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PRECISION SELECTION FOR MINIMALLY INVASIVE HEMATOMA EVACUATION IN SPONTANEOUS INTRACEREBRAL HEMORRHAGE: INTEGRATING HEMATOMA TOPOGRAPHY, SURGICAL TIMING, IMAGING BIOMARKERS, AND FUNCTIONAL RECOVERY

Norkulov Sirojiddin Najmiddinovich
Specialized Scientific and Practical Center of Neurosurgery and Neurorehabilitation,
Samarkand State Medical University

Abstract.

Background. Spontaneous intracerebral hemorrhage is a devastating cerebrovascular disorder associated with substantial mortality, long-term neurological impairment, and functional dependence. Although surgical hematoma evacuation can reduce intracranial mass effect and secondary tissue injury, the clinical effectiveness of surgery differs according to hematoma location, surgical timing, procedural technique, and neurological severity. Recent randomized clinical trials have renewed interest in minimally invasive hematoma evacuation.

Materials and Methods. A narrative analytical review of international guidelines, randomized controlled trials, observational investigations, and systematic reviews was performed. The evaluation focused on hematoma volume and location, computed tomography biomarkers, timing of intervention, evacuation techniques, perioperative complications, and functional outcomes.

Results. Evidence suggests that the clinical effectiveness of hematoma evacuation is influenced by anatomical location, baseline neurological condition, hematoma stability, technical completeness of evacuation, and access to comprehensive neurocritical care. Early minimally invasive evacuation has demonstrated functional benefit in selected patients with lobar hemorrhage, whereas results for deep hemorrhages remain less definitive. A conceptual ICH-SELECT assessment matrix was developed to organize potentially relevant determinants of surgical suitability and postoperative recovery.

Conclusion. Precision-oriented selection for minimally invasive hematoma evacuation should integrate hemorrhage topology, clinical severity, radiological characteristics, procedural feasibility, and rehabilitation potential. The proposed framework requires prospective validation before application as a clinical prediction instrument.

Keywords: spontaneous intracerebral hemorrhage, minimally invasive neurosurgery, hematoma evacuation, neuroimaging, surgical timing, neurological recovery, functional outcome, prognostic assessment.

SPONTAN MIYA ICHI QON QUYILISHIDA MINIMAL INVAZIV GEMATOMA EVAKUATSIYASI UCHUN BEMORLARNI INDIVIDUAL TANLASH: GEMATOMA JOYLASHUVI, JARROHLIK VAQTI, NEYROVIZUALIZATSION BIOMARKERLAR VA FUNKSIONAL TIKLANISHNING INTEGRATSIYASI

Norqulov Sirojiddin Najmiddinovich
Samarqand davlat tibbiyot universiteti huzuridagi Ixtisoslashtirilgan ilmiy-amaliy neyroxirurgiya va neyroreabilitatsiya markazi

Annotatsiya.

Dolzarbligi. Spontan miya ichi qon quyilishi o‘lim, og‘ir nevrologik nuqson va uzoq muddatli funksional qaramlikka sabab bo‘luvchi serebrovaskulyar patologiyalardan biridir. Gematomani jarrohlik yo‘li bilan evakuatsiya qilish intrakranial massa ta'sirini kamaytirishi mumkin, biroq klinik samaradorlik gematomaning lokalizatsiyasi, hajmi, operatsiya vaqti va bemorning boshlang‘ich nevrologik holatiga bog‘liq.

Materiallar va usullar. Xalqaro klinik tavsiyalar, randomizatsiyalangan tadqiqotlar, kuzatuv ishlari va tizimli sharhlar tahlil qilindi. Gematoma hajmi, anatomik joylashuvi, kompyuter tomografiya biomarkerlari, operatsiya vaqti, jarrohlik usullari va funksional natijalar o‘rganildi.

Natijalar. Minimal invaziv evakuatsiyaning samaradorligi gematoma topografiyasi, dastlabki nevrologik buzilishlar, qon ketishning barqarorlashuvi, operatsiyaning texnik natijasi va kompleks neyroreanimatsion yordam bilan bog‘liqligi aniqlandi. Mualliflik konsepsiyasi sifatida ICH-SELECT baholash matritsasi taklif qilindi.

Xulosa. Spontan miya ichi qon quyilishida jarrohlik davolashga nomzodlarni tanlash klinik, radiologik, anatomik va funksional mezonlarning kompleks baholanishiga asoslanishi zarur. Taklif etilgan model istiqbolli klinik tadqiqotlarda validatsiyadan o‘tkazilishi kerak.

Kalit so‘zlar: spontan miya ichi qon quyilishi, minimal invaziv neyroxirurgiya, gematoma evakuatsiyasi, kompyuter tomografiya, jarrohlik vaqti, nevrologik tiklanish, funksional prognoz.

ПЕРСОНАЛИЗИРОВАННЫЙ ОТБОР ПАЦИЕНТОВ ДЛЯ МИНИМАЛЬНО ИНВАЗИВНОЙ ЭВАКУАЦИИ ГЕМАТОМЫ ПРИ СПОНТАННОМ ВНУТРИМОЗГОВОМ КРОВОИЗЛИЯНИИ: ИНТЕГРАЦИЯ ЛОКАЛИЗАЦИИ ГЕМАТОМЫ, СРОКОВ ОПЕРАЦИИ, НЕЙРОВИЗУАЛИЗАЦИОННЫХ БИОМАРКЕРОВ И ФУНКЦИОНАЛЬНОГО ВОССТАНОВЛЕНИЯ

Норкулов Сирожиддин Нажмиддинович
Специализированный научно-практический центр нейрохирургии и нейрореабилитации при Самаркандском государственном медицинском университете

Аннотация.

Актуальность. Спонтанное внутримозговое кровоизлияние представляет собой тяжёлое цереброваскулярное заболевание, сопровождающееся высокой смертностью и выраженными функциональными нарушениями. Эффективность хирургической эвакуации гематомы определяется не только объёмом кровоизлияния, но и его локализацией, сроками оперативного вмешательства, техническими характеристиками удаления гематомы и исходной тяжестью неврологических расстройств.

Материалы и методы. Проведён аналитический обзор международных клинических рекомендаций, рандомизированных исследований, наблюдательных работ и систематических обзоров. Изучены объём и локализация гематомы, компьютерно-томографические биомаркеры, сроки операции, хирургические методы и функциональные исходы.

Результаты. Выделены основные параметры, определяющие потенциальную эффективность эвакуации гематомы: топография кровоизлияния, выраженность

неврологических нарушений, стабильность гематомы, техническая полнота эвакуации и качество нейрореанимационной помощи. Предложена концептуальная матрица ICH-SELECT.

Заключение. Индивидуализированный выбор хирургической тактики при спонтанном внутримозговом кровоизлиянии требует комплексной оценки клинических, нейровизуализационных, анатомических и функциональных характеристик. Предложенная модель нуждается в проспективной клинической валидации.

Ключевые слова: спонтанное внутримозговое кровоизлияние, минимально инвазивная нейрохирургия, эвакуация гематомы, компьютерная томография, сроки операции, неврологическое восстановление, функциональный прогноз.

Introduction. Spontaneous intracerebral hemorrhage (ICH) constitutes one of the most severe forms of acute cerebrovascular disease, characterized by rapid accumulation of blood within the cerebral parenchyma, mechanical disruption of neuronal networks, and a cascade of secondary biochemical and inflammatory processes. Despite substantial improvements in diagnostic neuroimaging, neurocritical care, blood pressure management, and neurosurgical technology, ICH continues to impose a considerable burden of mortality and long-term disability. Contemporary guidelines emphasize that effective treatment requires coordinated management of hematoma expansion, intracranial pressure, neurological deterioration, and systemic complications [1, 2]. The epidemiological burden of ICH varies considerably across geographical regions, populations, and healthcare systems. A systematic review by van Asch and colleagues demonstrated important differences in incidence and case fatality according to age and demographic characteristics [3]. An and colleagues subsequently summarized the clinical significance of hypertension, cerebral amyloid angiopathy, chronic kidney disease, and antithrombotic medication exposure as major contributors to spontaneous cerebral hemorrhage [4].

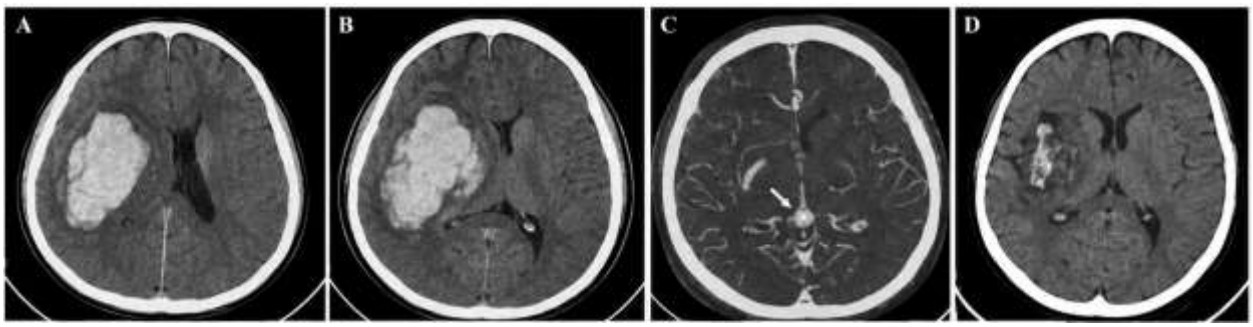
The Global Burden of Disease 2019 analysis estimated approximately 3.41 million new intracerebral hemorrhages worldwide in 2019, representing a substantial component of the global stroke burden [5]. These findings highlight the necessity of improving not only acute survival but also long-term neurological function, rehabilitation access, and secondary prevention. The biological mechanisms underlying ICH extend beyond the immediate formation of a hematoma. Qureshi, Mendelow, and Hanley described the complex interaction between primary mechanical tissue destruction, secondary cerebral edema, intracranial hypertension, and impaired microvascular perfusion [6]. Keep and colleagues further characterized secondary injury mechanisms involving thrombin activation, hemoglobin degradation products, iron-mediated oxidative stress, inflammatory signaling, and blood–brain barrier dysfunction [7].

The initial hematoma volume remains a major determinant of clinical outcome. Broderick and colleagues demonstrated that hemorrhage volume, particularly when combined with the Glasgow Coma Scale (GCS), provides substantial prognostic information regarding early mortality [8]. Kothari and colleagues introduced the widely used ABC/2 method for approximating hematoma volume on computed tomography (CT), facilitating rapid quantitative assessment in emergency settings [9]. The ICH Score proposed by Hemphill and colleagues incorporates neurological status, age, hematoma volume, intraventricular extension, and infratentorial location into a standardized prognostic instrument [10]. Although useful for describing initial severity, the score should not be interpreted as an individual determination of treatment futility or as a replacement for comprehensive clinical judgment. Importantly, ICH is a dynamic pathological process. Hematoma expansion may occur after the initial diagnostic scan, producing additional mechanical injury and

worsening neurological outcomes. Davis and colleagues demonstrated that hematoma growth is independently associated with mortality and functional disability [11]. Consequently, early identification of patients at risk of expansion is central to modern hemorrhagic stroke management.

CT angiography has introduced vascular imaging biomarkers that contribute to the estimation of ongoing bleeding risk. Wada and colleagues described the angiographic spot sign as a marker associated with subsequent hematoma enlargement [12]. The prospective PREDICT study subsequently confirmed an association between the spot sign, hematoma expansion, and adverse clinical outcomes, although its predictive performance varied across clinical populations [13]. Noncontrast CT also provides relevant morphological information. Boulouis and colleagues investigated hematoma heterogeneity and other radiological markers that may indicate a greater probability of continued bleeding [14]. These findings support the principle that surgical decisions should incorporate not only initial hematoma volume but also structural characteristics and evidence of hematoma stability. Cordonnier and colleagues emphasized that ICH management must be individualized because the underlying mechanisms, anatomical distribution, and clinical consequences differ considerably between patients [15]. A lobar hematoma located near the cerebral convexity differs fundamentally from a hemorrhage involving the internal capsule, thalamus, or deep basal ganglia.

Modern medical management remains essential regardless of whether surgical intervention is undertaken. The INTERACT2 trial investigated rapid blood pressure reduction in acute intracerebral hemorrhage and demonstrated favorable findings in analyses of functional outcome distribution, although its primary dichotomous outcome did not reach conventional statistical significance [16]. The ATACH-2 trial subsequently showed that more intensive blood pressure lowering did not provide additional functional benefit and was associated with greater renal adverse events [17]. The INTERACT3 trial provided additional evidence supporting coordinated implementation of a physiological care bundle targeting blood pressure, glucose, temperature, and anticoagulation abnormalities [18]. Such findings indicate that neurosurgical evacuation cannot be considered independently of optimized perioperative medical management. Hemostatic treatments have also been extensively investigated. The TICH-2 trial evaluated tranexamic acid and found that reduced early hematoma expansion did not translate into a significant improvement in the primary functional outcome at 90 days [19]. Similarly, the FAST trial of recombinant activated factor VII demonstrated that limiting hematoma enlargement was not necessarily sufficient to improve functional outcomes [20]. The 2026 FASTEST trial reinforced this distinction by demonstrating reduced hematoma growth without corresponding improvement in long-term functional outcome and with an increased risk of serious thromboembolic complications [21]. The ANNEXA-I trial demonstrated improved hemostatic efficacy with andexanet alfa in selected factor Xa inhibitor-associated hemorrhages, while also identifying thrombotic safety concerns [22].



1-picture. Intracerebral hemorrhage: CT imaging characteristics

Historically, neurosurgical treatment of spontaneous supratentorial ICH has generated considerable controversy. The first International Surgical Trial in Intracerebral Haemorrhage (STICH) did not establish an overall functional advantage of early conventional surgery over initial conservative management [23]. STICH II similarly failed to demonstrate statistically significant superiority for early surgery in its primary outcome among selected patients with superficial lobar hemorrhages, although the results suggested that surgery could be performed without increasing death or disability and might offer survival advantages in certain circumstances [24]. The development of minimally invasive procedures has introduced the possibility of evacuating intracerebral hematomas through smaller operative corridors while limiting additional disruption of surrounding brain tissue. The MISTIE III trial evaluated image-guided catheter-based evacuation with thrombolytic-assisted clot reduction and demonstrated procedural feasibility but did not achieve its primary functional efficacy endpoint [25]. A major change in the contemporary evidence base occurred with the ENRICH trial, which reported improved 180-day functional outcomes after early minimally invasive evacuation in selected patients. The benefit appeared predominantly attributable to intervention in lobar hemorrhages rather than anterior basal ganglia hemorrhages [26]. The SWITCH trial evaluated decompressive craniectomy without obligatory hematoma evacuation in patients with severe deep supratentorial ICH and suggested a possible reduction in death or profound dependence, although statistical uncertainty remained substantial [27]. The earlier ICES trial provided evidence concerning the feasibility and safety of image-guided endoscopic evacuation [28]. Intraventricular extension introduces further therapeutic challenges. The CLEAR III trial demonstrated that intraventricular thrombolytic treatment through an external ventricular drain did not significantly improve the prespecified primary functional outcome, despite important information regarding clot removal and mortality [29].

The neurological consequences of ICH continue well beyond the acute phase. Rehabilitation studies, including the AVERT trial, have shown that very early high-dose mobilization is not necessarily beneficial and may reduce the likelihood of favorable recovery [30]. Comprehensive stroke rehabilitation guidelines therefore emphasize individualized mobilization, multidisciplinary assessment, and coordinated functional recovery programs [31].

Early prognostic assessments also require caution. Becker and colleagues demonstrated that treatment withdrawal may contribute to self-fulfilling predictions of mortality in severe ICH [32]. Long-term outcome studies indicate that survivors remain at risk of recurrent hemorrhage and persistent disability [33]. Secondary prevention strategies, including decisions regarding antiplatelet therapy, require individualized assessment of recurrent hemorrhagic and ischemic risks, as illustrated by the RESTART trial [34]. These findings reveal a central unresolved challenge: selecting patients who are most likely to benefit from hematoma evacuation without exposing others to unnecessary surgical injury. The traditional focus on hemorrhage volume alone appears insufficient to address this complexity. The objective of this study is to critically evaluate the evidence supporting minimally invasive evacuation of spontaneous intracerebral hematomas and to propose an integrated conceptual framework that incorporates anatomical location, clinical severity, hematoma stability, surgical timing, procedural feasibility, and postoperative rehabilitation potential.

Materials and methods. This study was designed as a narrative analytical review of the contemporary literature concerning spontaneous intracerebral hemorrhage and its surgical management. The review incorporated peer-reviewed publications indexed in major biomedical research resources, including identifiable clinical trial reports, international recommendations,

systematic reviews, and observational studies. Emphasis was placed on studies examining neurosurgical intervention, imaging-based selection, functional outcome, and postoperative neurological recovery. The evidence base included historical trials of conventional craniotomy, randomized investigations of catheter-based evacuation, endoscopic surgery, early minimally invasive hematoma removal, and decompressive craniectomy. Relevant studies of medical stabilization, anticoagulation reversal, intracranial hemorrhage prognostication, and neurorehabilitation were also considered. The analysis was organized into clinical, radiological, anatomical, procedural, and functional domains.

Clinical assessment included baseline level of consciousness, Glasgow Coma Scale, focal neurological deficits, age, premorbid functional status, systemic comorbidities, and medication-associated bleeding risk. Radiological assessment addressed hematoma volume, anatomical compartment, intraventricular extension, midline displacement, hydrocephalus, hemorrhage heterogeneity, and CT angiography markers of active bleeding. Hematoma volume was considered using the conventional ABC/2 approximation:

Estimated hematoma volume (mL) = (A × B × C) / 2 In this expression, A represents the greatest hematoma diameter, B the greatest perpendicular diameter, and C the approximate craniocaudal extent of hemorrhage. The method is most suitable for approximately ellipsoidal hematomas; irregular or multilobulated lesions may require volumetric segmentation. Surgical strategies were classified according to operative corridor and mechanism of treatment. These included conventional craniotomy, catheter-based minimally invasive aspiration with thrombolysis, endoscopic or parafascicular evacuation, and decompressive craniectomy. The main clinical outcomes considered were mortality, neurological deterioration, procedural complications, the modified Rankin Scale (mRS), functional independence, and the need for long-term rehabilitation.

A comparative synthesis was performed without pooling trial populations or calculating new aggregate treatment effects, because the included investigations differed substantially in eligibility criteria, baseline hemorrhage characteristics, surgical approaches, and follow-up periods. As a conceptual contribution, a multidimensional assessment matrix named ICH-SELECT was developed. The framework was designed to organize clinically relevant factors that may influence surgical suitability and postoperative recovery. No new patient cohort was recruited. No original patient-level data were collected, and no independent randomized intervention or meta-analysis was performed. Therefore, the proposed matrix represents a research hypothesis rather than a validated clinical prediction score.

Results. Hematoma Topography as a Determinant of Surgical Strategy**.** The reviewed evidence indicates that hematoma location represents a fundamental variable in surgical decision-making. Cortical and subcortical lobar hemorrhages may provide relatively accessible surgical corridors, whereas deep hemorrhages frequently involve functionally indispensable structures. Lobar hematomas may occupy frontal, temporal, parietal, or occipital regions and cause neurological impairment through a combination of local tissue destruction, mass effect, edema, and disruption of cortical networks. Deep basal ganglia hematomas may directly injure the internal capsule, striatum, and adjacent perforating arterial territories. Consequently, even technically successful evacuation may not reverse deficits caused by primary destruction of descending motor pathways. Thalamic hemorrhages are further complicated by the proximity of sensory relay nuclei, internal capsule fibers, and ventricular structures. Intraventricular extension may produce obstructive hydrocephalus requiring cerebrospinal fluid diversion. The reviewed clinical trials support the interpretation that surgical accessibility and the extent of irreversible primary

neurological injury may influence the relationship between hematoma removal and functional recovery.

Table 1. Anatomical Characteristics of Intracerebral Hemorrhage and Their Potential Neurosurgical Implications

Hematoma location	Major anatomical concerns	Potential surgical considerations	Important limitations
Frontal lobar	Frontal cortex, subcortical white matter	Potentially accessible minimally invasive corridor	Executive dysfunction and frontal network injury
Temporal lobar	Language networks, optic radiations, temporal vessels	Selected endoscopic or parafascicular evacuation	Risk to dominant temporal functions
Parietal lobar	Sensorimotor association cortex, major white matter pathways	Image-guided evacuation in selected patients	Potential sensory and visuospatial deficits
Basal ganglia	Internal capsule, lenticulostriate arteries	Highly individualized surgical assessment	Primary motor pathway destruction may be irreversible
Thalamus	Sensory nuclei, internal capsule, ventricular system	Selected decompressive or ventricular interventions	Deep location and limited evidence of functional benefit from evacuation
Cerebellum	Brainstem, fourth ventricle, posterior fossa	Urgent surgical evacuation when clinically indicated	Rapid brainstem compression and obstructive hydrocephalus

Radiological Biomarkers and Hematoma Stability. Neuroimaging provides more than a static measurement of hematoma dimensions. The location, configuration, density distribution, intraventricular extension, and associated mass effect can contribute to risk assessment. The CT angiography spot sign is associated with active contrast extravasation and subsequent hematoma expansion. Noncontrast CT findings such as heterogeneous density, irregular margins, and internal hypodense regions may provide additional information. Nevertheless, none of these biomarkers independently establishes an indication for surgery. Their interpretation requires integration with neurological status, anticoagulation exposure, time from onset, and availability of repeated imaging. Serial CT imaging is particularly important when neurological deterioration occurs or when the initial assessment suggests active hemorrhage expansion. A stable hematoma may be more suitable for planned evacuation than one with continued uncontrolled bleeding, because the latter situation increases the risk of reaccumulation and additional neurological damage.

Table 2. Neuroimaging Parameters Relevant to Surgical Selection and Outcome Assessment

Parameter	Clinical interpretation	Potential relevance
Baseline hematoma volume	Quantifies initial hemorrhagic burden	Severity assessment and trial eligibility

Hematoma location	Identifies affected anatomical structures	Feasibility and risk of the surgical corridor
CT angiography spot sign	Suggests ongoing bleeding risk	Hematoma expansion surveillance
Noncontrast CT heterogeneity	May indicate hematoma instability	Supports integrated expansion-risk assessment
Intraventricular hemorrhage	Suggests ventricular involvement and hydrocephalus risk	Ventricular drainage and neurocritical care decisions
Midline shift	Reflects mass effect and hemispheric displacement	Assessment of intracranial pressure-related risk
Postoperative residual volume	Quantifies procedural evacuation result	Technical performance and postoperative monitoring
Postoperative rebleeding	Indicates an acute surgical complication	Repeat imaging and emergency reassessment

Comparative Outcomes of Major Surgical Trials. The clinical literature reveals important differences among surgical techniques and treatment populations. The original STICH trial evaluated conventional early surgery in a heterogeneous population and failed to demonstrate overall superiority in its primary functional endpoint. STICH II focused on more superficial lobar hemorrhages and found an unfavorable six-month outcome in 59% of surgical patients compared with 62% of conservatively managed patients in the analyzed groups. The difference was not statistically significant. MISTIE III introduced a standardized minimally invasive catheter-based approach with thrombolytic-assisted clot reduction. In the modified intention-to-treat analysis, the estimated proportion of patients achieving mRS 0–3 at one year was 45% in the intervention group and 41% in the control group, without statistically significant superiority. The ENRICH trial enrolled 300 patients with selected supratentorial hematomas. At 180 days, the mean utility-weighted mRS was 0.458 in the surgical group and 0.374 in the medical treatment group. The trial demonstrated superiority according to its prespecified Bayesian criterion, with benefit predominantly associated with lobar hemorrhage. The SWITCH trial evaluated decompressive craniectomy in severe deep hemorrhage. Death or very severe disability, defined as mRS 5–6 at 180 days, occurred in approximately 44% of surgically treated patients compared with 58% of medically treated patients. However, the result remained statistically uncertain, and substantial disability occurred among survivors.

Table 3. Comparison of Major Randomized Studies of Surgical Management in Intracerebral Hemorrhage

Trial	Year	Intervention	Main reported finding	Interpretation
STICH	2005	Conventional early surgery	No overall primary functional superiority	Routine open surgery not established for all supratentorial ICH
STICH II	2013	Early surgery for selected superficial lobar ICH	No statistically significant primary functional benefit	Possible benefit in selected circumstances

MISTIE III	2019	Catheter-based aspiration and thrombolysis	Primary functional endpoint neutral	Evacuation technically feasible; procedural completeness important
ENRICH	2024	Early minimally invasive parafascicular evacuation	Improved utility-weighted functional outcome	Benefit primarily supported for selected lobar hemorrhages
SWITCH	2024	Decompressive craniectomy for severe deep ICH	Possible reduction in death or profound dependence	Evidence uncertain; major residual disability remains common
ICES	2016	Image-guided endoscopic evacuation	Preliminary feasibility and safety findings	Supports technical development; limited trial size

Surgical Timing and Extent of Evacuation. Timing represents an important but incompletely resolved component of surgical planning. The potential advantage of early evacuation is reduction of mass effect and earlier interruption of hematoma-associated secondary injury. However, evacuation during an unstable bleeding phase may increase the risk of recurrent hemorrhage. The temporal relationship between onset, initial imaging, hematoma expansion, medical stabilization, and surgical intervention should therefore be considered as a continuous clinical process rather than as a single universal threshold. The ENRICH trial specifically evaluated intervention within an early treatment window, but its results should not be extrapolated to every hemorrhage location, volume, or clinical severity. The completeness of evacuation is another important variable. MISTIE III incorporated a residual hematoma target of 15 mL or less. Although the trial did not demonstrate overall superiority in its primary efficacy analysis, its procedural findings highlight the importance of achieving meaningful clot reduction while minimizing additional brain injury. However, more extensive evacuation should not automatically be considered preferable if it requires excessive disruption of functioning neural structures.

Functional Outcome and Rehabilitation Potential. Functional recovery after intracerebral hemorrhage depends on factors that extend beyond surgical removal of the hematoma. Primary neuronal destruction, secondary edema, ischemic injury, systemic complications, and reduced mobility can all influence long-term outcomes. Recovery may involve motor performance, cognition, language, swallowing, balance, emotional regulation, and activities of daily living. The modified Rankin Scale is useful for global disability assessment but cannot fully characterize the different dimensions of postoperative neurological recovery. Additional evaluation may include the Barthel Index, Functional Independence Measure, motor function scales, and structured cognitive assessment. Early rehabilitation planning is particularly important for patients who survive major hemorrhage but remain dependent on assistance. The intensity and timing of mobilization should be tailored to neurological stability, intracranial physiology, cardiopulmonary condition, and the patient's capacity to participate. Development of the ICH-SELECT Conceptual Framework**.** Based on the reviewed evidence, a multidimensional conceptual assessment framework was developed. The ICH-SELECT model integrates hemorrhage topography, neurological severity, radiological stability, surgical feasibility, and anticipated rehabilitation needs. Its purpose is not to calculate an immediate numerical probability of recovery. Instead, it provides a structured hypothesis for future clinical research investigating which combinations of variables may identify patients who benefit from minimally invasive evacuation.

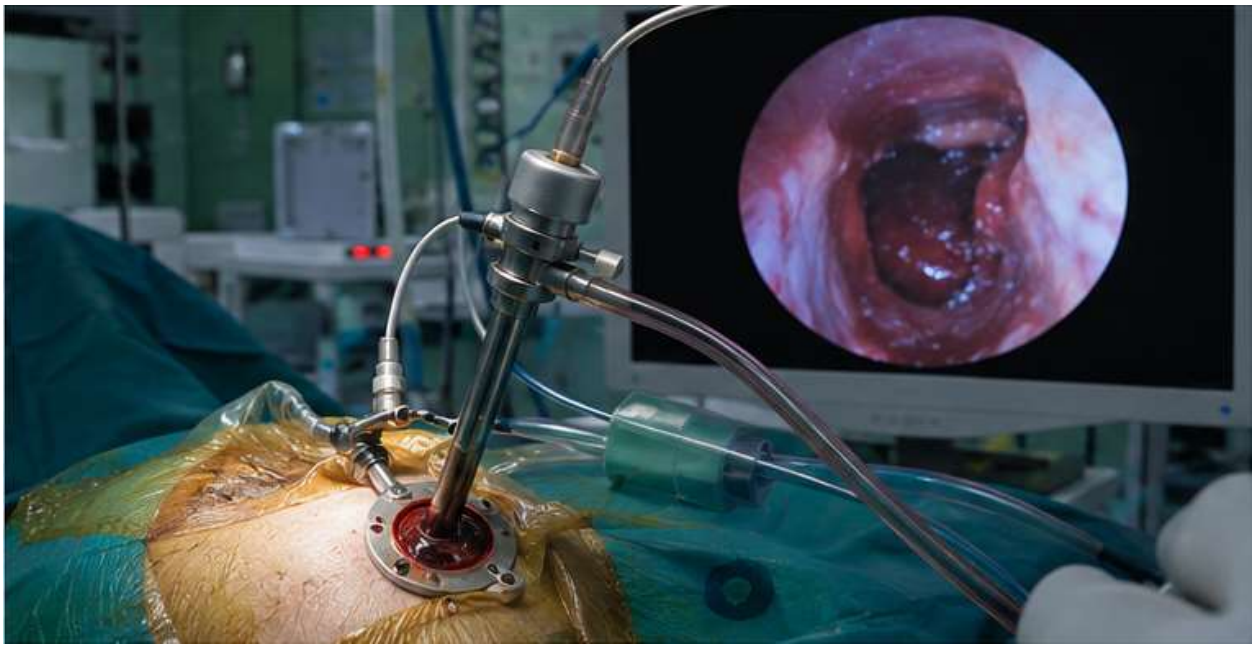
Table 4. Proposed ICH-SELECT Framework for Individualized Surgical Assessment

Assessment domain	Candidate variables	Clinical significance
Hemorrhage anatomy	Lobar or deep location, dominant hemisphere, white matter pathways	Determines surgical accessibility and risk to functional networks
Clinical severity	GCS, neurological deficits, premorbid functional status	Characterizes initial neurological burden
Hematoma characteristics	Volume, mass effect, intraventricular extension	Identifies structural and physiological consequences
Hemorrhage stability	Serial CT findings, spot sign, anticoagulation status	Assesses potential ongoing bleeding
Surgical feasibility	Available corridor, anticipated residual volume, procedural expertise	Balances evacuation benefit against operative injury
Physiological reserve	Age, comorbidities, organ dysfunction	Informs perioperative risk
Rehabilitation potential	Cognition, motor reserve, swallowing, participation capacity	Supports postoperative recovery planning
Treatment goals	Patient preferences and acceptable functional outcomes	Ensures individualized and ethically appropriate decisions

A future validation study could prospectively collect these variables, specify a primary endpoint such as 180-day ordinal mRS or 365-day functional independence, and investigate the association of candidate predictors with outcomes. Statistical analysis would require adjustment for confounding factors, assessment of predictor interactions, calibration, discrimination, and evaluation in independent clinical populations. Such research would also need to address the possibility that surgical suitability differs between lobar and deep hemorrhages.

Discussion. The management of spontaneous intracerebral hemorrhage has entered an important period of reassessment following the publication of newer minimally invasive surgical trials. Historically, conventional craniotomy did not consistently demonstrate overall functional benefit. However, more recent evidence indicates that the effectiveness of surgical treatment may depend substantially on patient selection and procedural approach. The 2022 American Heart Association/American Stroke Association guideline emphasizes that ICH treatment requires a coordinated approach incorporating neurological assessment, hemorrhage stabilization, management of secondary injury, and appropriate neurosurgical intervention [1]. The 2025 European Stroke Organisation and European Association of Neurosurgical Societies guideline provides an updated evidence-based framework that considers hematoma location, neurological status, timing, operative technique, and procedural risk when discussing surgery [2]. The epidemiological studies by van Asch and colleagues [3], An and colleagues [4], and the Global Burden of Disease collaborators [5] demonstrate the continuing global significance of hemorrhagic stroke. These investigations support the need to evaluate treatment strategies using long-term disability and independence, rather than restricting assessment to acute survival. The pathophysiological rationale for evacuation is based on the hypothesis that removal of hematoma volume may reduce mass effect, local pressure, and exposure of surrounding tissue to blood-derived neurotoxic substances. Nevertheless, the biological processes described by Qureshi and colleagues

[6] and Keep and colleagues [7] do not establish that evacuation can reverse pre-existing structural damage.



2-picture. Minimally invasive endoscopic hematoma evacuation

This distinction is particularly important in deep hemorrhages involving the internal capsule. Although removing the hematoma may decrease intracranial pressure or prevent further deterioration, restoration of severely damaged descending pathways may remain limited. Broderick and colleagues established the prognostic importance of baseline hematoma volume [8], whereas the ABC/2 method described by Kothari and colleagues made rapid volume estimation feasible in routine emergency care [9]. The ICH Score developed by Hemphill and colleagues subsequently provided a practical standardized description of initial clinical severity [10]. However, prognostic severity is not equivalent to treatment responsiveness. A patient with a substantial hematoma burden may have a poor predicted outcome under conventional management, yet still benefit from intervention if the underlying injury is potentially modifiable.

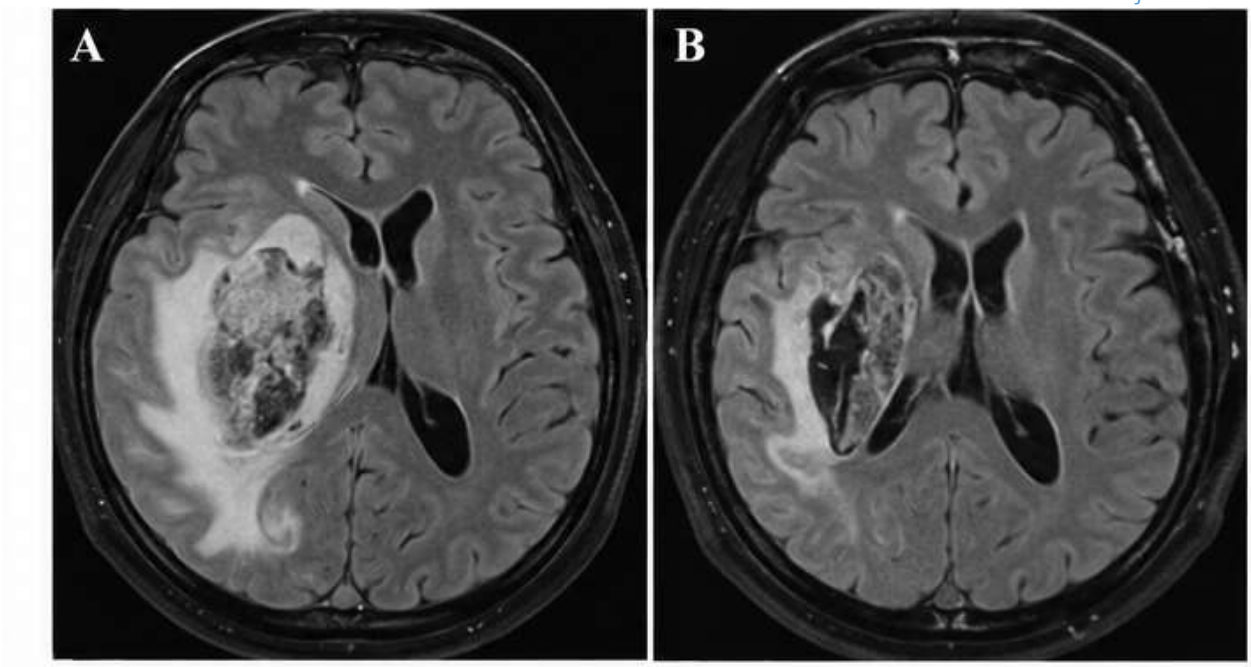
Davis and colleagues demonstrated the association between continued hematoma growth and poor outcomes [11]. Wada and colleagues [12] and Demchuk and colleagues [13] showed that angiographic imaging can identify patients at increased risk of hematoma expansion. Boulouis and colleagues subsequently characterized additional noncontrast CT markers of hemorrhage instability [14].

These findings indicate that neuroimaging biomarkers may contribute to surgical planning, particularly when assessing whether hemorrhage expansion has stabilized. However, it would be inappropriate to assume that identifying a high-risk biomarker automatically identifies a patient who will benefit from surgery. Cordonnier and colleagues emphasized the heterogeneous nature of ICH and the need for integrated clinical decision-making [15]. This principle is reinforced by studies of acute blood pressure management. INTERACT2 provided evidence supporting early, controlled blood pressure treatment, although different statistical analyses produced different levels of certainty [16]. ATACH-2 demonstrated that excessively intensive treatment does not necessarily improve outcome and may produce treatment-related complications [17]. The INTERACT3 study expanded the focus from individual interventions to organized care delivery. Its findings support the use of coordinated physiological management alongside specialist stroke and neurocritical care [18]. Hemostatic trials have further illustrated the limitations of relying on isolated surrogate

endpoints. In TICH-2, reduced early hematoma growth did not establish a corresponding improvement in the principal functional outcome [19]. The phase III factor VII trial reported by Mayer and colleagues showed a similar separation between radiological hemostasis and meaningful clinical recovery [20]. The FASTEST trial published in 2026 reinforced this observation. Although recombinant factor VIIa reduced hematoma growth when administered within two hours, it did not significantly improve functional outcomes and increased serious thromboembolic complications [21].

The ANNEXA-I trial showed that targeted anticoagulant reversal may improve hemostatic efficacy in selected patients receiving factor Xa inhibitors. Nevertheless, treatment-related thrombotic risks require careful evaluation [22]. Therefore, surgery and hemostatic management should be integrated within an individualized physiological and vascular risk assessment. The STICH trial established that routine early open surgery did not improve outcomes across a broad population of spontaneous supratentorial hemorrhages [23]. STICH II subsequently examined a more anatomically restricted group of superficial lobar hematomas but still did not demonstrate significant superiority in its primary functional endpoint [24]. These results should not be interpreted as proof that hematoma evacuation is universally ineffective. Rather, they reveal the importance of clinical heterogeneity, treatment timing, anatomical location, and additional tissue injury caused by surgical access. MISTIE III was designed to reduce surgical invasiveness through image-guided catheter placement and thrombolytic-assisted hematoma evacuation. The neutral primary functional result indicates that successful clot reduction does not guarantee clinical benefit across the entire treated population [25].

However, the relationship between residual hematoma volume, operative performance, and outcomes remains clinically relevant. The trial also demonstrated that consistent execution of the procedure is an important component of surgical quality. The ENRICH trial provided more encouraging evidence for early minimally invasive evacuation. Its primary endpoint demonstrated a favorable difference in utility-weighted functional outcomes at 180 days [26]. A particularly important finding was that the effect appeared primarily attributable to lobar hemorrhages. The smaller anterior basal ganglia subgroup did not demonstrate a similar treatment effect. Consequently, ENRICH should not be interpreted as evidence supporting universal minimally invasive evacuation of all deep hematomas. The difference between lobar and deep hemorrhages is biologically plausible. Lobar hematomas may be removed along relatively accessible corridors, whereas deep hemorrhages may involve compact white matter pathways and perforating vessels that are highly vulnerable to surgical injury. The SWITCH trial addressed a different therapeutic question: whether decompressive craniectomy without obligatory hematoma removal could reduce death or profound dependence in severe deep ICH [27]. The numerical reduction in the primary adverse outcome suggested potential benefit but did not provide definitive statistical evidence. Furthermore, survival remained associated with substantial disability in many patients.



3-picture. Preoperative and postoperative MRI assessment

The ICES trial contributed to the development of stereotactic endoscopic evacuation by demonstrating technical feasibility and providing preliminary safety information [28]. However, small early-phase studies cannot independently establish broad treatment efficacy. The CLEAR III trial further illustrates that an intervention may improve aspects of clot removal without producing a significant effect on its prespecified primary disability outcome [29]. The distinction between parenchymal hematoma evacuation and intraventricular clot treatment is important because these procedures target different anatomical and physiological mechanisms. Beyond acute treatment, rehabilitation remains a major determinant of long-term independence. The AVERT trial demonstrated that very early high-dose mobilization can adversely affect recovery in a mixed stroke population [30]. Although those results cannot be transferred without qualification to every postoperative ICH patient, they reinforce the importance of individualized rehabilitation intensity. The stroke rehabilitation guidelines published by Winstein and colleagues emphasize multidisciplinary assessment of motor, cognitive, communication, swallowing, and psychosocial deficits [31]. Accordingly, postoperative outcome studies should incorporate standardized functional measurements rather than relying solely on radiological clot reduction. Prognostic communication also requires particular caution. Becker and colleagues demonstrated how premature treatment withdrawal can contribute to self-fulfilling predictions of mortality [32]. This observation highlights the ethical limitations of converting population-level prognostic associations into irreversible individual treatment decisions.

Long-term follow-up remains essential. Poon and colleagues documented persistent risks and adverse long-term outcomes among ICH survivors [33]. The RESTART trial additionally demonstrated the complexity of secondary prevention decisions in patients who remain vulnerable to both hemorrhagic and ischemic vascular events [34]. Collectively, these studies suggest that the clinical value of minimally invasive evacuation depends on a combination of anatomical opportunity, potentially reversible injury, procedural safety, and the capacity for subsequent functional recovery. The ICH-SELECT framework was developed to organize these considerations into a structured research model. Its principal conceptual contribution is the separation of three related but distinct domains: anatomical feasibility of clot removal, biological and physiological

consequences of hemorrhage, and anticipated long-term functional recovery. For example, two patients may have hematomas of similar volume but markedly different clinical characteristics. A lobar hemorrhage producing mass effect without extensive destruction of essential white matter pathways may represent a different surgical problem from an equally large deep hemorrhage involving the internal capsule. Similarly, patients with comparable radiological evacuation results may demonstrate different long-term outcomes because of differences in premorbid function, medical complications, neuronal reserve, and rehabilitation access.

These variations provide a rationale for future prediction studies incorporating anatomical segmentation, diffusion-based tract evaluation where feasible, standardized surgical performance measures, and longitudinal functional assessment. However, any such model would require carefully controlled prospective validation. Variable selection should be prespecified, statistical overfitting minimized, and calibration and discrimination independently evaluated. The proposed framework also has important limitations. The present article represents a narrative review rather than a registered systematic review or quantitative meta-analysis. The included trials differ in patient populations, surgical methods, eligibility thresholds, and endpoint definitions. Furthermore, several proposed prognostic dimensions are supported primarily by biological plausibility or observational evidence rather than definitive treatment-interaction analyses. Their inclusion in the conceptual matrix should therefore not be interpreted as proof of predictive effectiveness. In future investigations, an important methodological distinction will be necessary between variables that predict poor outcome and variables that predict greater benefit from surgery. These two groups are not necessarily identical. An optimal clinical selection instrument would ideally identify both the patient's baseline risk and the incremental treatment effect associated with a specific surgical intervention. Thus, precision-oriented neurosurgical decision-making in ICH should move beyond the simple question of whether a hematoma can be removed toward a more comprehensive assessment of whether its removal is likely to improve survival with an acceptable degree of functional independence.

Conclusion. Spontaneous intracerebral hemorrhage remains a major neurosurgical and neurocritical care challenge because its clinical consequences arise from the interaction of primary tissue destruction, secondary injury, hematoma expansion, intracranial mass effect, and systemic complications. Modern minimally invasive techniques offer the possibility of hematoma evacuation through smaller operative corridors, potentially reducing additional brain injury associated with conventional approaches. The available clinical evidence indicates that surgical benefit is not uniform across all hemorrhage subtypes. Anatomical localization, baseline neurological severity, hemorrhage stability, procedural timing, completeness of evacuation, and surgical expertise should be considered during treatment planning. Selected patients with lobar hemorrhage may benefit from early minimally invasive evacuation, whereas the effectiveness of similar approaches for deep hemorrhages remains more uncertain. Decompressive craniectomy addresses a different therapeutic mechanism and requires separate interpretation. Postoperative assessment should include both structural and functional outcomes. Hematoma volume reduction alone is insufficient to characterize neurological recovery, independence, cognition, quality of life, or rehabilitation needs. The proposed ICH-SELECT conceptual framework integrates anatomical, clinical, radiological, procedural, and rehabilitation-related variables to support future research into individualized surgical selection. The framework has not been clinically validated and should not be used as an independent treatment-decision algorithm. Prospective multicenter investigation, standardized outcome measurement, and external validation are necessary before its prognostic or predictive utility can be established.

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