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Original Article

Navigating the Landscape of Intracerebral Haemorrhage: A Comprehensive Systematic Review of Minimally Invasive Surgical Approaches

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Abstract

Background: Intracerebral haemorrhage (ICH) is a common cause of morbidity and mortality worldwide. Aggressive surgical treatment for ICH remains controversial as it has not demonstrated significant improvement in the prognosis and mortality. This study critically analyses minimally invasive surgery (MIS) techniques, including Brain Path system, Apollo system, and catheter-based pharmacological approaches for ICH management.

Methods: A comprehensive search of four electronic databases, including PubMed, Google Scholar, Science Direct, and Frontiers, was conducted. Studies that analysed the use of minimally invasive surgery to evacuate haemorrhagic stroke were included in the review. The primary outcomes assessed in these studies encompassed postoperative complications, length of surgery and blood loss, duration of hospitalization, postoperative neurological deficit, and rebleeding rates.

Results: The existing literature suggests that the use of minimally invasive techniques in the management of intracerebral haemorrhage exhibits a substantial improvement in outcomes when compared to conservative treatment and traditional surgical evacuation strategies. This underscores the potential efficacy of MIS in enhancing the overall prognosis for individuals with ICH, presenting a promising avenue for further exploration and clinical application.

Conclusion: The role of minimally invasive techniques (MIS) in the management of intracerebral haemorrhage (ICH) is currently a subject of contention. Nevertheless, an accumulating body of evidence within the scholarly literature indicates that MIS is correlated with markedly enhanced outcomes in comparison to both conservative treatment and conventional surgical evacuation strategies.

Introduction

Intracerebral haemorrhage (ICH) occurs when there is bleeding within the brain tissue, typically without any associated trauma. Its incidence is estimated to be approximately 24.7 cases per 100,000 person-years, affecting a significant number of individuals in Russia annually [4]. This condition carries a high burden of disability and mortality, with 40% mortality within one month and an annual mortality rate of 50%, leaving only a small proportion of patients able to achieve long-term independence [1]. Despite advances in technology and numerous clinical studies, there has been little improvement in the prognosis for ICH patients [11].

Intracerebral haemorrhage not only poses significant medical challenges but also has profound emotional and socioeconomic impacts on patients and their families [5]. The sudden onset of symptoms and the need for long-term care can result in substantial disruptions to daily life [9]. Additionally, the financial burden of treatment and ongoing healthcare needs adds to the stress experienced by affected individuals. Therefore, identifying effective treatment strategies, such as minimally invasive surgical approaches, is crucial for improving clinical outcomes and addressing the holistic needs of patients, ultimately reducing the societal burden of this condition [14].

Treatment for spontaneous intracerebral haemorrhage lacks consensus and effectiveness due to the diverse nature of the condition and limited evidence-based data [2]. This has led to considerable variation in clinical management practices and has spurred research into various surgical approaches [3]. Minimally invasive techniques for evacuating intracerebral haemorrhages have gained attention as alternatives to open surgery, aiming to minimize surgical morbidity [13].

These minimally invasive surgical (MIS) approaches involve mechanical techniques using tubular retractors and small-diameter instruments, as well as pharmacological methods utilizing catheters for passive drainage over several days [7]. A meta-analysis by Scagiante et al. found that certain patients with supratentorial ICH experienced benefits with MIS compared to alternative treatments, irrespective of the specific MIS technique or evacuation timeline [6]. Ongoing studies such as ENRICH and INVEST are further exploring MIS techniques, with initial findings showing promise and potential implications for future ICH management strategies [8].

This review aims to evaluate the latest advancements in MIS approaches for evacuating intracranial haemorrhage, providing a comprehensive assessment of the current status, significant findings, and emerging trends in this field.

Patients and Methods

Information Sources

Following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, we conducted a search of terms in the PubMed/Medline, Cochrane, and Embase databases [10].

Inclusion Criteria

To be eligible for inclusion, articles had to meet the following criteria:

1. The study population included patients with intracranial haemorrhage (ICH).
2. The study discussed innovative minimally invasive surgical and pharmacological catheter-based approaches for the treatment of intracranial haemorrhage.
3. The sample size was at least 10 patients.
4. The article was published in English or translated into English.

Exclusion Criteria

Articles were excluded if they met any of the following criteria:

1. The study population included only paediatric cases.
2. The article was a case report or technical report.
3. The article was not published in English or lacked an English translation.

Search Strategy

The search strategy was developed using the PICO framework:

- **Population:** Patients with intracranial haemorrhage (ICH) or related conditions.
- **Intervention:** Innovative minimally invasive surgical and pharmacological catheter-based approaches.
- **Comparison:** Not applicable for certain studies, as some were observational studies or single-arm trials.
- **Outcome:** Evaluation of neurological outcomes, haemorrhage volume reduction,procedure-related complications, and overall treatment efficacy.

Search terms were subsequently refined using Medical Subject Headings (MeSH) to expand the keyword strategy. The primary search terms included intracerebral haemorrhage, BrainPath system, Apollo system, and catheter-based pharmacological approaches.

The literature search included studies published up to 2024.

Study Selection and Data Extraction

Two reviewers independently screened the titles and abstracts of all identified articles to determine their eligibility for inclusion. Potentially relevant studies were then subjected to full-text review to confirm compliance with the predefined inclusion and exclusion criteria. Any disagreements regarding study eligibility were resolved through discussion and consensus.

Data Items and Quality Assessment

The following data items were extracted from the selected studies:

Study Characteristics

- Authors
- Year of publication
- Study design (retrospective, prospective, clinical trial, etc.)

Patient Demographics

- Characteristics of the study population
- Sample size

Intervention Details

- Description of the innovative minimally invasive procedure or system
- Specifics of the catheter-based approach
- Use of thrombolytic agents, where applicable
- Preoperative and postoperative intracranial haemorrhage volume

Outcomes

- Neurological outcomes
- Volume reduction of intracranial haemorrhage
- Procedure-related complications
- Functional outcomes assessed using validated scales, such as the Glasgow Coma Scale (GCS) and the modified Rankin Scale (mRS)

Quality Assessment Parameters

- Evaluation of study quality and risk of bias
- Assessment of methodological rigor
- Consideration of potential confounding variables
- Applicability of findings to the broader patient population

Quality Assessment

The quality of the included studies was assessed using established tools appropriate to each study design. This process involved evaluating the risk of bias, methodological quality, and reliability of reported outcomes. Standardized assessment instruments, including the Newcastle–Ottawa Scale for cohort studies and the Cochrane Risk of Bias Tool for randomized controlled trials, were employed to ensure a systematic and objective evaluation.

Quality assessment was performed independently by two reviewers. Any disagreements were resolved through discussion or, when necessary, consultation with a third reviewer. The overall quality of evidence was subsequently considered during the synthesis and interpretation of study findings. This approach enhanced the reliability and validity of the review by accounting for both the internal and external validity of the included studies.

Results

Study Selection

The initial database search identified 480 articles relevant to the topic. After the removal of 80 duplicate records, 400 articles remained for title and abstract screening. This process resulted in the selection of 110 articles for full-text review.

Following detailed assessment of the full texts, 96 articles were excluded because they contained unclear or outdated data, focused on alternative treatment modalities, or had unavailable full-text versions. Ultimately, 10 studies met all inclusion and exclusion criteria and were included in the final review.

A total of 767 patients underwent innovative minimally invasive procedures for the treatment of intracranial haemorrhage. (Figure 1).

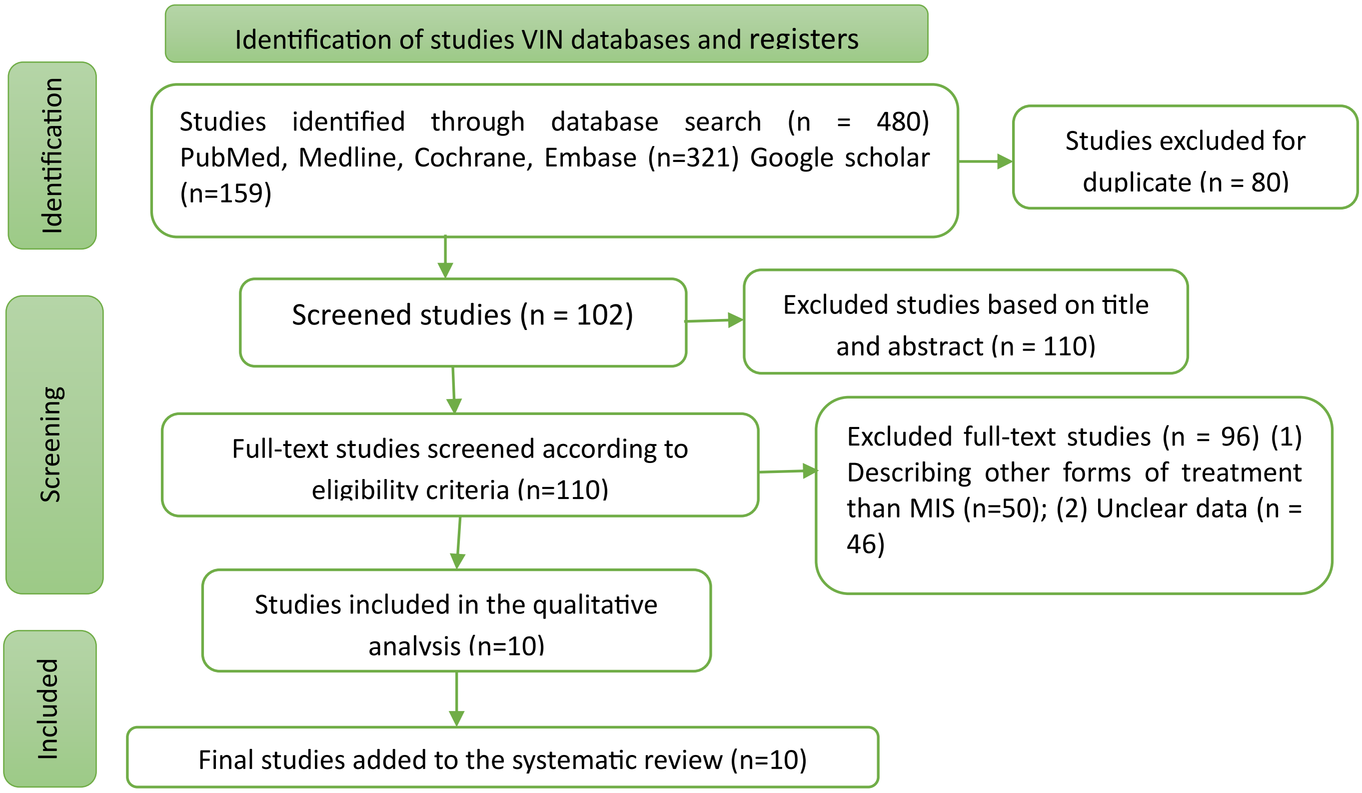

Figure 1: Study selection according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA).

Results of individual studies

Ten studies with 480 patients were analyzed. It should be noted that the studies did not report all the variables studied in this review. There was significant inconsistency in the reporting of data in the literature making analysis a challenge.

Results of Individual Studies

BrainPath System:

Bauer et al (Prospective Pilot): With 18 patients, the BrainPath System led to improved Glasgow Coma Scale (GCS) scores by 10–14 points preoperatively.

The study reported a high percentage (95.7%) of ICH removal. Limitations included a small sample size and a single-center design [16].

Labib et al (Retrospective Multicenter): Minimally invasive subcortical perifascicular transsulcal access for clot evacuation (The MI SPACE approach) in 39 patients resulted in increased GCS by 10–15 points. ICH removal was reported to be >90% in 72% of patients. However, complications such as rebleeding and artery infarction were noted [22], and the study was limited by its retrospective nature and small sample size [18,19].

Griessenauer et al (Retrospective Cohort): In a cohort of 5 patients, the BrainPath System showed preoperative GCS 2 (1–3) and postoperative GCS 3. The study did not report complications but had limitations, including a retrospective design, a small sample size, and delayed treatment time [17]. (See table 1).

Prybylowski et al (Retrospective): In a study involving 11 patients, the use of end port-assisted microsurgical evacuation (EAME) with Brain Path resulted in 36% of individuals achieving functional independence at 90 days, with two displaying moderate functionality. The study reported a high percentage (87%) of ICH removal, but bleeding was not statistically significant, highlighting limitations such as a small sample size and retrospective nature [32,20]

Table 1. Results of Individual Studies (BrainPath System)

Research	Research Method	Intracerebral haemorrhage Evacuation Methods	Number of Participants	Neurological Outcome	Intracerebral haemorrhage Assessment	Initial Volume (cm3)	Percentage of ICH Removed	Procedure-Associated Complications	Limitations
Bauer et al (2017) [16]	Prospective Pilot Study	BrainPath System	18	Enhanced GCS by 10–14 points prior to surgery	2.4 (SD 1.0)	52.7 (SD 22.9)	95.7 (SD 5.8)	Not specified	Limited sample size, single-center setup
Labib et al (2017) [18]	Multicentre Retrospective	MI SPACE approach	39	Improved GCS by 10–15 points	2 (Range: 0–3)	36 (Range: 27–65)	>90% in 72%	Rebleeding (n=1), perforating middle cerebral artery infarct (n=1)	Retrospective analysis, small participant pool
Griessenauer et al (2018) [17]	Retrospective Cohort	BrainPath System	5	GCS before surgery: 2 (1–3), after surgery: 3	2 (1–3)	42.3 (SD 9.1)	=	Not mentioned	Retrospective study, limited participant count, delay in treatment
Prybylowski et al (2015) [32]	Retrospective Study	EAME with BrainPath	11	36% functionally independent after 90 days, 2 with moderate functionality	2 (Range: 1–4)	51 (Range: 9–168)	87% (38%–99%)	Bleeding: p=1	Limited sample size, retrospective design

Apollo System:

Spiotta et al (Multicenter, Retrospective Case Series): Among 29 patients, the Apollo System demonstrated varied outcomes, with acute and chronic neurological deficits reported. Complications included rebleeding and enhanced decompressive craniectomy. The study faced limitations such as a retrospective design, delayed edema reporting, and lack of functional outcomes/ICH characteristics [27,23].

Griessenauer et al (Retrospective Cohort): In 5 patients, the Apollo System led to a preoperative GCS of 9 and postoperative GCS of 10. No postoperative complications were reported, but limitations included a retrospective design, a small sample size, and delayed treatment time [17,24].

Goyal et al (Retrospective Case-Control): In 18 patients, the Apollo System showed outcomes comparable to other studies, but the study had limitations such as a retrospective design and no assessment of ICH visualization volumes [26]. (See table 2).

Kellner et al (Retrospective Case Series): The Stereotactic Underwater Blood Aspiration (SCUBA) with Apollo in 47 patients showed a high percentage (88.2%) of ICH removal, but bleeding complications were reported in a small percentage (0.6–2.1%). The study faced limitations, including a retrospective design, no visualization of ICH volumes, and differences in care cessation [28,25].

Table 2. Results of Individual Studies (Apollo System)

Research	Research Type	Intracerebral haemorrhage Evacuation Method	Number of Patients	Neurological Outcome	Intracerebral haemorrhage Assessment	Preoperative Volume (cm3)	Intracerebral haemorrhage Removal %	Procedure-Related Complication	Limitations
Spiotta et al (2015) [27]	Multicentre, Retrospective	Apollo System	29	Acute neurological deficit (n=12), chronic neurological deficit (n=2)	-	45.4 (SD 30.8)	54.1% (SD 39.1)	Rebleeding and enhanced decompressive craniectomy (n=2)	ICH characteristics reported
Griessenauer et al (2018) [17]	Retrospective Cohort	Apollo System	5	Preoperative GCS 9, postoperative GCS 10	3 (Range: 1–4)	50.7 (SD 23.9)	=	No postoperative complications	Retrospective, small sample size, delayed treatment time
Goyal et al (2019) [26]	Retrospective Case-Control	Apollo System	18	=	2,2 (SD 0,9)	40 (Range: 21–52)	60% (median: 24cm3)	=	Retrospective, no assessment of ICH visualization volumes, differences in care cessation
Kellner et al (2018) [28]	Retrospective Case Series	SCUBA with Apollo	47	=	=	42.6 (SD 29.7)	88.2% (SD 20.8)	Bleeding: IO - 0.6%, PO - 2.1% (n=1)	Retrospective, no visualization of ICH volumes, differences in care cessation

Pharmacological Catheter-Based Methods:

Hanley et al (Multicenter, Phase II - MISTIE II): With 96 patients, the Minimally Invasive Surgery plus Alteplase for Intracerebral Haemorrhage Evacuation II (MISTIE II) trial reported GCS scores improvement in various categories. However, complications included symptomatic and asymptomatic bleeding. Limitations included a small trial size, low screening efficiency, and efficacy not being fully assessed [33].

Hanley et al (Multicenter, Open-Label Phase III - MISTIE III): In a larger cohort of 499 patients, the MISTIE III trial reported favorable outcomes, with a 69% ICH removal rate. Complications included symptomatic bleeding and bacterial infections. Limitations included an open design and the use of different sizes and surgeons for the procedure [34,35]. (See table 3).

Table 3. Results of Individual Studies (Pharmacological Catheter-Based Methods)

Research	Research Type	Intracerebral haemorrhage Evacuation Method	Number of Patients	Neurological Outcome	Intracerebral haemorrhage Assessment	Preoperative Volume (cm3)	Intracerebral haemorrhage Removal %	Procedure-Related Complications	Limitations
Hanley et al (2016) [33]	Multicentre, Phase II	MISTIE II	96 (54 MIS+ alteplase, 42 Standard Medical Management	GCS scores: 3–8 (n=17), 9–12 (n=12), 13–15 (n=17)	II	48.2 (SD 19.6)	57% (SD 25)	Symptomatic bleeding (n=5), asymptomatic bleeding (n=3)	Small trial size, low screening efficiency, efficacy not assessed
Hanley et al (2017) [34]	Multicentre, Open-Label Phase III	MISTIE III	499 (250 MIS+ alteplase, 249 Standard Medical Management)	Admission GCS: 3–8 pts (n=64), 9–12 pts (n=111), 13–15 pts (n=75)	II	41.8 (Range: 30.8–54.5)	69%	Symptomatic bleeding (n=6), bacterial infections (n=2), 30% serious adverse events at 30 days	Open design, use of different sizes and surgeons for the procedure.

Discussion

Neurological Outcome

The comparison of various minimally invasive surgical (MIS) techniques for intracranial haemorrhage (ICH) evacuation reveals notable differences in neurological outcomes [21]. Studies, such as those involving the BrainPath System and Apollo System, consistently highlight improved neurological function following intervention. These advancements are particularly evident in cases where the Glasgow Coma Scale (GCS) showed significant improvement postoperatively [22,12].

However, the degree of neurological enhancement varied across different MIS methods, emphasizing the need for a nuanced evaluation based on the specific technique employed

ICH Volume Change

Reduction in hematoma volume is a crucial parameter in assessing the efficacy of MIS approaches [22]. The

BrainPath System, Apollo System, and catheter-based pharmacological methods, such as MISTIE II and MISTIE III, demonstrated varying degrees of success in minimizing ICH volume. While some techniques reported substantial reductions, others showed more modest outcomes [19].

Understanding the nuances of ICH volume change is essential for tailoring interventions to individual cases, considering factors like hematoma location, size, and patient characteristics.

Complications

The comparison of complications across MIS techniques reveals distinct patterns. The BrainPath System and Apollo System demonstrated favourable safety profiles, with limited reported complications [19].

However, concerns were raised in some studies regarding delayed treatment times and complications associated with catheter-based pharmacological approaches. The potential risk of bleeding, infections, or adverse events must be carefully weighed against the benefits, necessitating a thorough understanding of the complications associated with each MIS technique

Hospital Stay

One of the key advantages of MIS techniques is the potential for shorter hospital stays. Studies consistently reported reduced hospitalization durations following interventions with the BrainPath System, Apollo System, and certain catheter-based approaches. The ability to minimize hospitalization is crucial for patient recovery and resource optimization [21].

However, variations in reported hospital stays emphasize the need for a comprehensive analysis, considering factors such as intervention success, complications, and postoperative care.

Comparative Analysis

The BrainPath System and Apollo System emerge as promising MIS techniques, showing favourable neurological outcomes, substantial ICH volume reduction, and limited complications [29]. Catheter-based pharmacological approaches, while demonstrating benefits in ICH volume reduction, require careful consideration due to associated complications [30].

The variability in reported outcomes emphasizes the importance of tailored interventions based on patient-specific factors. Future research should focus on standardizing methodologies, expanding sample sizes, and refining techniques to provide a clearer understanding of the comparative effectiveness of MIS approaches for ICH evacuation.

Limitations

The study has several limitations, encompassing inherent heterogeneity in study methodologies, variations in reported parameters across different minimally invasive surgical (MIS) methods, and the inclusion of small sample sizes in specific investigations.

Furthermore, potential biases associated with retrospective study designs and variances in surgeon expertise might influence the generalizability of findings. Efforts to address these limitations would bolster the robustness and applicability of the insights derived from this review.

Conclusion

The exploration of minimally invasive techniques for intracranial haemorrhage (ICH) reveals promising approaches like the BrainPath System, Apollo System, and catheter-based pharmacological methods. Despite their potential benefits, challenges and variations underscore the importance of standardized reporting and further investigation for refinement.

The studies highlight the significance of surgeon experience, patient selection, and postoperative care. While acknowledging limitations like retrospective designs and small sample sizes, ongoing research and standardized reporting are crucial for establishing these techniques in clinical practice and improving outcomes in ICH management.

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