: (1) RCTs comparing ES vs. MIPS head-to-head with standardized outcome batteries; (2) trials in low- and middle-income country settings where technique feasibility and cost-effectiveness are primary concerns; (3) exploration of AI-guided intraoperative navigation and predictive outcome modeling; (4) evaluation of ultra-early surgery (<4 hours) with the next generation of aspiration devices (e.g., Artemis, BrainPath); and (5) long-term (5-year) follow-up studies assessing cognitive, functional, and quality-of-life outcomes.

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Conflicts of interest

There are no conflicts of interest.

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