

Review Article

Middle Meningeal Artery Embolisation Versus Surgical Drainage for Chronic Subdural Haematoma

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Abstract

Background: Chronic subdural haematoma (cSDH) is increasingly common in older adults and is usually treated by burr-hole drainage, but recurrence after surgery alone remains substantial. Middle meningeal artery (MMA) embolisation targets the membrane vasculature sustaining the haematoma.

Objective: To review the rationale, trial evidence, safety and cost-effectiveness of MMA embolisation with and without surgical drainage.

Methods: Narrative synthesis of retrospective series, meta-analyses, four pivotal randomised trials (EMBOLISE, STEM, MAGIC-MT, EMPROTECT) and consensus guidance.

Findings: Adjunctive embolisation reduced treatment failure or recurrence from roughly 11-39% to 4-16% versus surgery or standard care alone, though a high-risk surgical cohort showed a smaller, non-significant benefit. Complication rates were low and similar between arms. Cost-effectiveness data favour selective use in high-recurrence-risk patients over unselected adoption.

Conclusions: Adjunctive MMA embolisation meaningfully lowers cSDH recurrence after drainage and is a reasonable standalone option in selected non-operative candidates, but patient selection and cost-effectiveness remain unresolved.

Keywords: Middle meningeal artery embolisation; Chronic subdural haematoma; Recurrence; Surgical drainage; Randomised controlled trial

Abstract

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Keywords: middle meningeal artery embolisation; chronic subdural haematoma; recurrence; surgical drainage; randomised controlled trial

Introduction

Chronic subdural haematoma is among the most common conditions encountered in neurosurgical practice, and its incidence is rising steeply as populations age, anticoagulant and antiplatelet use becomes more prevalent, and cross-sectional imaging is obtained more liberally after minor head trauma or falls [1,2]. Once regarded as a straightforward surgical disease, cSDH is now recognised as a dynamic, recurrence-prone condition whose management has changed relatively little

for decades: burr-hole or twist-drill craniostomy, with or without a closed subdural drain, remains the mainstay of treatment for symptomatic collections. A landmark randomised trial established that a passive subdural drain placed after burr-hole drainage roughly halves recurrence and reduces mortality compared with drainage without a drain, and this simple intervention has since become standard practice in most units [3]. Even with contemporary technique, however, recurrence requiring reoperation is reported in a meaningful minority of patients, particularly those who are elderly, frail, anticoagulated, or who have bilateral, loculated or heavily membranous haematomas that resist simple evacuation [1].

Over the past decade, endovascular embolisation of the middle meningeal artery (MMA) has emerged first as a salvage option for recurrent disease, then as an adjunct to primary surgical evacuation, and now, in selected patients, as a stand-alone alternative to surgery altogether. The rationale rests on the recognition that cSDH is not a static blood collection but a chronic inflammatory and angiogenic process driven by a friable, hypervascular outer membrane that continually leaks and re-bleeds [4,5]. As interventional experience accumulated and embolic technology matured, a series of large, methodologically rigorous, industry- and investigator-sponsored randomised trials was designed specifically to test whether devascularising this membrane translates into fewer reoperations and better patient-centred outcomes than surgery or observation alone. This review synthesises the pathophysiological rationale for embolisation, the trajectory of evidence from early case series and retrospective cohorts to the four recently completed phase III randomised trials, and the safety, patient-selection and cost-effectiveness considerations that are now shaping how the procedure is incorporated into everyday neurosurgical and

neurointerventional practice.

Pathophysiology and Rationale for Embolisation

Chronic subdural haematoma arises when trivial or unrecognised trauma separates the dural border cell layer, triggering formation of an outer neomembrane rich in fragile, leaky capillaries and inflammatory mediators including vascular endothelial growth factor [1]. This membrane is the biological engine of the disease: repeated microhaemorrhage and plasma exudation from its immature vasculature, rather than the volume of the original bleed, sustain and progressively enlarge the collection over weeks to months, which explains why simple evacuation of liquefied blood without addressing the membrane itself leaves an intact substrate for recurrence [5]. Ageing further predisposes to this process through brain atrophy, which widens the subdural space and increases traction on bridging veins, and through age-related changes in coagulation and fibrinolysis that favour a chronic, low-grade rebleeding cycle rather than a single self-limited haemorrhage [1].

Because the outer membrane is supplied almost exclusively by dural branches of the MMA rather than by pial or cortical vessels, selective microcatheterisation and embolisation of these branches can devascularise the membrane and arrest the angiogenic cycle without disturbing the haematoma cavity or requiring general anaesthesia in most patients [4]. This mechanistic insight, first exploited in small case series using coils, particles and, increasingly, liquid embolic agents such as ethylene-vinyl alcohol copolymers and n-butyl cyanoacrylate, provided the rationale for embolisation as either a stand-alone treatment in minimally symptomatic patients unfit for surgery or an adjunct performed before or after conventional drainage to reduce the risk of subsequent reaccumulation [6,7].

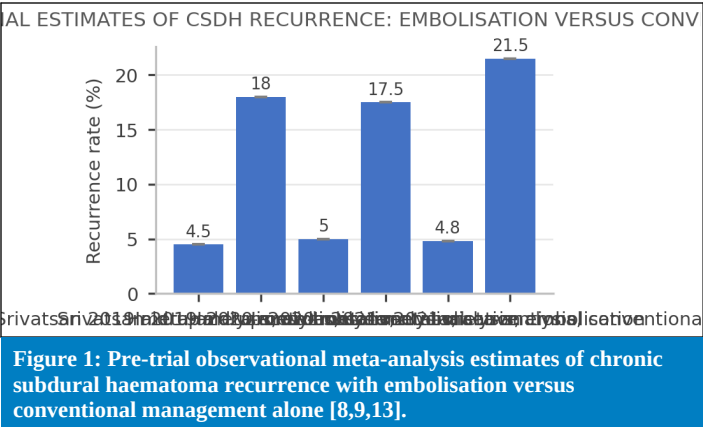
Surgical Drainage and the Limits of Standard Care

Burr-hole or twist-drill craniostomy with drain placement remains rapid, widely available, inexpensive and effective for acute symptom relief when a haematoma is causing mass effect, and the Santarius trial's demonstration that a drain reduces recurrence and mortality relative to drainage alone has shaped modern practice worldwide [3]. Nonetheless, pooled series consistently report recurrence rates in the low double digits after surgery alone, rising further in patients with coagulopathy or ongoing antithrombotic therapy, loculated or heavily membranous haematomas, or low-lying, atrophic brain that impairs re-expansion of the cortex against the dura [8,9]. Reoperation for recurrence carries its own morbidity in a population that is frequently frail, cognitively impaired or medically complex, and repeated general or local anaesthetic exposure is far from trivial in patients in their eighth or ninth decade. These persistently imperfect outcomes, despite incremental refinements in drain type, drain duration and burr-hole number, created the clinical space into which MMA embolisation was introduced as a way of addressing the underlying membrane biology rather than simply removing its liquid product.

Early Evidence: Retrospective Series and Pre-Trial Meta-Analyses

Initial reports described embolisation as a rescue technique for recurrent haematoma after failed surgery, with case series from single centres suggesting recurrence rates well below historical surgical benchmarks even in patients who had already failed one or more prior operations [10,11]. Larger retrospective cohorts, including a comparative analysis of embolisation against conventional management describing the endovascular technique and its radiographic correlates in detail, reported lower rates of haematoma progression and reoperation with acceptable procedural safety across a range of embolic agents and operator experience levels [6,4]. Institutional technical analyses and combined

subdural evacuating port system plus embolisation series extended this experience from recurrent disease to primary, treatment-naïve haematomas, and from single-centre cohorts to multicentre practice, suggesting the approach generalised beyond the pioneering centres [7,12]. The first prospective, though non-randomised, United Kingdom cohort added further real-world reassurance about feasibility and safety outside the trial setting [11].



Aggregating this rapidly growing observational literature, successive systematic reviews and meta-analyses estimated embolisation-associated recurrence at roughly 4-5% versus 15-20% for conventional management alone, alongside low and broadly comparable complication rates between approaches [8,9,13]. All of these pooled analyses, however, were explicitly limited by selection bias favouring embolisation in patients thought likely to do well, heterogeneous embolic agents and adjunctive surgical strategies across included studies, variable follow-up duration, and, above all, the complete absence of randomisation. This body of promising but methodologically vulnerable retrospective work was nonetheless consistent enough in direction and magnitude of effect to justify the substantial investment required to mount large, adequately powered randomised trials, including a formal published protocol for one such study, MEMBRANE, registered specifically to test

adjunctive embolisation after primary surgical evacuation of newly diagnosed cSDH [14].

The Pivotal Randomised Controlled Trials

Four large randomised trials, largely reported in 2024-2025, now anchor the evidence base. EMBOLISE randomised 400 patients undergoing surgical evacuation to adjunctive MMA embolisation or surgery alone and found a 90-day composite of recurrence or progression requiring further surgical drainage in 4.1% of the embolisation group versus 11.3% of controls (relative risk 0.36) [15]. STEM enrolled 310 patients receiving either surgical or non-surgical standard care and found 180-day treatment failure - residual or reaccumulated haematoma, reoperation, or major stroke, myocardial infarction or death - in 15.2% with adjunctive embolisation versus 39.2% with standard care alone (odds ratio 3.60 favouring embolisation) [16]. MAGIC-MT, a Chinese multicentre trial of 722 patients using liquid embolic material, reported 90-day symptomatic recurrence or progression in 7.2% of the embolisation arm versus 12.2% of usual-care controls, with fewer serious adverse events in the embolisation group [17]. EMPROTECT, restricted to 342 higher-risk patients after surgical evacuation, found six-month recurrence of 14.8% with adjunctive embolisation versus 21% with standard care, a numerically favourable but statistically non-significant difference (adjusted odds ratio 0.64) [18]. Read together, these trials show a consistent direction of effect favouring embolisation, with the strongest and most statistically robust benefit in patients also receiving concurrent surgical evacuation, and a more modest signal in the EMPROTECT population that had already been selected for elevated recurrence risk [19].

Table 1: Design and primary outcome of the four pivotal randomised controlled trials of adjunctive or standalone middle meningeal artery embolisation for chronic/nonacute subdural haematoma [15,16,17,18].

Trial	N	Population	Comparator	Primary outcome (window)	Embolisation vs control
EMBOLISE	400	Post-surgical evacuation	Surgery alone	Recurrence/progression needing reoperation (90 d)	4.1% vs 11.3%
STEM	310	Surgical or non-surgical standard care	Standard care alone	Composite treatment failure (180 d)	15.2% vs 39.2%
MAGIC-MT	722	Nonacute SDH, mostly post-drainage	Usual care	Symptomatic recurrence/progression or death (90 d)	7.2% vs 12.2%
EMPROTECT	342	High-risk, post-surgical evacuation	Standard care alone	Radiographic recurrence (6 mo)	14.8% vs 21.0%

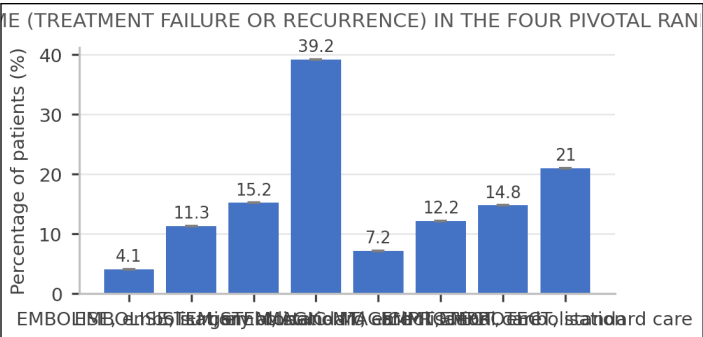


Figure 2: Primary treatment-failure or recurrence outcome, embolisation versus control arm, in the four pivotal randomised trials: EMBOLISE 4.1% vs 11.3% [15]; STEM 15.2% vs 39.2% [16]; MAGIC-MT 7.2% vs 12.2% [17]; EMPROTECT 14.8% vs 21.0% [18].

Pooled Analyses, Safety, and Patient Selection

Meta-analyses pooling the randomised trials confirm a significant reduction in treatment failure with adjunctive embolisation and materially narrow the confidence intervals around the individual-trial estimates [20,21]. A large multi-institutional analysis of 636 embolisations identified predictors of clinical and radiographic failure, including younger membrane age, incomplete membrane coverage and non-liquid embolic agents, informing procedural technique [22]. Systematic review of complications across observational and trial cohorts found embolisation to be generally well tolerated, with

neurological, cardiovascular, infectious and access-site complications each occurring in a low single-digit percentage of procedures, comparable to or lower than complication rates for surgical drainage alone [23]. A multisociety consensus statement now recommends embolisation as an adjunct in patients with high recurrence risk and as a reasonable stand-alone option in minimally symptomatic or high-surgical-risk patients, while cautioning that antithrombotic therapy, a major driver of both bleeding risk and recurrence, should be individually weighed given its independent association with cSDH recurrence and mortality [24,25]. Elderly, frail and anticoagulated patients - the population in whom cSDH is most prevalent - stand to gain the most from a lower-morbidity adjunct, a point emphasised in a literature review focused specifically on this age group [2].

Table 2: Reported complication categories after middle meningeal artery embolisation for chronic subdural haematoma, pooled across observational and trial cohorts [23,22].		
Complication category	Approximate pooled rate	Notes
Neurological (stroke, seizure, deficit)	~3.8%	Includes both procedure- and disease-related events
Cardiovascular	~3.6%	Access-site and systemic events
Infectious	~2.9%	Predominantly wound/access-related
Other/miscellaneous	~3.1%	Contrast reaction, groin haematoma, and similar
Predictors of treatment failure	Not applicable	Younger membrane, incomplete branch coverage, non-liquid agent

Cost-Effectiveness and Practice Implications

Because embolisation adds procedural time, angiography-suite resources, contrast and radiation exposure, and interventionalist availability to an already-effective surgical pathway, its economic value has drawn considerable scrutiny from health systems weighing whether to fund it routinely. A national cross-sectional comparative study found broadly

comparable overall costs between embolisation and conventional treatment once the downstream savings from avoided reoperation and shorter length of stay were included in the analysis [26], while a pooled cost analysis performed alongside the four pivotal trials concluded that unselected, population-wide adoption of adjunctive embolisation is unlikely to be cost-effective for most health systems, but that targeted use restricted to patients at demonstrably higher recurrence risk - for example those who are anticoagulated, have bilateral disease, or have already recurred once - likely is [21]. This distinction between population-wide adoption and risk-stratified selection, rather than a simple binary verdict on cost-effectiveness, is likely to define how embolisation is incorporated into national and institutional guidelines, reimbursement policy and multidisciplinary care pathways over the next several years, alongside ongoing work to identify which embolic agents and technical approaches deliver the most durable benefit per unit cost.

Conclusion

The evidence base for MMA embolisation in chronic subdural haematoma has matured rapidly, from mechanistic case reports through retrospective cohorts to four large randomised trials. Adjunctive embolisation after surgical drainage reduces recurrence substantially and consistently, with a safety profile comparable to surgery alone, while its role as a stand-alone treatment and its cost-effectiveness remain more dependent on patient selection. Future work should refine which patients derive the greatest absolute benefit, standardise embolic-agent choice, and define durable, system-level cost-effectiveness thresholds.

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