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Middle Meningeal Artery Embolization for Chronic Subdural Hematoma: Understanding Procedural Risks and Complications

Justyna Kowalczevska^{1*}

ABSTRACT

Chronic subdural hematoma (cSDH) is frequently diagnosed in older patients, and the incidence continues to increase as the population ages, antithrombotic therapy becomes more common, and diagnostic imaging is more widely available. Recurrence after surgical treatment remains an important clinical issue. Middle meningeal artery embolization (MMAE) is a minimally invasive treatment that reduces cSDH recurrence by interrupting the vascular supply to the hematoma membrane. However, increasing use of MMAE requires careful consideration of its procedure-related risks. This narrative review summarizes current evidence regarding the safety and complications of MMAE for cSDH. Recent findings indicate that MMAE has a generally promising safety profile. Although sporadic serious complications may occur. The most clinically important adverse events include ischemic stroke, intracranial hemorrhage, visual impairment, facial nerve palsy, vascular injury, and access-site complications. Non-target embolization through ophthalmic, intracranial, or cranial nerve vascular anastomoses represents an important mechanism of neurological complications. Four recent randomized controlled trials—EMBOLISE, MAGIC-MT, STEM and EMPROTECT—did not demonstrate a substantial increase in overall serious adverse events associated with MMAE. However, rare procedure-related ischemic events were reported. Careful angiographic identification of dangerous collateral pathways, appropriate distal microcatheter positioning and controlled embolic agents delivery are essential measures for reducing procedural risk. MMAE appears to be a relatively safe treatment option for appropriately selected patients with cSDH. Standardized reporting of adverse events and further prospective studies are recommended to better characterize the safety profile of MMAE.

Keywords: chronic subdural hematoma (cSDH), middle meningeal artery embolization (MMAE), complications, endovascular treatment, recurrence of cSDH

1. INTRODUCTION

Chronic subdural hematoma (cSDH) is one of the most prevalent conditions requiring cranial neurosurgical intervention. The incidence ranges from 3.39 to 39.10/100,000 person-years (Dziho et al., 2025) and increases with age. It reaches 58.10/100,000 person-years in the population over 65 years of age (Kudo et al., 1992).

The incidence of cSDH is rising with population aging (El Rahal et al., 2023). The increase in incidence is also attributed to the greater use of anticoagulants and antiplatelet drugs, which are another risk factor for cSDH (El Rahal et al., 2023; Rauhala et al., 2020). Moreover, better access to radiological examinations, especially computed tomography (CT) of the head, increases the number of diagnosed cases (Rauhala et al., 2020). Other risk factors are: head trauma, male sex, brain atrophy, coagulopathies, alcohol abuse, and intracranial hypotension (Dziho et al., 2025; Rauhala et al., 2020). Considering the patient's condition and the size of the cSDH, there are several treatment options: conservative management (including: discontinuation of antithrombotic therapy, steroids and atorvastatin, follow-up CT of the head), burr-hole drainage, craniotomy and middle meningeal artery embolization (MMAE), (Mehmandoost et al., 2025). The postoperative recurrence rate ranges from 5-30%, with a median time to reoperation of approximately 25 days (Cofano et al., 2020; Rauhala et al., 2020). Due to the growing number of patients with cSDH, the significant recurrence rate, and the resulting higher treatment costs, it is crucial to find a method that would effectively address this medical problem. Minimally invasive MMAE may be considered as a promising alternative (Dziho et al., 2025; El Rahal et al., 2023). This review summarizes the current knowledge on this area and demonstrates potential complications arising from MMAE.

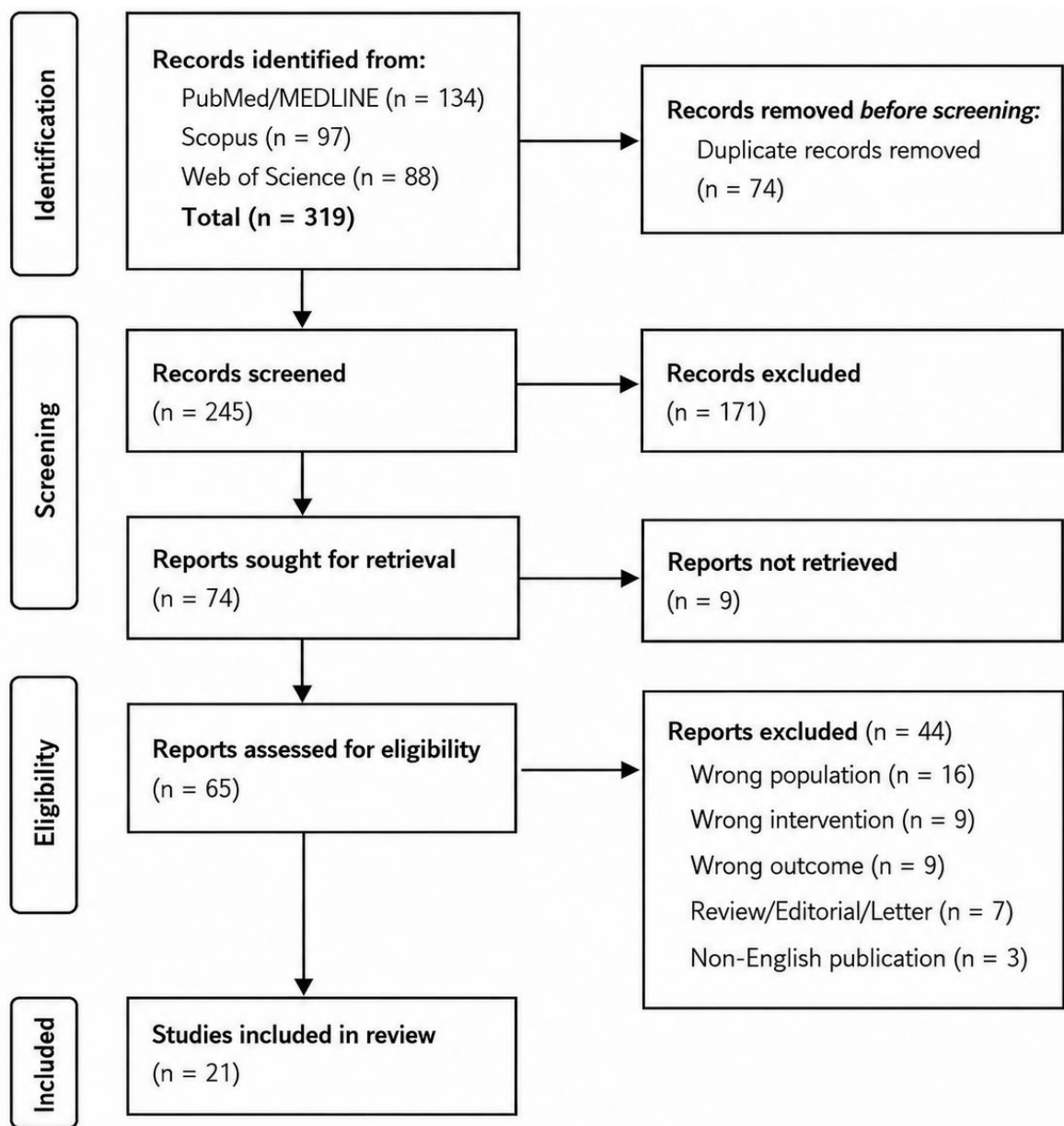


Figure 1. PRISMA 2020 flow diagram and study selection process.

2. REVIEW METHODS

This narrative review summarizes current knowledge on the safety and complications associated with MMAE in cSDH. A systematic literature search was performed in PubMed/MEDLINE and Scopus for English-language studies published up to July 15, 2026. Search terms included: "chronic subdural hematoma", "middle meningeal artery embolization", "MMAE", "complications", "adverse events", "safety", "stroke", "hemorrhage", "visual loss" and "cranial nerve palsy". Randomized controlled trials, observational studies, systematic reviews, meta-analyses, consensus statements and relevant case series addressing the safety and complications of MMAE for cSDH were considered. After screening and eligibility assessment, 21 publications were selected in the final narrative synthesis (Figure 1).

3. RESULTS AND DISCUSSION

Currently, cSDH is considered an active inflammatory and pathological angiogenic process, rather than merely a remnant of a previous hemorrhage in the subdural space (De Oliveira Manduca Palmiero and Gadelha Figueiredo, 2026). This promotes recurrent microbleeding and the formation of a highly vascularized hematoma capsule. MMAE may reduce perfusion of the hematoma capsule (as distal branches of the MMA supply it) and, consequently, limit the risk of further recurrence in patients with refractory or recurrent cSDH (Papageorgiou et al., 2025; Yadav et al., 2016). MMAE can be used as the standalone treatment or as adjunctive approach to operative neurosurgical treatment (Mascitelli et al., 2026). MMAE may be a beneficial treatment method in patients with a high risk of cSDH recurrence or with contraindications to surgery. According to the "Multidisciplinary consensus-based statement on the current role of middle meningeal artery embolization (MMAE) in chronic subdural hematoma (cSDH)", MMAE may be considered as a standalone treatment option in patients with de novo or recurrent cSDH requiring intervention when surgery cannot be safely performed because of coagulopathy or an unacceptably high risk associated with interruption of antithrombotic therapy. Furthermore, adjunctive MMAE may be considered in patients undergoing surgical treatment for recurrent cSDH (Bartek et al., 2024). Liquid agents (like Onyx, Squid, n-Butyl Cyanoacrylate [n-BCA]), particulates (like polyvinyl alcohol [PVA], microspheres) and coils could be used as embolic agents. To date, no specific embolic agent has shown a clear advantage over others across studies (De Oliveira Manduca Palmiero and Gadelha Figueiredo, 2026).

Complications

The rate of complications after MMAE ranges from 0.8% to 4.9% (Fiorella et al., 2025; Liu et al., 2024, Shafi et al., 2025). Severe complications are approximately 1% (Omura and Ishiguro, 2023) and include: cerebral infarction, visual loss, facial nerve palsy, intracranial hemorrhage and vascular injury. Minor adverse events include seizures, headache, transient neurological deficits, renal dysfunction and access-site hematoma. Serious neurological complications may result from non-target embolization through high-risk anastomoses involving the retinal circulation or the vasa nervorum of the facial nerve. Careful angiographic assessment, distal microcatheter positioning and strict control of embolic reflux are fundamental to minimize procedural risk (Omura & Ishiguro, 2023). In a meta-analysis of 34 studies including 921 patients - 35 complications (3.8%) were identified (Shafi et al., 2025). The types of complications were divided into neurological, cardiovascular, infectious, and miscellaneous. Neurological adverse events were reported with an incidence of 3.8%, and included: new-onset seizures, ischemic stroke, aphasia, visual impairment (central retinal artery occlusion), and hemiplegia. As cardiovascular complications (3.6 %) were defined: MMA rupture, fistula formation, aortic dissection, and femoral artery pseudoaneurysm. Pneumonia and empyema were categorized as infectious complications, and their incidence was 2.9%. Miscellaneous complications (3.1%) comprised other complications not classified into the previous groups, such as: guide catheter herniation, retained microcatheter or death. Jindal et al. reported a 3.3% rate of MMAE-related complications in a systematic literature review of 9,780 patients (Jindal et al., 2026). Similarly to the study by Shafi et al., procedure-related complications were classified into neurological (1.2% - aphasia, visual changes - retinal artery embolization, strokes, facial nerve palsy - non-target embolization through vascular anastomoses or accidental involvement of the petrosal branch of the MMA, intracranial hemorrhage), intracranial vascular (0.1% - MMA rupture or perforation or arteriovenous fistula formation), access-site-related (0.6% - hematoma, pseudoaneurysm), and miscellaneous categories (<0.1% - catheter entrapment, retained catheter). Post-procedural adverse events were also reported and comprised neurological complications (0.5%), including seizures, delirium, worsening headache, and neurological deterioration, as well as systemic complications (0.8%), such as infections, acute kidney injury, contrast-related allergic reactions, and deep vein thrombosis.

Musmar et al. in meta-analysis of 44 studies reported that MMAE as a standalone treatment or as an adjunctive to surgery was linked to a significant reduction in recurrence compared with surgery alone (Musmar et al., 2025). Nevertheless no notable differences

were observed in overall complication rates or favorable functional outcomes at the final follow-up. What’s more, transradial MMAE access appeared to be associated with fewer access-site complications than transfemoral access.

In meta-analysis of four clinical trials including 1680 patients with cSDH Elfil et al. demonstrated that MMAE as an adjunctive treatment was associated with a 44% lower risk of recurrence of cSDH and a 47% reduction in mortality compared with surgical treatment. Compared with standard treatment MMAE was not related to an increased risk of serious adverse events or major disabling stroke, while functional outcomes did not differ significantly between the groups (Elfil et al., 2025).

Safety in Randomized Controlled Trials

Four randomized controlled trials published between 2024 and 2026 - EMBOLISE, MAGIC-MT, STEM and EMPROTECT- have evaluated the safety of MMAE (Table 1). Although these studies differed in patient populations, embolization techniques and outcome definitions, their findings consistently supported an overall favorable safety profile of the procedure.

Table 1. Randomized controlled trials evaluating MMAE in cSDH.

Trial	Patients (n)	Treatment strategy	Embolic agent	Main efficacy outcome	Main safety / complications findings
EMBOLISE – Davies et al., 2024	400	Surgery + MMAE vs surgery alone	Onyx	Recurrence/progression requiring repeat surgery: 4.1% vs 11.3%; RR 0.36; P=0.008	MMAE-related SAEs within 30 days: 2.0%; 2 disabling strokes. No additional serious MMAE-related events through 180 days. 90-day mortality: 5.1% vs. 3.0%.
MAGIC-MT – Liu et al., 2024	722	MMAE + usual care vs usual care	Onyx	Symptomatic recurrence/progression at 90 days: 6.7% vs 9.9%; not statistically significant	MMAE-related complications: 0.8% - facial nerve palsy 0.3%, contrast allergy 0.6%. 90-day SAEs: 6.7% vs. 11.6%; mortality: 0.6% vs. 2.2%.
STEM – Fiorella et al., 2025	310	MMAE + standard treatment vs standard treatment	Squid	Treatment failure at 180 days: 16% vs 36%; OR 0.36; P=0.001	Primary 30-day safety endpoint (major disabling stroke or death): 3% vs. 3%. 180-day mortality: 8% vs. 5%.
EMPROTECT – Shotar et al., 2025	342	Postoperative MMAE vs standard postoperative care	Microparticles	Recurrence at 6 months: 14.8% vs 21.0%; OR 0.64; P=0.13	Major procedure-related complication: 0.6% - ischemic stroke due to MCA occlusion. Minor procedure-related AEs: 1.8% - transient hemiparesis, transient aphasia, mild headache.

Abbreviations: cSDH, chronic subdural hematoma; MMAE, middle meningeal artery embolization; n-BCA, n-butyl cyanoacrylate; OR, odds ratio; RR, relative risk; SAE, serious adverse event; AE, adverse event; MCA, middle cerebral artery.

In the EMBOLIZE trial - 197 patients received MMAE (Onyx) as an adjunct to surgery and 203 patients underwent surgical treatment alone. During the EMBOLISE study, 4 patients (2.0%) experienced serious adverse events directly related to MMAE within 30 days, including 2 cases of permanently disabling stroke (Davies et al., 2024).

The MAGIC-MT trial included 722 patients. 360 patients were assigned to the MMAE (Onyx) group and 362 to usual care. Within 30 days - 1 facial nerve palsy and 2 allergic reactions to the contrast agent were described as MMAE-related complications (0.8%). During the 90- day follow-up, serious adverse events were less common among patients after MMAE (6.7%) than among those who received usual care (11.6%) (Liu et al., 2024).

The STEM study included 149 patients after MMAE (Squid) and 161 in the control group. In patients with symptomatic cSDH, the addition of MMAE to standard treatment significantly reduced the risk of treatment failure without increasing the short-term incidence

of disabling stroke or death. During the STEM study of 149 patients after embolization, 3% of the patients had a major disabling stroke or died within 30 days - the same as in the control group (Fiorella et al., 2025).

The EMPROTECT study included 342 patients - 171 in the standard care group and 171 in the standard care + MMAE (microparticles) group. No significant reduction in 6-month cSDH recurrence with adjunctive MMAE was found, while adverse event rates were similar between the treatment groups. During the EMPROTECT trial, 1 of 171 (0.6%) patients after MMAE had a major complication – stroke due to middle cerebral artery occlusion. Minor procedure-related adverse events occurred in three patients (1.8%), including: transient hemiparesis, transient postprocedural aphasia and mild headache (Shotar et al., 2025).

In summary current research indicates that MMAE has a favorable safety profile. Systematic reviews and large observational studies show that complications associated with MMAE are rare and that their frequency depends on the definition of "complication" and study methodology. Thromboembolic and neurological events appear to be the most clinically significant complications. Visual loss and facial nerve palsy are rare but potentially irreversible. Neurological complications are associated with off-target embolization via extracranial-intracranial, ophthalmic, or cranial nerve anastomoses. Therefore, detailed angiographic evaluation and appropriate experience during the embolization procedure are essential. The last four randomized controlled trials did not suggest a significant increase in the overall number of serious adverse events associated with MMAE. However, they did report rare procedure-related ischemic complications. The benefits of MMAE, such as reducing the risk of recurrence, progression and treatment failure in cSDH, must be balanced against the small but clinically significant risk of endovascular complications.

Prevention of MMAE-related complications

According to the Society of Neurointerventional Surgery Standards and Guidelines Committee before embolization a detailed angiographic evaluation should be performed. It is vital to identify potentially dangerous collateral pathways to minimize complications (Mascitelli et al., 2026). The MMA can exhibit significant anatomical variability and can connect with the ophthalmic circulation, the internal carotid artery, the vertebrobasilar system, and vessels that supply the facial nerve. Consequently, accidental embolization of these anastomoses can lead to complications such as visual impairment, cranial nerve palsy or cerebral ischemia. It can also connect with extracranial vessels which could influence cSDH recurrence. Therefore, accurate angiography before MMAE is necessary to minimize the risk of complications and recurrence of cSDH (Jindal et al., 2026).

Link et al. highlighted the careful angiographic identification of MMA ophthalmic anastomoses and petrosal branches, selective distal catheterization and continuous monitoring (blank fluoroscopic roadmapping) to prevent embolic reflux and non-target embolization and neurological complications (Link et al., 2018).

Because cSDH occurs most often in people over 65 years of age, it must be taken into account that intravascular catheter manipulation during MMAE is correlated with an increased risk of embolism, which may cause stroke due to the atherosclerosis occurring in this population (Jindal et al., 2026).

Due to possible complications, the patient should be carefully monitored after MMAE. Neurological evaluation is particularly important, including visual and cranial nerve function. Assessment of the intravascular access site is also important to rule out access-related complications.

4. CONCLUSION

MMAE appears to be a relatively safe treatment option for patients with cSDH. However, careful patient selection is essential. To avoid rare complications that can significantly impact quality of life, detailed assessment of the vascular anatomy of MMA, appropriate microcatheter placement and controlled administration of the embolizing agent are essential to minimize procedural risks. Further prospective studies and reporting of adverse events associated with MMAE are needed to more accurately determine the incidence of rare complications and identify patients in whom the benefits of embolization clearly outweigh the risks. Future research should also focus on identifying patient- and procedure-related risk factors to improve patient selection and further enhance the safety of MMAE procedures.

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Informed consent

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Ethical approval

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Conflict of interest

The author declares that there is no conflict of interest, competing financial interests or personal relationships that could have influenced the work reported in this paper.

Data and materials availability

All data associated with this study will be available based on the reasonable request to corresponding author.

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