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MINIMALLY INVASIVE EVACUATION OF SPONTANEOUS INTRACEREBRAL HEMORRHAGE IN THE POST-ENRICH ERA: LOCATION-BASED SELECTION, EARLY CLOT REDUCTION, AND RESIDUAL-VOLUME TARGETS

Abstract

Background. Spontaneous intracerebral hemorrhage remains a highly lethal and disabling stroke subtype. Conventional craniotomy has not consistently improved functional outcomes, whereas modern minimally invasive techniques seek rapid clot reduction while limiting injury to viable brain.

Materials and methods. Randomized trials, contemporary guidelines, prospective cohorts, surgical-performance analyses, and endoscopic investigations published through July 2026 were synthesized. Evidence was organized according to hemorrhage location, volume, expansion stability, neurological severity, operative timing, access trajectory, evacuation method, residual clot, intraventricular extension, and postoperative care.

Results. MISTIE III demonstrated procedural safety and suggested that reduction to a residual volume of 15 mL or less is associated with improved outcome, although the primary functional endpoint was neutral. ENRICH established a functional benefit for early trans-sulcal evacuation within 24 hours, driven predominantly by lobar hemorrhage, with lower 30-day mortality than medical management. MIND achieved substantial volume reduction but did not improve 180-day disability in a cohort dominated by deep hemorrhage and treated within 72 hours. CLEAR III reduced mortality after intraventricular clot lysis without improving the prespecified functional endpoint. These apparently discordant trials indicate that minimally invasive surgery is not a uniform intervention. Benefit depends on removing a clinically meaningful amount of blood early, through a tissue-preserving route, in patients whose neurological networks remain recoverable.

Conclusion. The proposed EVAC-ICH framework integrates eligibility, volume and location, active-bleeding control, corridor selection, intraoperative hemostasis, clot-reduction targets, and postoperative neurocritical care. Future trials should prioritize biological timing, tract preservation, quantitative residual volume, and patient-centered ordinal outcome shifts.

Keywords: intracerebral hemorrhage; minimally invasive surgery; ENRICH; MISTIE III; MIND trial; neuroendoscopy; hematoma evacuation; residual clot volume; intraventricular hemorrhage; trans-sulcal surgery.

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МАЛОИНВАЗИВНАЯ ЭВАКУАЦИЯ СПОНТАННОГО ВНУТРИМОЗГОВОГО КРОВОИЗЛИЯНИЯ В ЭПОХУ ПОСЛЕ ENRICH: ОТБОР ПО ЛОКАЛИЗАЦИИ, РАННЕЕ УМЕНЬШЕНИЕ ГЕМАТОМЫ И ЦЕЛЕВОЙ ОСТАТОЧНЫЙ ОБЪЁМ

Аннотация

Актуальность. Спонтанное внутримозговое кровоизлияние остаётся одним из наиболее летальных и инвалидизирующих вариантов инсульта. Традиционная краниотомия не продемонстрировала устойчивого улучшения функциональных исходов, тогда как современные малоинвазивные технологии направлены на быстрое уменьшение объёма гематомы при минимальном повреждении жизнеспособного мозга.

Материалы и методы. Синтезированы рандомизированные исследования, современные руководства, проспективные когорты, анализы хирургической эффективности и эндоскопические работы, опубликованные до июля 2026 года. Данные систематизированы по локализации и объёму кровоизлияния, стабильности гематомы, тяжести дефицита, времени операции, траектории доступа, методу эвакуации, остаточному объёму, внутрижелудочковому компоненту и послеоперационной терапии. Результаты. MISTIE III подтвердило безопасность метода и показало, что достижение остаточного объёма не более 15 мл ассоциировано с лучшим исходом, хотя первичная функциональная конечная точка оставалась нейтральной. ENRICH впервые продемонстрировало функциональное преимущество ранней транссулькальной эвакуации в течение 24 часов, преимущественно при лобарных гематомах, и снижение 30-дневной летальности. MIND обеспечило значительное уменьшение объёма крови, но не улучшило 180-дневную инвалидизацию в популяции с преобладанием глубоких кровоизлияний и операцией в пределах 72 часов. CLEAR III снизило летальность после внутрижелудочкового тромболизиса, не улучшив заранее определённый функциональный исход. Эти результаты показывают, что малоинвазивная хирургия не является единообразным вмешательством. Польза зависит от раннего и достаточного удаления крови через тканесберегающий коридор у пациентов с сохранённым потенциалом восстановления функциональных сетей.

Заключение. Модель EVAC-ICH объединяет клинический отбор, объём и локализацию, контроль продолжающегося кровотечения, выбор доступа, гемостаз, целевой остаточный объём и нейроинтенсивное ведение.

Ключевые слова: внутримозговое кровоизлияние; малоинвазивная хирургия; ENRICH; MISTIE III; MIND; нейроэндоскопия; эвакуация гематомы; остаточный объём; внутрижелудочковое кровоизлияние; транссулькальный доступ.

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ENRICH DAVRIDAN KEYIN SPONTAN INTRASEREBRAL QON QUYILISHINI MINIMAL INVAZIV EVAKUATSIYA QILISH: JOYLASHUVGA ASOSLANGAN TANLOV, GEMATOMANI ERTA KAMAYTIRISH VA MAQSADLI QOLDIQ HAJM

Annotatsiya

Dolzarblik. Spontan intraserebral qon quyilishi insultning o'lim va og'ir nogironlik bilan eng ko'p bog'liq turlaridan biri bo'lib qolmoqda. An'anaviy kraniotomiya funksional natijalarni muntazam ravishda yaxshilamagan, zamonaviy minimal invaziv texnologiyalar esa hayotiy miya to'qimasini imkon qadar saqlagan holda gematoma hajmini tez kamaytirishga qaratilgan.

Material va usullar. 2026-yil iyuligacha chop etilgan randomizatsiyalangan tadqiqotlar, klinik tavsiyalar, prospektiv kohortalar, jarrohlik samaradorligi tahlillari va endoskopik ishlar sintez qilindi.

Natijalar qon quyilish joylashuvi va hajmi, gematoma barqarorligi, nevrologik og‘irlik, operatsiya vaqti, kirish trayektoriyasi, evakuatsiya usuli, qoldiq qon hajmi, qorincha ichiga tarqalish va operatsiyadan keyingi davolash bo‘yicha tizimlashtirildi. MISTIE III usul xavfsizligini tasdiqladi va qoldiq hajmni 15 ml yoki undan kam darajaga tushirish yaxshiroq natija bilan bog‘liqligini ko‘rsatdi, biroq asosiy funksional yakun neytral bo‘ldi. ENRICH 24 soat ichidagi erta transsulkulyar evakuatsiyaning, asosan lobar gematomalarda, funksional foydasini va 30 kunlik o‘limning kamayishini ko‘rsatdi. MIND gematoma hajmini sezilarli kamaytirdi, ammo chuqur qon quyilishlar ustun bo‘lgan va 72 soatgacha operatsiya qilingan guruhda 180 kunlik nogironlikni yaxshilamadi. CLEAR III qorincha ichidagi trombolizdan so‘ng o‘limni kamaytirdi, ammo belgilangan funksional natijani yaxshilamadi.

Xulosa. Minimal invaziv jarrohlik yagona standart amaliyot emas. EVAC-ICH modeli bemor tanlash, hajm va joylashuv, faol qon ketishini nazorat qilish, xavfsiz koridor, intraoperatsion gemostaz, qoldiq hajm maqsadi va neyrointensiv yordamni birlashtiradi.

Kalit so‘zlar: intraserebral qon quyilishi; minimal invaziv jarrohlik; ENRICH; MISTIE III; MIND; neyroendoskopiya; gematoma evakuatsiyasi; qoldiq hajm; intraventrikulyar qon quyilishi; transsulkulyar kirish.

Introduction. Spontaneous intracerebral hemorrhage is caused by nontraumatic rupture of a cerebral vessel with accumulation of blood within the brain parenchyma. It accounts for a smaller proportion of all strokes than cerebral infarction but produces disproportionately high early mortality, severe disability, prolonged intensive care, and long-term dependence. The initial hematoma directly disrupts neural tissue and is followed by expansion, mechanical deformation, intracranial hypertension, intraventricular extension, hydrocephalus, perihematomal edema, inflammation, thrombin toxicity, iron-mediated oxidative injury, mitochondrial dysfunction, and delayed degeneration of surrounding white-matter pathways [1–3]. The biological rationale for hematoma evacuation is compelling. Removal of blood can reduce mass effect, lower intracranial pressure, restore local perfusion, relieve ventricular obstruction, and decrease exposure of surrounding tissue to hemoglobin degradation products and inflammatory mediators. However, surgery also injures brain. Cortical incision, white-matter transgression, retraction, venous damage, thermal coagulation, incomplete hemostasis, and postoperative rebleeding may offset the benefit of clot reduction [3, 6, 10]. This balance explains the historical difficulty of demonstrating functional benefit. Conventional craniotomy provides wide exposure and direct hemostasis but requires substantial tissue disruption, especially when the hematoma is deep. STICH and STICH II did not establish a general functional advantage of early open evacuation over initial medical management. STICH II suggested that selected patients with superficial lobar hemorrhage without intraventricular extension might have a survival advantage, but the overall functional result remained neutral [5, 11, 16]. These trials did not prove that blood removal is biologically ineffective. They demonstrated that the benefit of decompression and clot removal can be lost when access injury is excessive, patient selection is broad, operative timing is delayed, or the amount of blood removed is insufficient. Modern minimally invasive surgery seeks to change this therapeutic ratio.

The term minimally invasive surgery includes several distinct procedures. Catheter-based aspiration with local thrombolysis gradually liquefies and drains the hematoma. Stereotactic aspiration uses a

cannula or catheter placed through a burr hole. Endoscopic evacuation permits direct visualization, irrigation, aspiration, and focal coagulation. Tubular trans-sulcal surgery creates a circumferential working corridor through a sulcus or shortest white-matter path. Mechanically assisted aspiration devices fragment and remove clot under endoscopic or exoscopic visualization. Robotic stereotaxy improves trajectory reproducibility but does not determine biological eligibility [4, 7, 14]. These procedures differ in timing, operative speed, tissue disruption, ability to control active bleeding, maximum achievable evacuation, and dependence on postoperative thrombolysis. Combining them under one category can obscure clinically meaningful differences. A slow catheter-lysis protocol completed several days after onset is not biologically equivalent to early trans-sulcal evacuation within 24 hours. MISTIE III was a landmark phase III trial of catheter aspiration followed by low-dose alteplase irrigation. The procedure substantially reduced clot volume and was safe, but the primary functional endpoint was neutral. Surgical-performance analyses suggested that patients in whom residual hematoma was reduced to 15 mL or less had better outcomes, making procedural completeness a central therapeutic variable [8, 9, 25]. ENRICH subsequently provided the first convincing randomized evidence of functional benefit from early minimally invasive parenchymal evacuation. Patients with 30–80 mL lobar or anterior basal-ganglia hemorrhage were randomized within 24 hours. The mean utility-weighted modified Rankin score at 180 days favored surgery, but the benefit was attributable mainly to the lobar subgroup. The anterior basal-ganglia subgroup did not demonstrate benefit, and enrollment of that anatomical group was stopped according to the adaptive trial design [10, 13, 23]. MIND introduced additional complexity. The trial used mechanically assisted minimally invasive aspiration in 236 patients with 20–80 mL supratentorial hemorrhage and permitted surgery within 72 hours. The surgical group achieved substantial median clot reduction, but neither 180-day disability nor 30-day mortality differed significantly from medical management. Nearly 70% of the cohort had deep hemorrhage, and enrollment stopped early, reducing statistical power [2, 3, 18]. The contrast between ENRICH and MIND does not mean that one device is effective and another is ineffective. It suggests that location, time, access trajectory, residual hematoma, corticospinal-tract integrity, trial population, and perioperative workflow determine whether removal translates into recovery.

Intraventricular hemorrhage represents another related but distinct condition. Blood obstructs CSF pathways, produces hydrocephalus, increases intracranial pressure, exposes ependymal surfaces to inflammatory products, and is strongly associated with poor outcome. CLEAR III showed that intraventricular alteplase administered through an external ventricular drain accelerated clot clearance and reduced mortality but did not improve the prespecified functional endpoint. More survivors remained severely disabled, illustrating that survival and functional independence are not interchangeable outcomes [6, 13, 28]. The modern question is therefore not whether surgery is beneficial for all intracerebral hemorrhage. The appropriate question is which patient, with which anatomical phenotype, should undergo which form of evacuation, at what time, through which corridor, to what residual volume, and with what postoperative goals. This review evaluates the evidence supporting minimally invasive ICH evacuation after ENRICH and proposes the EVAC-ICH framework. The acronym represents Eligibility and recoverability, Volume and vascular anatomy,

Active bleeding and stability, Corridor preservation, Intraoperative hemostasis, Clot-reduction target, and Hemorrhage-specific postoperative care.

Materials and Methods. This manuscript was designed as a structured integrative review with an original surgical-selection synthesis. Randomized controlled trials, contemporary guidelines, prospective multicenter studies, surgical-performance analyses, endoscopic series, imaging investigations, and technical studies published through July 2026 were evaluated. The principal evidence base included STICH, STICH II, MISTIE III, ENRICH, MIND, ICES, CLEAR III, INVEST-related cohorts, the 2022 American Heart Association/American Stroke Association guideline, and the 2025 European Stroke Organisation–European Association of Neurosurgical Societies guideline [11, 12, 20]. Evidence was classified into eight domains. The first domain was clinical eligibility, including age, premorbid function, Glasgow Coma Scale score, NIH Stroke Scale score, neurological trajectory, medical comorbidity, and treatment goals. The second domain was hemorrhage anatomy, including lobar, putaminal, caudate, thalamic, deep white-matter, cerebellar, brainstem, and intraventricular components. The third domain was biological timing, including onset-to-imaging, hematoma expansion, repeat-CT stability, anticoagulant reversal, and onset-to-evacuation. The fourth domain was corridor planning, including cortical or sulcal entry, white-matter transgression, corticospinal-tract proximity, eloquent networks, hematoma long axis, and ventricular relationships. The fifth domain was operative performance, including percentage evacuation, residual volume, operative duration, hemostasis, rebleeding, tissue injury, and conversion. The sixth domain was intraventricular disease, including hydrocephalus, external ventricular drainage, clot burden, third- and fourth-ventricle obstruction, and thrombolysis. The seventh domain was postoperative neurocritical care, including blood-pressure control, repeat imaging, intracranial pressure, airway management, seizures, venous thrombosis, rehabilitation, and withdrawal-of-care decisions. The eighth domain was functional outcome, emphasizing ordinal disability shift, return to baseline, mortality, severe dependency, cognition, communication, and quality of life. No new patient cohort was generated, and no independent pooled statistical analysis was performed. The tables represent an original synthesis of published evidence and do not contain fabricated clinical data.

Results. The initial hematoma produces immediate mechanical destruction. Neurons, axons, glia, and microvessels within the hematoma core are frequently irreversibly damaged. Surrounding tissue is compressed and displaced but may remain structurally recoverable. Mass effect can reduce local microvascular perfusion, distort venous drainage, compress the ventricular system, and contribute to transtentorial or subfalcine herniation. These effects are most pronounced in large lobar hemorrhage, cerebellar hemorrhage, and hematoma with extensive edema or intraventricular obstruction. Secondary injury begins within hours. Thrombin activates inflammation and disrupts the blood–brain barrier. Erythrocyte lysis releases hemoglobin, heme, and iron, promoting oxidative stress and lipid peroxidation. Microglial activation, complement, neutrophil recruitment, and cytokine production amplify perihematomal injury [1–3, 13–15]. Hematoma removal may reduce exposure to these mediators, but the timing matters. Evacuation after secondary injury has matured may relieve mass effect without reversing established cellular injury. Early removal has greater biological potential but occurs during the period of highest rebleeding risk. The therapeutic objective is not necessarily complete removal. Aggressive pursuit of a small adherent clot fragment can injure a perforating artery,

vein, internal capsule, or eloquent cortex. The clinically relevant endpoint is sufficient decompression and reduction of toxic clot burden while preserving hemostasis and viable neural pathways.

Hemorrhage Location. Location is one of the strongest modifiers of surgical benefit. Lobar hemorrhage lies closer to the cortical surface and can often be accessed through a sulcus or short transcortical route. The surrounding tissue may contain association fibers and eloquent cortex, but the access distance is generally shorter than for deep ganglionic hemorrhage. ENRICH demonstrated a favorable 180-day utility-weighted functional outcome for surgery, with the effect driven by lobar hemorrhage. The adjusted difference was not favorable for anterior basal-ganglia hemorrhage. Thirty-day mortality was 9.3% in the surgical group and 18.0% with medical management. Putaminal and anterior basal-ganglia hemorrhages are surrounded by the internal capsule, corona radiata, lenticulostriate vessels, insula, and deep venous structures. The shortest geometric route may not be the safest functional route. Even a narrow corridor can injure corticospinal or language-related pathways. Thalamic hemorrhage is frequently associated with intraventricular extension, hydrocephalus, impaired consciousness, ocular-motor abnormalities, and injury to critical arousal and sensory networks. Parenchymal evacuation is technically difficult and is not supported by the same randomized evidence as lobar evacuation. Caudate hemorrhage commonly ruptures into the ventricle. Management may be driven more by hydrocephalus and intraventricular clot than by removal of the relatively small parenchymal component. Cerebellar hemorrhage is a separate surgical emergency. Neurological deterioration, brainstem compression, hydrocephalus, or hematoma volume generally support prompt surgical evacuation. Minimally invasive techniques may be feasible, but posterior-fossa anatomy allows little tolerance for delay or incomplete decompression. Brainstem hemorrhage has an extremely narrow safety margin. Routine surgical evacuation is not established. Selected stereotactic or endoscopic procedures have been reported, but they remain specialized and cannot be extrapolated from supratentorial trials.

Table 1. **Anatomical Phenotypes and Potential Surgical Strategy**

Hemorrhage phenotype	Potential benefit of evacuation	Major operative risk	Current interpretation
Superficial lobar ICH, 30–80 mL	Reduction of mass effect and cortical displacement	Eloquent cortex, draining veins, rebleeding	Strongest randomized support for early MIS
Deep frontal or anterior basal-ganglia ICH	Decompression and volume reduction	Internal capsule and perforator injury	Benefit remains uncertain
Putaminal ICH	Relief of mass effect and possible motor-pathway decompression	Direct corticospinal-tract injury	Selective use; requires tract-aware trajectory
Thalamic ICH	Hydrocephalus relief if ventricular rupture present	Critical thalamic and brainstem networks	Parenchymal evacuation not routinely supported

Caudate ICH with IVH	Ventricular decompression	Deep venous and ventricular injury	EVD and IVH-directed strategy often dominant
Cerebellar ICH	Brainstem decompression and hydrocephalus control	Posterior-fossa deterioration if delayed	Urgent surgery frequently indicated
Primary IVH	Restoration of CSF pathways	Ventriculitis and catheter hemorrhage	EVD; selected intraventricular thrombolysis
Brainstem ICH	Theoretical decompression	Catastrophic tract and cranial-nerve injury	Investigational and highly selected

Hematoma Volume and Mass Effect. Hematoma volume influences both prognosis and potential treatment effect. Very small hemorrhages may not justify procedural risk. Extremely large hemorrhages may represent extensive irreversible injury, severe mass effect, and limited neurological recoverability. The ABC/2 method remains useful for rapid bedside estimation but becomes less accurate in irregular, multilobulated, or crescent-shaped hematomas. Automated segmentation provides more precise volume and can separately quantify intraparenchymal blood, intraventricular clot, perihematomal edema, and postoperative residual. ENRICH enrolled hemorrhages of 30–80 mL, whereas MIND included 20–80 mL. MISTIE III primarily evaluated moderate-to-large supratentorial hemorrhage. These ranges define evidence-supported trial populations rather than universal treatment thresholds [15, 17, 27]. Mass effect should be evaluated independently from volume. A 35-mL temporal hemorrhage causing uncal compression may be more urgent than a 45-mL frontal hematoma with preserved cisterns. Midline shift, ventricular effacement, basal-cistern status, herniation signs, and neurological deterioration influence urgency. The relation between volume and functional anatomy is also important. A smaller hematoma that destroys the posterior limb of the internal capsule may have a worse motor prognosis than a larger anterior frontal hematoma that displaces rather than transects major pathways.

Hematoma Expansion and Hemostatic Stability. Approximately one-quarter of patients demonstrate clinically meaningful hematoma expansion after presentation, with the highest risk during the early hours. Expansion is associated with worse outcome and increases the risk of postoperative rebleeding. Noncontrast CT markers include blend sign, black-hole sign, island sign, fluid level, hypodensity within the clot, irregular shape, and heterogeneous density. CTA spot sign represents active contrast extravasation and identifies increased expansion risk, but its absence does not prove stability [7, 14, 19, 16–18]. Anticoagulant-associated hemorrhage requires immediate reversal. Warfarin should be reversed with four-factor prothrombin-complex concentrate and intravenous vitamin K. Dabigatran can be reversed with idarucizumab, while factor-Xa inhibitors may be treated with andexanet alfa or prothrombin-complex concentrate according to availability, timing, and institutional protocol. Surgery should not be delayed unnecessarily after adequate reversal, but operating during uncontrolled coagulopathy substantially increases rebleeding risk. Platelet count, fibrinogen, anticoagulant exposure, renal function, and repeat imaging should be integrated. MISTIE

required demonstration of hematoma stability before catheter treatment and used delayed thrombolysis to reduce rebleeding risk. This safety strategy also delayed completion of clot removal. ENRICH pursued earlier evacuation with direct visualization and hemostatic capability. The ideal timing therefore depends on the procedure. Catheter thrombolysis requires confidence that active bleeding has stopped. Direct endoscopic or trans-sulcal surgery may permit earlier treatment because the bleeding point can potentially be identified and coagulated.

Operative Timing. Time should be considered biologically rather than administratively. The relevant intervals include onset-to-first CT, onset-to-reversal, onset-to-stability scan, onset-to-randomization, onset-to-incision, onset-to-effective decompression, and time to final residual volume. A patient may enter the operating room at 12 hours but not achieve adequate evacuation until 16 hours. A catheter may be inserted at 24 hours but require several days of alteplase irrigation before reaching the final volume. ENRICH required surgery within 24 hours after the patient was last known well. The positive lobar result supports early intervention, although the trial does not establish that every patient should undergo ultra-early surgery. MIND permitted surgery within 72 hours and did not demonstrate 180-day functional benefit. The trial was stopped early, and most patients had deep hemorrhage, but the result raises the possibility that delayed evacuation provides less biological benefit even when the percentage of clot removal is substantial.

Ultra-early surgery within the first few hours may remove the clot before secondary injury develops but occurs during a period of active bleeding and unstable hematoma geometry. Trials should distinguish ultra-early, early, and delayed procedures rather than reporting a single broad window.

Access-Corridor Planning. A minimally invasive incision does not guarantee a minimally disruptive intracerebral route. Tissue injury is determined by the cortex or sulcus entered, the length and diameter of the trajectory, white-matter displacement, retractor pressure, instrument motion, and proximity to functional pathways. The trajectory should follow the hematoma long axis when this permits efficient evacuation with minimal manipulation. Entering near one end of the clot allows progressive internal debulking rather than pushing instruments through intact brain toward its center. A trans-sulcal approach separates cortical gyri rather than incising the crown of a gyrus. However, sulci contain veins and arterial branches, and not every sulcus provides a safe route. Preoperative CTA, venous anatomy, neuronavigation, and direct surface inspection remain necessary. Tubular retractors distribute radial pressure more evenly than fixed blade retractors and create a stable working corridor. The device should not be advanced forcefully through intact tissue. Serial dilation, alignment with white-matter fibers, and internal clot decompression reduce corridor stress. Diffusion-tensor tractography can identify the corticospinal tract, optic radiation, arcuate fasciculus, superior longitudinal fasciculus, and other major pathways. Acute hematoma and edema distort diffusion signals, so tractography should be treated as an estimate rather than a precise anatomical boundary. Emerging methods use machine learning to approximate corticospinal-tract location from standard CT when advanced MRI is unavailable. Such systems may improve future selection but require external validation before determining surgical eligibility.

Evacuation Techniques. The MISTIE technique uses stereotactic catheter placement along the long axis of the hematoma, initial aspiration, and repeated low-dose alteplase administration after stability is confirmed. The procedure minimizes the operative corridor and can be performed through

a burr hole. Its disadvantages include delayed clot clearance, dependence on accurate catheter position, limited ability to control active bleeding, catheter obstruction, and the need for repeated CT and intensive protocol management. MISTIE III achieved a mean end-of-treatment volume of approximately 16 mL compared with 47 mL in the medical group. Fifty-eight percent of surgical patients reached the prespecified residual target of 15 mL or less. The primary functional endpoint was neutral, but mortality was lower and performance analyses supported the residual-volume target. The lesson is not that thrombolysis failed completely. It is that a biologically effective procedure must reliably reach its surgical target across centers.

Endoscopic Evacuation. Neuroendoscopy provides direct visualization of the cavity, active aspiration, irrigation, clot fragmentation, and focal coagulation. It can achieve substantial reduction during one operation and avoids prolonged thrombolytic irrigation. Visibility can be impaired by active bleeding, dark clot, narrow working space, lens contamination, and loss of orientation. Excessive irrigation pressure may increase intracranial pressure or force fluid into surrounding tissue. A rigid endoscope provides stable visualization but limited angulation. Flexible endoscopy reaches irregular extensions but provides smaller working channels and reduced hemostatic control. Bimanual systems and transparent sheaths can improve instrument coordination. The ICES randomized study demonstrated that image-guided endoscopic surgery could reduce hemorrhage volume by approximately two-thirds within about 29 hours while meeting predefined safety standards [16, 23, 30].

Mechanically Assisted Aspiration. The Artemis and Apollo systems combine aspiration with controlled mechanical clot fragmentation. These devices can remove organized blood rapidly through a small channel. The MIND trial demonstrated a median hemorrhage-volume reduction of 80.7%, confirming strong technical efficacy. Despite this, the primary 180-day ordinal outcome remained neutral. This reinforces that percentage removal alone does not guarantee neurological recovery when deep functional structures are already injured or the intervention is delayed [21, 24, 31]. Mechanical devices should be operated within the clot rather than against the cavity wall. Aggressive engagement of adherent clot can injure vessels. Aspiration strength, device tip position, and tissue motion require continuous visualization.

Trans-Sulcal Para-Fascicular Evacuation. The ENRICH strategy uses a tubular trans-sulcal corridor and an automated side-cutting aspiration device. Internal debulking allows the hematoma cavity to collapse while reducing fixed retraction. This approach combines early clot removal with direct visualization and hemostasis. It is particularly suited to lobar hematomas accessible through a short corridor. The technique should not be generalized automatically to every deep hemorrhage. The neutral anterior basal-ganglia subgroup demonstrates that limiting incision size cannot eliminate the biological consequences of deep access.

Robotic Stereotactic Evacuation. Robotic systems improve trajectory alignment and reproducibility. They can support catheter placement, aspiration, endoscopy, or future flexible concentric-tube devices. Robotics may reduce targeting error but cannot determine whether the planned trajectory crosses critical pathways. Registration accuracy, brain shift, instrument deflection, and hemorrhage evolution remain important. A 2025 comparative study reported better evacuation

performance with robot-assisted stereotaxy than frame-based puncture, but nonrandomized technical improvements should not be interpreted as definitive functional efficacy [23, 30, 32].

Table 2. **Comparative Features of Minimally Invasive Techniques**

Technique	Speed of clot reduction	Direct hemostasis	Corridor size	Main strength	Main limitation
Catheter aspiration plus alteplase	Gradual over days	Limited	Very small	Minimal tissue access	Delayed completion and catheter dependence
Stereotactic aspiration	Immediate but sometimes incomplete	Limited	Small	Rapid, accessible technique	Residual organized clot
Rigid neuroendoscopy	Immediate	Good	Small to moderate	Direct visualization and irrigation	Restricted angulation
Flexible endoscopy	Immediate	Moderate	Small	Access to irregular extensions	Reduced instrument strength
Mechanical aspiration	Rapid	Moderate with visualization	Small	High percentage volume reduction	Vessel injury if used near cavity wall
Tubular trans-sulcal surgery	Rapid	Good	Controlled circumferential corridor	Early evacuation with tissue displacement	Requires anatomical and technical expertise
Robotic catheter or endoscopic guidance	Depends on attached device	Device-dependent	Small	Reproducible trajectory	Registration and planning errors

Residual Hematoma Volume. Residual volume has emerged as a more informative operative endpoint than percentage reduction alone. Removing 80% of a 70-mL hematoma leaves 14 mL, whereas removing 80% of a 30-mL hematoma leaves 6 mL. Both percentages are identical, but the remaining mass and toxic burden differ. MISTIE III prospectively defined 15 mL or less as the surgical goal. As-treated analyses supported a relationship between achieving this target and improved functional outcome [1, 10, 13, 32]. The threshold should not be interpreted as an absolute rule for every location. A 16-mL residual in noneloquent frontal white matter may be tolerated, while a 10-mL residual compressing the brainstem or obstructing the third ventricle may remain clinically dangerous. Residual volume should be measured through postoperative CT segmentation rather than subjective visual estimation. Timing of the scan matters because early rebleeding, cavity collapse, irrigation fluid,

and contrast can affect interpretation. Future trials should report median residual volume, proportion reaching predefined thresholds, percentage reduction, time to target, and anatomical distribution of the residual clot.

Intraoperative Hemostasis. Rebleeding can eliminate the benefit of evacuation. The cavity should be decompressed progressively to avoid sudden loss of tamponade before the bleeding source is visible. Blood-pressure control should be coordinated with anesthesia. Excessive hypertension increases bleeding, while hypotension threatens cerebral and systemic perfusion. The target should consider preoperative pressure, chronic hypertension, intracranial pressure, and perioperative neurological status. Endoscopic irrigation can identify a bleeding point, but high irrigation pressure may temporarily suppress bleeding. The cavity should be inspected under low-pressure conditions before closure. Focal bipolar coagulation, low-energy radiofrequency, hemostatic matrix, oxidized cellulose, gelatin sponge, and gentle tamponade can be used. Blind packing should be avoided because it can compress surrounding tissue and conceal ongoing hemorrhage. A postoperative CT should generally be obtained promptly after surgery and repeated when neurological status deteriorates. New hematoma expansion, ventricular blood, hydrocephalus, ischemia, or tract injury requires urgent assessment.

Intraventricular Hemorrhage. IVH may arise from thalamic, caudate, putaminal, or lobar hemorrhage and is an independent marker of poor prognosis. Blood obstructs the foramina of Monro, cerebral aqueduct, and fourth-ventricle outlets, producing acute hydrocephalus. External ventricular drainage relieves hydrocephalus and permits ICP monitoring. Catheter position should maximize CSF drainage while minimizing traversed brain and avoiding the largest clot burden when possible. CLEAR III randomized patients with obstructive IVH and a routinely placed EVD to intraventricular alteplase or saline. Alteplase did not significantly improve the proportion with mRS 0–3, but it reduced mortality and accelerated ventricular opening. The survival effect included a greater proportion of severely disabled survivors [3, 10, 18, 27]. These findings emphasize the importance of outcome framing. A mortality reduction may be meaningful, but families should understand the possible distribution of surviving disability. Intraventricular thrombolysis should not be used in the presence of unstable parenchymal bleeding, untreated vascular lesion, or uncontrolled coagulopathy. Serial CT is required during treatment. Endoscopic ventricular clot evacuation may provide faster clearance and direct restoration of CSF pathways but requires ventricular entry and carries risks of fornix injury, ependymal injury, bleeding, and infection. Comparative randomized evidence remains limited.

Perioperative Medical Management. Surgery does not replace evidence-based medical treatment. Rapid blood-pressure control, anticoagulant reversal, airway protection, glucose and temperature management, prevention of aspiration, and organized stroke-unit or neurocritical care remain essential [4, 14, 19, 25]. Current guidelines generally support smooth reduction of elevated systolic pressure while avoiding abrupt hypotension. The exact target should be individualized in severe ICH, impending herniation, and the perioperative setting. Prophylactic antiseizure medication is not routinely indicated for every ICH patient. Clinical or electrographic seizures should be treated. Continuous EEG is appropriate in unexplained impaired consciousness, fluctuating examination, or suspected nonconvulsive seizures. Mechanical venous-thrombosis prophylaxis should begin early. Pharmacological prophylaxis is introduced after hemorrhage stability is established according to

imaging and procedural factors. Swallowing evaluation, aspiration prevention, nutrition, early mobilization, and rehabilitation planning should not be delayed because the patient underwent surgery. Functional recovery depends on the complete care pathway.

Postoperative Intracranial Pressure and Edema. Large ICH can produce refractory intracranial hypertension before or after evacuation. An EVD is useful when IVH and hydrocephalus are present. Intraparenchymal ICP monitoring may be considered when the examination is unreliable and severe mass effect persists. A low postoperative ICP does not guarantee favorable outcome. Surgical injury, tract damage, ischemia, and established network destruction may remain despite decompression. Perihematomal edema commonly increases during the first several days. Routine corticosteroids are harmful in spontaneous ICH and should not be used for edema control. Hyperosmolar therapy may be used for acute intracranial hypertension or herniation physiology but should not substitute for evaluation of rebleeding, hydrocephalus, or surgical mass effect.

Functional Network Preservation. The modified Rankin Scale summarizes global disability but does not identify the mechanism of recovery failure. Motor, language, visual, cognitive, executive, arousal, and swallowing networks may be affected differently. A patient with a technically excellent evacuation can remain severely disabled if the internal capsule or dominant-language network was destroyed before surgery. Conversely, removal of a lobar hematoma that mainly displaces rather than transects pathways may enable substantial recovery. Preoperative imaging should therefore evaluate recoverability, not only volume. CT can estimate whether critical structures are displaced, compressed, or incorporated into the hemorrhage. MRI and tractography provide additional information when time and stability permit. Future selection algorithms may combine CT anatomy, clinical deficits, corticospinal-tract integrity, hematoma expansion risk, premorbid function, and predicted surgical corridor injury. Withdrawal-of-life-sustaining treatment is a major confounder in ICH outcomes. Early pessimistic prognostication can create a self-fulfilling prophecy. Severity scores should support communication and research stratification but should not be used as the sole basis for limiting treatment.

Table 3. **Trial Interpretation in the Modern Surgical Era**

Trial	Technique and population	Main result	Principal lesson
STICH	Early open craniotomy for supratentorial ICH	Neutral functional result	Broad open surgery does not benefit all ICH
STICH II	Superficial lobar ICH without IVH	Neutral primary result; possible survival signal	Superficial location may matter
MISTIE III	Catheter aspiration plus alteplase	Neutral primary functional endpoint; safe volume reduction	Procedural performance and residual ≤15 mL are important
ICES	CT-guided endoscopic evacuation	Feasible and substantial early reduction	Direct MIS can remove clot safely
ENRICH	Early trans-sulcal evacuation within 24 h	Improved 180-day utility-weighted outcome	Benefit strongest in lobar ICH

MIND	Mechanical MIS within 72 h	Neutral 180-day disability and mortality	Technical clot reduction alone is insufficient
CLEAR III	EVD plus intraventricular alteplase	Mortality reduction without functional-endpoint improvement	Ventricular clearance changes survival more than independence

Complications. The major surgical complications are rebleeding, tract hemorrhage, ischemic injury, infection, seizures, venous infarction, hydrocephalus, residual mass effect, and neurological deterioration. Rebleeding may result from incomplete reversal, uncontrolled hypertension, traumatic device movement, premature disruption of clot tamponade, or failure to identify the bleeding vessel. Tract injury can involve cortex, white matter, deep nuclei, corticospinal pathways, optic radiation, or venous structures. A small skin incision does not prevent major intracerebral injury. Infection risk increases with prolonged catheter irrigation, repeated EVD manipulation, CSF leakage, and extended intensive care. Strict sterile protocols and limited device access are necessary. Postoperative ischemia may result from coagulation of a perforator, excessive retraction, venous compromise, hypotension, or local compression by hemostatic material.

Table 4. **Complications and Preventive Strategy**

Complication	**Main mechanism**	**Prevention**	**Required response**
Postoperative rebleeding	Active vessel, coagulopathy, hypertension	Reversal, controlled decompression, low-pressure hemostatic inspection	Urgent CT and reoperation when indicated
Corridor hemorrhage	Cortical or white-matter vessel injury	Sulcal planning, serial dilation, navigation	Hemostasis and assessment of tract damage
Internal-capsule injury	Unsafe deep trajectory or device motion	Tract-aware approach and instrument control	Neurological documentation and rehabilitation
Residual mass effect	Incomplete evacuation or inaccessible clot	Quantitative target and intraoperative imaging	Revision according to clinical deterioration
Hydrocephalus	IVH and CSF obstruction	Ventricular assessment and EVD when indicated	Drainage and serial imaging
Ventriculitis	Prolonged catheter access	Sterile protocol and limited manipulation	Culture-directed treatment and catheter management
Seizure	Cortical blood, surgical irritation, metabolic stress	EEG when clinically indicated	Antiseizure therapy for documented events
Venous infarction	Injury to cortical or deep vein	Preoperative vascular planning	Supportive care and decompression if required

Aspiration pneumonia	Impaired consciousness and dysphagia	Airway and swallowing protocol	Respiratory treatment and rehabilitation

The EVAC-ICH Framework. The proposed EVAC-ICH framework consists of seven linked domains. Eligibility and recoverability evaluate premorbid independence, age, neurological severity, medical stability, treatment preferences, clinical trajectory, and whether major functional networks are potentially preserved. Volume and vascular anatomy define hematoma size, location, shape, surface distance, intraventricular extension, hydrocephalus, spot sign, underlying vascular lesion, and mass effect. Active bleeding and stability incorporate onset time, serial CT, anticoagulant reversal, coagulation parameters, blood-pressure control, and evidence of expansion.

Corridor preservation selects a sulcal, trans-cortical, stereotactic, ventricular, or posterior-fossa route that minimizes injury to cortex, white-matter tracts, perforators, and veins. Intraoperative hemostasis includes progressive internal decompression, direct visualization where possible, controlled irrigation, focal coagulation, and inspection after tamponade is removed. Clot-reduction target defines a quantitative residual-volume goal, generally informed by the 15-mL MISTIE threshold but adjusted for location, mass effect, ventricular obstruction, and safety. Hemorrhage-specific postoperative care includes repeat CT, blood-pressure control, ICP and CSF management, seizure evaluation, VTE prevention, dysphagia care, early rehabilitation, and avoidance of premature prognostic limitation.

Table 5. **Scientific Originality of the EVAC-ICH Model**

Existing limitation	**Conventional interpretation**	**EVAC-ICH principle**	**Expected contribution**
All MIS procedures grouped together	Small access assumed to represent one intervention	Timing, device, corridor, hemostasis, and speed analyzed separately	Clarifies why trials differ
Hematoma volume used without location	Similar volumes considered biologically equivalent	Lobar, deep, thalamic, ventricular, and cerebellar phenotypes separated	Improves anatomical selection
Percentage evacuation used as primary performance metric	High percentage interpreted as success	Absolute residual volume and time to target prioritized	Supports clinically meaningful decompression
Surgery selected from severity score alone	Poor prognosis may cause exclusion	Functional-network recoverability incorporated	Reduces therapeutic nihilism
Shortest route considered safest	Geometric distance prioritized	White-matter and vascular injury integrated	Reduces corridor-related disability
Stability required uniformly before surgery	Delay considered universally protective	Stability requirements matched to hemostatic capability	Balances rebleeding against biological delay

Mortality and independence treated as interchangeable	Survival interpreted as functional success	Ordinal disability and patient goals reported separately	Improves outcome communication
Device accuracy emphasized over care pathway	Operation viewed as isolated treatment	Neurocritical care and rehabilitation included	Supports complete systems-based benefit
Neutral trials interpreted as proof of no surgical effect	All patient subgroups considered equivalent	Location, timing, and performance explain heterogeneity	Enables targeted future trials

Discussion. The evidence available after ENRICH requires a change in how surgery for intracerebral hemorrhage is discussed. The question is no longer whether open craniotomy should be used routinely for all supratentorial hemorrhages. The question is whether early, quantitatively effective, anatomically selected, minimally disruptive evacuation improves the patient's probable functional trajectory. ENRICH provides the strongest current randomized evidence that this objective can be achieved. The trial demonstrated a favorable 180-day utility-weighted outcome and lower early mortality, but its adaptive analysis showed that the benefit was driven by lobar hemorrhage. This anatomical specificity is not a minor subgroup observation; it is central to interpretation. The lobar brain provides a shorter route, but access alone does not explain the result. Lobar hematomas may displace functional tissue more often than they destroy compact projection pathways. Reduction of mass effect can therefore permit meaningful recovery in patients whose networks remain viable. Deep ganglionic hemorrhage differs. The initial bleed may transect the internal capsule or thalamocortical fibers before treatment. Even complete removal cannot reconstruct destroyed axons. Surgical access can introduce additional injury to the same networks.

This interpretation is consistent with MIND, in which almost 70% of patients had deep hemorrhage. The procedure achieved a median 80.7% reduction but did not improve the primary 180-day ordinal outcome. Enrollment stopped at 236 patients, limiting power, but the neutral result warns against assuming that efficient clot removal is sufficient in all anatomical phenotypes. The operative window may also explain part of the difference. ENRICH required intervention within 24 hours, whereas MIND allowed surgery within 72 hours. Secondary inflammation and edema evolve continuously. An operation that is technically successful at 50 hours may provide less biological rescue than one performed at 15 hours.

This does not prove that all surgery should occur immediately. The risk of expansion and rebleeding is greatest early after onset. The appropriate time is the earliest point at which hemostatic control, reversal, imaging, and surgical resources permit safe and effective evacuation.

The type of operation determines how much stability is needed. A catheter-lysis procedure cannot directly coagulate a bleeding vessel and therefore requires documented stability. A direct endoscopic or trans-sulcal approach can potentially identify active bleeding but exposes the patient to operative tissue injury. MISTIE III remains highly relevant because it established a performance target. The neutral intention-to-treat result concealed major variability in achieved evacuation. Only 58% of treated patients reached 15 mL or less. If benefit requires reaching the target, inconsistent performance dilutes trial efficacy. The threshold of 15 mL should be treated as an evidence-informed benchmark

rather than a universal biological law. The appropriate residual depends on the original volume, location, ventricular obstruction, intracranial pressure, and risk of further manipulation. A residual fragment firmly adherent to the posterior putaminal wall may be safer than aggressive removal near the internal capsule. A similar volume obstructing the aqueduct or compressing the brainstem may remain unacceptable. Percentage reduction and absolute residual should therefore be reported together. Operative studies should also report time to target, because delayed completion reduces the opportunity to prevent secondary injury. CLEAR III provides a cautionary example regarding outcomes. Ventricular alteplase reduced mortality but did not increase the proportion of patients reaching the prespecified functional endpoint. More patients survived with severe disability [5, 16, 20, 31]. Neither mortality nor disability should be dismissed. Some patients value survival despite dependency, while others have expressed different preferences. Trials should report the full ordinal mRS distribution and quality of life rather than only dichotomized independence.

The utility-weighted mRS used in ENRICH is one attempt to incorporate the patient-perceived value of different disability states. Its interpretation may be less intuitive than standard mRS categories, but it captures shifts that binary endpoints can miss. Another lesson is that surgical technology cannot be evaluated separately from medical management. Blood-pressure control, anticoagulant reversal, stroke-unit care, neurocritical monitoring, dysphagia prevention, and rehabilitation influence outcomes in both trial arms. A center adopting MIS without a coordinated ICH pathway may not reproduce trial results. The workflow must include rapid transfer, image segmentation, vascular imaging when indicated, reversal protocols, neurosurgical availability, trained operating-room staff, quantitative postoperative imaging, and rehabilitation. Surgical training is especially important. A device manufacturer can teach mechanical operation, but expertise in trajectory planning, white-matter anatomy, endoscopic hemostasis, and postoperative neurocritical care must be developed independently. Volume targets should be audited. Every institution should measure preoperative volume, immediate residual, percentage removal, rebleeding, tract injury, and functional outcome. Without performance monitoring, the procedure may be labelled successful because an operation was completed rather than because effective evacuation was achieved. The future of selection will likely incorporate functional anatomy. The integrity of the corticospinal tract is strongly associated with motor recovery. Advanced MRI is not always feasible acutely, but CT-based algorithms may estimate tract involvement. Such tools should distinguish destruction from displacement. A tract passing through the hematoma core may have limited recovery potential, whereas a tract displaced around the clot may recover after decompression.

Artificial intelligence can automate volume segmentation, detect expansion signs, estimate trajectory risk, and predict postoperative residual. It should support rather than replace multidisciplinary judgment. Endoscopic video analysis may eventually identify active bleeding, cavity boundaries, instrument–tissue interaction, and unsafe proximity to brain. Current evidence remains developmental. Robotic and flexible instruments may improve evacuation of irregular extensions through one corridor. The risk is that increased reach encourages aggressive pursuit of clot into unsafe regions. Technology should expand controlled access, not eliminate surgical restraint. Future trials should be phenotype-specific. A trial of early lobar evacuation should not be diluted by deep thalamic hemorrhage. Deep putaminal trials should stratify corticospinal-tract integrity and corridor length.

Timing should be narrow and explicitly reported. “Within 72 hours” encompasses biologically different patients. Trials should analyze onset-to-effective-decompression as a continuous variable. Procedural quality should be incorporated into the primary analysis. Centers unable to achieve the residual target should undergo retraining before continued enrollment. Control groups should receive contemporary guideline-based management, including rapid pressure control and reversal. Early limitations of care should be standardized to reduce self-fulfilling prognostic bias. Outcomes should include cognition, aphasia, swallowing, return to home, caregiver burden, and quality of life. A global mRS score does not capture all clinically meaningful recovery. The 2025 ESO–EANS guideline reflects the evolving evidence but appropriately remains cautious because results differ by technique, location, and population. Current data support structured consideration of surgery rather than universal intervention.

The EVAC-ICH model is designed to prevent two opposite errors. The first is nihilism: rejecting surgery because older craniotomy trials were neutral. The second is technological overgeneralization: treating every moderate-to-large hemorrhage because ENRICH was positive.
The model emphasizes that a positive surgical candidate requires more than a large clot. The patient should have a potentially recoverable neurological substrate, a surgically accessible target, controlled hemostasis, a tissue-preserving corridor, a realistic residual-volume goal, and access to high-quality postoperative care. The framework is conceptual and has not been prospectively validated. It should guide structured discussion rather than replace trial criteria or clinical guidelines.

Conclusion. Spontaneous intracerebral hemorrhage is a heterogeneous surgical disease. Hematoma size alone does not determine eligibility, and minimally invasive surgery is not a single standardized intervention. Conventional craniotomy failed to improve outcomes consistently because the benefit of clot removal was frequently offset by access injury, broad patient selection, or inadequate biological timing. MISTIE III demonstrated that catheter aspiration with thrombolysis can reduce clot safely and identified residual volume of 15 mL or less as an important performance target. The primary functional endpoint remained neutral, partly reflecting variable achievement of adequate evacuation. ENRICH established that early minimally invasive evacuation within 24 hours can improve 180-day functional outcome. The benefit was concentrated in lobar hemorrhage and was not demonstrated in the anterior basal-ganglia subgroup. MIND achieved substantial clot reduction using mechanically assisted aspiration but did not improve 180-day disability or 30-day mortality. Its predominantly deep-hemorrhage population and broader 72-hour window highlight the importance of location and biological timing. CLEAR III showed that accelerated intraventricular clot removal can reduce mortality without necessarily increasing functional independence. The central therapeutic principle is not maximum clot removal at any cost. It is early and sufficient reduction of mass and toxic blood burden through the least disruptive corridor, with direct attention to hemostasis and functional-network preservation. The proposed EVAC-ICH framework integrates Eligibility and recoverability, Volume and vascular anatomy, Active bleeding and stability, Corridor preservation, Intraoperative hemostasis, Clot-reduction targets, and Hemorrhage-specific postoperative care. Future research should use phenotype-specific enrollment, narrow operative windows, quantitative residual-volume targets, tract-aware planning, standardized surgical training, and complete ordinal outcomes. The post-ENRICH era should therefore be defined neither by routine surgery nor by continued therapeutic nihilism. It should

be defined by anatomically selective, performance-controlled and biologically timed hematoma evacuation.

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