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Research Article

# Middle Meningeal Artery Embolization with Embospheres for the Treatment of Chronic Subdural Hematomas

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## Abstract

**Background**: Chronic subdural hematomas (cSDH) represent a common neurosurgical pathology with an incidence of 1.7-20.6 per 100,000 persons per year. Surgical evacuation shows a significant recurrence rate with the need of re-evacuation up to 10-20%. Middle meningeal artery embolization (MMAE) is an increasingly common procedure involved in the treatment of chronic subdural hematoma (cSDH) that can be an adjuvant intervention or an alternative to traditional medical or surgical therapies.

**Objective**: This case series aims to evaluate the effectiveness and safety of the endovascular embolization of the middle meningeal artery with Embosphere® Microspheres for the treatment of cSDHs.

**Methods**: From 06/2019 to 08/2020 a total of 26 consecutive patients (19 m / 7f; median age 79 (71-85)) with 35 cSDHs (9 bilateral) were treated with MMA embolization. Patients underwent embolization as stand-alone treatment or as adjunct to surgical evacuation either prior to or after surgery. Patients were assessed clinically and with cCT 2, 6 weeks and 3 months after the procedure. Primary outcome was absence of significant recurrence with need for surgery. Complete hematoma resolution or significant reduction of more than 50% of its initial size, periprocedural complications and clinical outcome after the modified Rankin Scale (mRS) were secondary outcome parameters.

**Results**: MMA embolization was successfully performed in all patients with no serious adverse events. 1 Patient (3.8%) presented a hematoma at the inguinal puncture site without need for further treatment. 13 hematomas received MMAE without surgery, 18 for recurrence after surgical evacuation and 4 in combination with surgical evacuation. From 21/26 patients (80.7%) with 28 cSDHs (80%) follow-up was available for analysis with a median follow-up of 12 weeks (12-15). During follow-up one patient died due to an unrelated cause. From the 28 sufficiently evaluated cSDHs 2 (7.1%) needed surgery for recurrent cSDH after embolization whereas 26 (92.9%) met the primary outcome with 21 (75%) having a complete resolution. The median mRS on admission was 3 (2-4) with mRS at the last follow-up being 1 (0-1).

**Conclusion**: Data showed that endovascular embolization of the middle meningeal artery with Embosphere® Microspheres is an effective and safe treatment method for patients with chronic subdural hematoma as a stand-alone procedure or in combination with surgery.

***Keywords:*** *Chronic Subdural Hematoma, Middle Meningeal Artery, Embolization, Embolic Agents*

# Introduction

Chronic subdural hematoma (cSDH) is the pathologic collection of blood and blood products in the subdural space with an insidious onset and progression. The incidence varies in the existing literature between 1.7-20.6 per 100,000 persons per year reaching an incidence of 79.4 per 100,000 per year in patients over 65 years of age with rising incidence. [1, 2].

Surgical evacuation of the hematoma via burr hole craniostomy or craniotomy with or without subdural drainage is the gold standard of surgical therapy for symptomatic patients. Several studies in the literature tried to compare these surgical methods, with the results showing a higher rate of residual hematoma for the burr hole craniostomy and higher morbidity for craniotomy. Despite these established surgical methods the existing literature shows a high recurrence rate, with the need of reevacuation in up to 10-20%. [3]

# Methods

### Patient Selection

Consecutive patients who underwent MMA embolization for symptomatic cSDH in a tertiary single institution from June 2019 to August 2020 were included. There were three groups of patients that received treatment: A. Patients who received MMA embolization as a stand-alone treatment, B. Patients who showed hematoma recurrence after surgical evacuation and underwent embolization as a rescue therapy and C. patient who were treated with MMA Embolization as prophylaxis of recurrence just before or after the surgical evacuation (Figure 1). The decision of treating patients of group C as surgical adjunct was surgeon dependent based on specific hematoma characteristics (SDH thickness, midline shift, membrane formation) and was discussed with the patient before consent. Patients with mixed hematomas and significant acute component were excluded from this study.

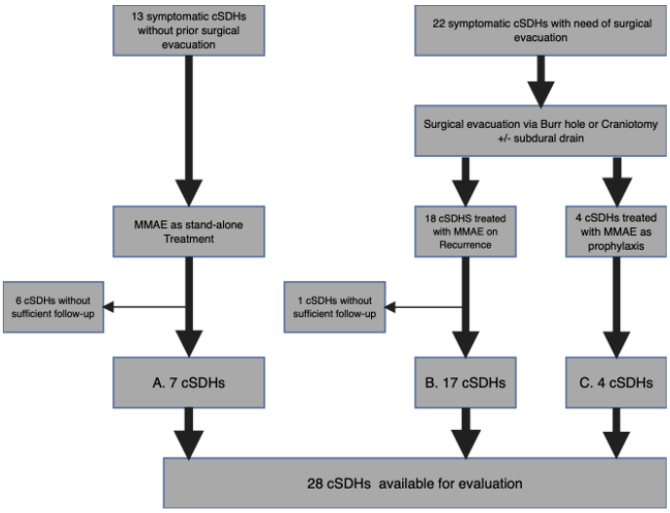


**Figure 1.**

### MMA-Embolization Procedure

Embolization was performed under conscious sedation or general anesthesia depending on the neurological patient's status. Biplane fluoroscopy was used. Heparinization with 5.000 units was used in all patients. After placement of 6 french guiding catheter in the proximal external carotid artery a microcatheter (Prowler Select Plus; Johnson&Johnson Medical Ltd., England) was navigated over a microwire (Synchro-14; Stryker Neurovascular, Fremont, CA). A superselective angiography through the microcatheter was performed to select target MMA branches and to rule out hazardous collaterals to the ophthalmic and ICA branches. The embolization was performed with Embosphere® Microspheres (TCAG 150-500 µm, Merit Medical, France). To optimize diffusion of microspheres into the neoavasculature of the hematoma membranes, we prepared a fairly dilute solution with 1 ml of microspheres, 10ml 0.9% NaCl and 10 ml non-ionic contrast agent. Injection was performed with a 1 cc syringe slowly under continuous fluoroscopic control.

No microcatheter occlusion occurred due to particle precipitation. When flow stasis of the MMA was confirmed (s. Fig. 2), the procedure was stopped. The guide catheter and femoral sheath were then removed and femoral hemostasis obtained with an AngioSeal closure device.

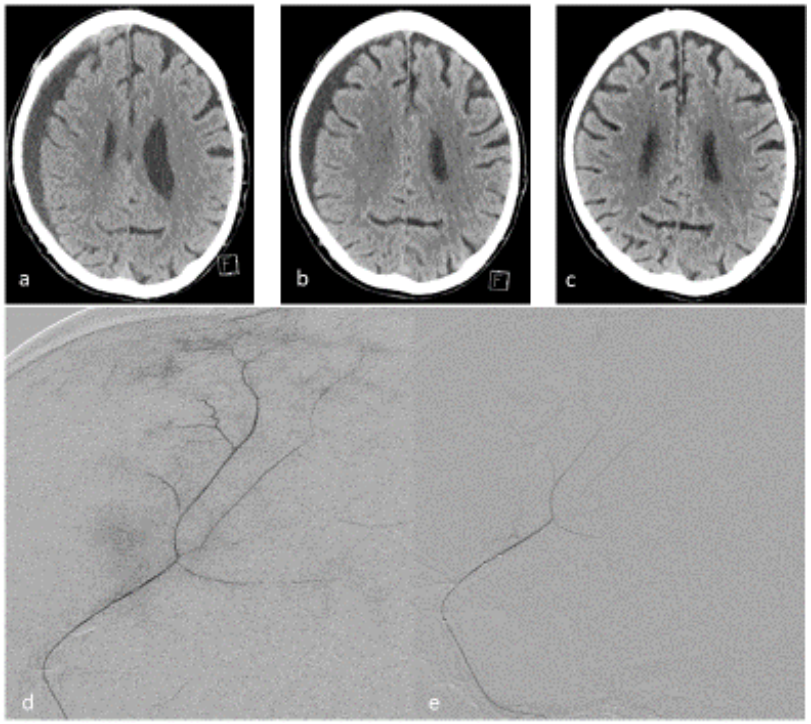


**Figure 2. (a)** Pretreatment CCT shows SDH in right frontal and parietal lobes. **(d)** Microcatheter angiography of the MMA before embolization shows typical cotton wool like enhancement of the hematoma membranes. **(e)** Complete embolization of the MMA branches. **(b)** CCT follow-up after two weeks shows decrease in maximum width and mass effect of hematoma. **(e)** Three-months follow-up CCT shows complete resolution of the SDH.

### Data Collection

Patients who underwent MMA-Embolization were assessed clinically and through CT Imaging 2, 6 weeks and 3 months after the procedure and individually in further regular intervals if deemed necessary. Data collection was performed ambispectively with prospective patient collection and retrospective analysis of patient charts and radiographic examinations. Seven patients were lost to follow-up. Patient's demographics included age, gender, use of anticoagulation or antiplatelet therapy, comorbidities based on the age-adjusted Charlson comorbidity index, symptoms and neurologic deficits, functional scores based on the modified Rankin Scale, the need and method of surgical evacuation and the use of a subdural drainage. Hematoma characteristics included the laterality of the pathology and the maximal axial width of the hematoma evaluated on CT Imaging

### Outcome Assessment

The primary outcome parameter was defined as the absence of significant radiographic and clinical hematoma recurrence requiring surgical evacuation. Complete hematoma resolution or significant reduction of more than 50% of its initial size, periprocedural complications and improvement of functional score modified Rankin Scale (mRS) were secondary outcome parameters.

## Results

A total of 26 patients with 35 symptomatic cSDHs (9 patients had bilateral hematomas) were treated with embolization of the middle meningeal artery. Of these, 13 hematomas underwent MMAE as a stand-alone treatment without prior surgical evacuation, 18 were treated for recurrence after surgical evacuation and 4 as prophylactic adjunct just prior or immediately after surgical evacuation without signs of recurrence. 5 patients with 7 cSDHs (2 with bilateral) failed to keep up with the follow up and were excluded from the evaluation. Figure 1. demonstrates the 3 treatment groups and those without sufficient follow up. 21 patients with 28 hematomas were included in the evaluation Figure 1. The median modified Rankin Scale on admission was 3.

| **Table 1.** Patient Characteristics | |
|---|---|
| **Patient characteristic** | **Patients (%), N= 21** |
| **Demographics** | |
| Age, years (median, IQR) | 79 [71,84] |
| Male Sex | 15 (71.2%) |
| Antiplatelet medication | 6 (28.5%) |
| **Type of Antiplatelet medication** | |
| Aspirin | 5 (23.8%) |
| Clopidogrel | 1 (4.7%) |
| Anticoagulation | 6 (28.5%) |
| **Type of anticoagulation** | |
| Phenprocoumon | 6 (28.5%) |
| **Presenting symptoms** | |
| Headache | 7 (33.3%) |
| Altered mental status | 7 (33.3%) |
| Gait instability | 6 (28.5%) |
| Mild motor weakness | 9 (42.8%) |
| Aphasia | 4 (19.0%) |
| **Comorbidities** | |
| Age adjusted CCI (median, IQR) | 6 [4,9] |
| **Functional score** | |
| Admission mRS (median, IQR) | 3 [2,4] |

21 symptomatic patients were treated with embolization of the middle meningeal artery. The median age was 79 years [71,84] with 15 (71.2%) being male. Most of the patients had significant comorbidities, median Age adjusted Charlson Comorbidity Index was 3 [2,4]. A total of 6 (28.5%) patients were on antiplatelet medication, 5 (23.8%) taking aspirin and 1 (4.7%) clopidogrel. 6 (28.5%) were on anticoagulation therapy with phenprocoumon at the time of admission. The most common presenting symptom was mild motor deficit 9 (42.8%), followed by headache 7 (33.3%), altered mental status 7 (33.3%), gait instability 6 (28.5%) and aphasia 4 (19.0%). Patient characteristics are presented in Table 1.

| **Table 2.** Hematoma Characteristics | |
|---|---|
| **Characteristic** | **Hematomas (%), N=28** |
| **Laterality** | |
| Right | 13 (46.4%) |
| Left | 15 (53.6%) |
| Bilateral | 12 (42.8%) |
| **Treatment group** | |
| Stand-alone | 7 (25.0%) |
| Recurrence after surgical evacuation | 17 (60.7%) |
| Prophylactic with surgical evacuation | 4 (14.3%) |
| Surgical evacuation | 21 (75.0%) |
| **Type of surgical evacuation** | |
| Burr hole | 19 (67.9%) |
| Craniotomy | 2 (7.1%) |
| Subdural Drain | 15 (53.6%) |
| **Size** | |
| SDH width on admission, mm (median,IQR) | 18 [10,24] |

Out of a total of 28 hematomas 15 (53.6%) were on the left side with 12 (42.8%) being bilateral. The median axial hematoma width on admission was 18 mm [10,24]. According to the treatment groups 7 (25.0%) cSDHs received MMAE as a stand-alone therapy, 17 (60.7%) were treated after failure of a surgical evacuation with signs of symptomatic and radiographic recurrence and 4 (14.3%) were embolized adjunct to surgical treatment. From a total of 21 (75%) surgically treated SDHs, 19 (67.9%) received burr hole craniostomy and 2 (7.1%) were treated with craniotomy with 15 (53.6%) having a subdural drain. Table 2. shows the hematoma characteristics.

| **Table 3.** Clinical Outcomes | |
|---|---|
| **Clinical Outcome** | **Patients (%), N= 21** |
| Follow-Up, weeks (median,IQR) | 12 [12 ,15] |
| **Mortality** | 1 (4.8%) |
| **Complications** | |
| Puncture site hematoma | 1 (4.8%) |
| **Functional score** | |
| mRS on last Follow-Up (median,IQR) | 1 [0 ,1] |
| mRS improvement | 16 (76.1%) |
| mRS stable | 4 (19.1%) |
| mRS decline | 1 (4.8%) |

| **Table 4.** Radiographic Outcomes | |
|---|---|
| **Radiographic Outcome** | **Hematomas (%), N=28** |
| SDH width on last follow-up, mm (median, IQR) | 0 [0,3] |
| SDH width on last follow-up, mm (mean,SD) | 2.3 ± 4.8 |
| **cSDH Improvement** | |
| Complete resolution | 21 (75.0%) |
| Reduction > 50% | 3 (10.8%) |
| Reduction < 50% | 2 (7.1%) |
| Recurrence | 2 (7.1%) |
| No need for further surgical treatment | 26 (92.9%) |

The median follow-up for a total of 21 patients was 12 weeks. 1 patient (4.8%) died during the follow-up of a cause unrelated to the procedure. He developed a pneumonia 3 months after the procedure and was treated in the geriatric department dying of sepsis. An inguinal puncture site hematoma was documented in 1 patient (4.8%) as a minor adverse event not needing further treatment. No serious adverse events were seen related to the procedure. Regarding the functional score the median modified Rankin scale on last follow-up showed an improvement compared to admission being 1 [0 ,1]. A total of 16 (76.1%) presented an improvement of their initial mRS. In 4 (19.1%) mRS was stable in comparison to admission and 1 (4.8%) declined neurologically. The clinical outcomes are presented in Table 3.

Table 4 summarizes the radiographic findings of the final evaluation. 26 (92.9%) of 28 hematomas met the primary outcome by not needing further surgical evacuation after MMAE. Considering the secondary radiographic outcomes 21 (75%) hematomas showed a complete resolution at any given point of the follow-up, 3 (10.8%) had a significant reduction of more than 50% of their initial size and 2 (7.1%) presented a reduction of less than 50%. Two (7.1%) hematomas had an increase of their size after embolization and underwent surgical rescue treatment.

## Discussion and Conclusion

Chronic subdural hematoma (cSDH) is one of the most common pathologic processes necessitating neurosurgical intervention [1, 2]. It is increasingly understood as an angiogenic and inflammatory disease driven by fragile neovascular membranes that sustain hematoma persistence and growth [3]. This evolving pathophysiological concept provides the rationale for middle meningeal artery embolization (MMAE) as a disease-modifying treatment targeting the vascular supply rather than the mass effect alone. Randomized controlled trials, single- and multi-center studies as well as meta-analyses has established MMAE as an effective adjunct to surgical evacuation, significantly reducing recurrence rates compared with surgery alone, while maintaining a favorable safety profile. [4-18]

These findings have led to a paradigm shift in the management of cSDH and are reflected in current guideline recommendations, which support adjunctive MMAE as a class I indication in appropriately selected patients and recognize its role as a stand-alone treatment in high-risk populations. [19, 20, 21]

In this context, the present study demonstrates high technical success and an excellent safety profile, with no major procedure-related complications. Clinical outcomes were favorable, with a low recurrence rate of 7.1% and a high proportion of patients avoiding surgical intervention. Notably, no patient treated with stand-alone MMAE required subsequent surgical evacuation, and most patients achieved complete hematoma resolution. Regarding the clinical outcomes 76.1% of the patients in this study could clinically benefit from their treatment showing an improvement of their initial mRS with 85.7% having a favourable mRS (0-2) at the follow-up. These results are consistent with the growing body of literature supporting MMAE as both a primary and adjunctive treatment strategy and further reinforce its role in contemporary neurointerventional practice. [9-18]

From a neurointerventional perspective, treatment success appears to depend less on the specific embolic material used and more on achieving effective distal penetration into the pathological microvascular network of the hematoma membranes. This concept aligns with current guideline statements emphasizing the importance of technical execution and careful anatomical assessment, including the identification of dangerous collateral pathways prior to embolization [19, 20]. Distal microcatheter positioning within the frontal and parietal branches of the middle meningeal artery is critical, as proximal embolization alone is insufficient to address the extensive collateral supply and distal neovascularization. Procedural strategy must therefore be adapted to the embolic material used: particulate embolization requires preservation of antegrade flow to facilitate distal particle transport, whereas liquid embolic agents benefit from controlled wedging to limit reflux and promote forward penetration. Across all techniques, slow and controlled injection with continuous fluoroscopic monitoring is essential to ensure safe and effective embolization.

The choice of embolic material remains a subject of ongoing debate. Particle-based embolization, most commonly using polyvinyl alcohol (PVA) particles, is widely adopted due to its technical simplicity, availability, and cost-effectiveness. [15, 19, 24, 25, 28] Adjusting particle size enables modulation of proximal-to-distal penetration. However, the irregular shape and aggregation tendency of PVA particles may result in proximal vessel occlusion and variable distal penetration. Calibrated microspheres such as trisacryl gelatin microspheres (TAGM, Embosphere®) were developed to overcome some limitations of conventional PVA particles. Embosphere® are flexible particles that support temporary compression by 20 to 30 % and can travel more distally in a given vessel and are less prone to clumping. [24-28] Embosphere Microspheres penetrate more distally into the lesion than PVA particles of similar size.

Reduction of the arterial blood supply to the lesion is therefore more progressive. Although smaller particle sizes may improve distribution, the extent of microvascular embolization remains variable and operator-dependent. For particle-based MMAE, low-concentration mixtures are helpful to achieve more distal penetration and to avoid unintentionally microcatheter and proximal vessel occlusion.[25] Overall, MMAE procedures have a good safety profile, with an overall complication rate of about 3% in the current literature. The risks for stroke, hemorrhage, and visual loss are below 1% individually. [19, 30,31]

Historically, particle-based embolization, particularly using PVA particles or calibrated microspheres, has been the most commonly reported MMAE technique worldwide. This predominance is reflected in early observational studies and systematic reviews, where particulate agents accounted for the majority of embolization procedures. However, recent randomized controlled trials have largely utilized EVOH-based liquid embolic agents, suggesting a gradual shift in contemporary practice patterns.[15, 24, 28] Liquid embolic agents, including n-butyl cyanoacrylate and ethylene-vinyl alcohol copolymers (Onyx, Squid), provide a different mechanisms of vessel occlusion enabling more controlled, homogeneous, and distal embolization. [32] NBCA polymerizes rapidly upon contact with blood, producing permanent vessel occlusion. EVOH-based agents precipitate in an “outside-in” fashion, creating a cohesive sponge-like cast that can be injected in a controlled manner.[32] Their flow-independent penetration allows for deeper access to the pathological capillary network, which may facilitate more complete devascularization of the subdural membranes.[33] Unlike PVA particles, liquid embolic agents are not incorporated into thrombus-dependent vessel occlusion and may therefore provide a more durable embolization.[34] In addition, their intrinsic radiopacity enables real-time visualization of embolic distribution, which may enhance procedural control.

These benefits come at the cost of increased technical complexity, longer procedure times, and a higher risk of non-target embolization, particularly in the presence of unrecognized anastomoses.[19,33, 34] Additionally, the intervenionalist must be aware flushing the microcatheter with dimethyl sulfoxide (DMSO) can lead to hemodynamic instability and, in the worst case scenario, asystole during the intervention. Futhermore, DMSO can cause significant pain in awake patients. A potential preventive strategy is using prophylactic intraarterial lidocaine before flushing the microcatheter with DMSO.[35] For the reasons mentioned, most neurointerventionalists prefer embolisation with EVOH-based agents under general anaesthesia.

However, currently available RCTs, single- and multi-center studies as well as meta-analyses do not permit definitive conclusions regarding superiority of liquid embolic agents over particulate agents. Importantly, three of the four studies were conducted using liquid embolic agents exclusively, potentially contributing to the observed treatment effects. Data from matched analysis found no differences in radiological improvement, surgical rescue, or major complications between embolic materials in MMAE. These data suggest that future trials involving particles are likely to produce similar outcomes [29].

Current consensus recommendations support MMAE as an evidence-based treatment for cSDH, supported by multiple randomized controlled trials demonstrating significant reduced recurrence and reoperation rates. Nevertheless, MMAE should presently be regarded as complementary to, rather than a substitute for surgical evacuation in patients with symptomatic mass effect.

The role of stand-alone (MMAE in asymptomatic cSDH remains incompletely defined. Current consensus statements consistently emphasize that patients with asymptomatic cSDH and no significant mass effect generally do not require immediate intervention and are typically managed conservatively with clinical and radiological surveillance. However, embolization may be considered in selected neurologically stable patients with progressive hematoma enlargement, elevated surgical risk, or contraindications to operative management. Although early results are promising, even in our study, the role of stand-alone MMAE in asymptomatic cSDH remains an important area for future investigation.

## Conflict of Interest

The authors declare that they have no conflict of interest.

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