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A Part of Sage

Coil embolization alone appears sufficient for middle meningeal artery embolization

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Abstract

Background: Middle meningeal artery embolization (MMAE) has shown promise as an alternative treatment for chronic subdural hematoma (cSDH); however, the most effective procedural technique is debated. We sought to assess the safety and efficacy of coil embolization as a stand-alone technique for MMAE in cSDH.

Methods: A single-center retrospective analysis was performed of patients who underwent MMAE for chronic SDH with coil embolization alone.

Results: Forty-five patients were included in the study. All underwent successful stand-alone coil MMAE, of which 51.1% were bilateral. Indications for MMAE were varied, but 13.3% of patients required ongoing anticoagulation and another 11.1% had severe thrombocytopenia. Conscious sedation or no sedation was used in 73.2% of patients; 10 patients (22.2%) were scheduled electively and discharged same day. There were no severe or minor procedural complications identified. Of the 45 patients, only 3 (6.6%) underwent unplanned repeat surgical intervention: one patient developed a large recurrence at eight weeks after MMAE and underwent burr hole drainage; the second patient received burr hole drainage prior to MMAE but needed repeat burr hole drainage two weeks later due to residual; the third patient received two burr hole drainages at two and three weeks post MMAE due to persistent disease.

Conclusion: Stand-alone MMAE with coiling can be performed under conscious sedation as an outpatient procedure and may be sufficient to prevent cSDH recurrence in most cases without the need for particle penetration of cSDH microvascular beds. Larger confirmatory studies are necessary.

Keywords

MMA embolization, coils, chronic subdural hematoma, recurrence

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Introduction

Chronic subdural hematoma (cSDH) is a common disease, especially among the elderly population.[1] It is characterized by an organized collection of blood in the subdural space.[2] Traditionally, it was believed that cSDH is a result of slow accumulation of venous bleeding secondary to the tearing of bridging veins.[3] Management of this potentially life-threatening pathology has classically been either via observation (in smaller hemorrhages without significant mass effect) or through surgical evacuation (in symptomatic patients) via bedside twist drill craniostomy, burr hole craniostomy, or open craniotomy.[3,4] These interventions, however, are associated with surgical complications and suboptimal recurrence rates. Ducruet et al., in a meta-analysis of over 5400 procedures, quoted the recurrence rate for cSDH as 28.1% for bedside, twist drill craniostomy, 19.4% for open craniotomies, and 11.7% for burr hole craniostomies.[5]

Middle meningeal artery embolization (MMAE) has since emerged as a promising treatment for cSDH.[6] The middle meningeal artery (MMA) supplies blood to the dura mater and contributes to neovascularized membranes within cSDHs that are thought to ooze, leading to cSDH growth. The cycle of cSDH formation and growth may be broken through the devascularization of the cSDH membrane via MMAE.[7] Several studies have shown significantly decreased recurrence rates and reduction in hematoma size when MMAE is used in conjunction with surgical treatment or even as a stand-alone treatment modality.[8] However, the choice of technique by which the MMA is embolized remains debated.[9] Most published series have reported on the use of particle embolization (polyvinyl alcohol [PVA] particles), liquid embolic agents (Onyx and n-BCA), or the combination of coils and another embolizing agent.[10] The rationale for using liquid or particulate embolysate agents is born out of the desire to improve distal penetration of the embolysate

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into the microvascular bed as this is thought to decrease the potential for recurrence.[10–12] Use of particulates, however, carries the risk of accidental embolization into important structures like the ophthalmic artery or cranial nerves.[13] Furthermore, some studies have suggested the addition of particles or liquid embolics may not offer extra clinical benefit compared to plugging the main arterial trunk using coils alone.[9] In fact, small case series have shown that coil embolization alone is sufficient and the recurrence rate comparing coil embolization alone to coil embolization plus particulates is similar.[14]

We have observed a very low need for surgical intervention using a stand-alone coiling strategy at our institution. We sought to explore and report on the safety, efficacy, and outcomes of cSDH MMAE using coiling alone by reviewing this patient database.

Methods

Study design and patient selection

Institutional board approval was obtained prior to study initiation. A retrospective review of a prospectively maintained database was performed to identify all adult patients who underwent MMAE by the senior author from October 2019 to May 2023 at our institution. Only patients who underwent stand-alone coil embolization of the MMA were included. Patient data were collected from medical records and imaging reports. Baseline demographic and clinical data were collected for each patient, including age, gender, presence of bilateral SDH, acute and chronic SDH characteristics, size of SDH, midline shift, Glasgow Coma Scale score, and the presence of contralateral hemi body weakness or neurological deficit. Information regarding prior surgical evacuation procedures, including craniotomy, burr hole, or subdural evacuation port system (SEPS), was also recorded. Inpatient versus elective outpatient MMAE was recorded.

Patients were segregated into three separate groups based on clinical course and relationship to surgical intervention: Group 1 (no history of surgical drainage and no plan for drainage); Group 2 (history of surgical cSDH drainage prior to MMAE and MMAE performed to prevent recurrence due to large residual collection or due to recurrent growth); and Group 3 (MMAE performed prior to planned surgical drainage in the near future as a means of preventing recurrence after evacuation).

Procedural data

The access route for embolization, either femoral or radial, type of anesthesia used during the procedure, procedural duration, procedural specifics (bilateral or unilateral embolization), embolization side, closure of frontal and parietal branches of MMA, and the method of embolization (e.g., coil embolization), were queried and documented.

Procedural complications were assessed based on the following criteria. Severe procedural complications were defined as peri-procedural stroke, neurological death, sudden cSDH enlargement, myocardial infarction, new visual loss, new cranial neuropathy, new neurological deficit, and major bleeding event requiring blood transfusion or surgery related to access site. Minor procedural complications were defined as access site hematoma or complication not requiring transfusion, sedation or anesthetic-related complication not requiring prolongation of admission, or drug reaction.

General MMA embolization procedure

Most procedures were performed under conscious sedation using radial access. A 6F radial sheath was placed and the ipsilateral internal carotid artery (ICA) was accessed to evaluate baseline anatomy and perfusion, observe ophthalmic artery anatomy, and rule out an anomalous ICA origin of the MMA. The external carotid artery (ECA) was then accessed and a 6F guiding catheter was placed in the ECA just prior to the superficial temporal artery-internal maxillary artery bifurcation. Using roadmap guidance, a 0.018-inch microcatheter was then navigated into the intracranial MMA frontal branch. Coils were then implanted (most commonly Nester coils) in the frontal branch down across foramen spinosum into the distal portion of the extracranial MMA until minimal anterograde flow was present through the coil mass. The guide catheter was then withdrawn into the common carotid artery and angiography was repeated over the head to ensure no thromboembolic complications. This is then repeated on the contralateral side if bilateral MMAE is performed.

Clinical outcomes

The primary outcome was defined as need for unplanned surgical drainage of the hematoma following MMAE. The rate of recurrent symptomatic SDH and repeat surgical evacuation was determined. Computed tomography (CT) scans were obtained typically at 2–4 weeks followed by interval surveillance imaging, often performed at approximately 2–3 months and 4–6 months after embolization depending on patient follow-up, symptomatology, and need to restart blood thinners.

Data analysis

Descriptive statistics were used to summarize the baseline characteristics, technical aspects, and clinical outcomes. Mean values and percentages were calculated for continuous and categorical variables, respectively. No inferential statistical analyses were conducted in this study.

Results

Patient sample

A total of 46 patients met inclusion criteria; however, one patient was excluded after being diagnosed with

intracranial hypotension as the source of recurring bilateral extra-axial fluid collections and improved following appropriate treatment. Patient demographics, presenting factors, patient groups, and indications for MMAE are displayed in Table 1. Most patients underwent MMAE without a history of drainage procedure and without plan for future drainage (Group 1). Of 5 patients with severe thrombocytopenia as the indication for MMAE, peri-procedural platelet counts at time of consultation were 6, 16, 22, 7 and 22×10^3 μL and at time of procedure were 8, 24, 41, 33 and 19×10^3 μL, respectively.

Procedural results

All patients underwent successful MMAE with coiling. Procedural data are displayed in Table 2. No peri-procedural severe or minor complications were identified. There were no cases of sudden enlargement and no new visual loss or facial weakness. All of the 10 patients that underwent elective outpatient MMAE were discharged to home the same day.

Table 1. Patient demographics, groups, and imaging findings on presentation and indications for MMAE.

Presenting factor	*N* (%) or mean (IQR)
Age	71 (67, 80)
Male gender	34 (75.5%)
Glasgow Coma Score	14 (14.5,15.5)
Laterality of SDH	
Right	18 (40%)
Left	16 (35.5%)
Bilateral	11 (24.4%)
Maximal SDH diameter (mm)	20 (10.5,25.5)
Midline shift (mm)	6 (3.8,8.1)
SDH imaging characteristics	
Chronic without visible neomembranes	9 (20%)
Chronic with visible neomembranes	8 (18%)
Acute-on-chronic	28 (62.2%)
Patient group	
1: No history of surgical drainage and no plan for drainage	21 (46.6%)
2: History of surgical cSDH drainage prior to MMAE	22 (48.8%)
Prior SEPS/burr hole drainage performed once	15 (68.1%)
Prior SEPS/burr hole drainage performed 2+ times	7 (31.8%)
3: MMAE performed prior to planned surgical drainage	2 (4.4%)
Indication for MMAE	
Progressive recurrence after drainage	11 (24.4%)
Large residual cSDH or dense membranes after drainage	10 (22.2%)
Need for antiplatelet/anticoagulation (PE, heart valve)	6 (13.3%)
Severe thrombocytopenia (AML, chemotherapy)	5 (11.1%)
Presence of CSF shunt system for normal pressure hydrocephalus	1 (2.2%)
Patient preference only	12 (26.6%)
Admission status	
Hospital inpatient	35 (77.7%)
Length of stay (days)	6.95 (1.82,10.13)
Elective outpatient MMAE (same day discharge)	10 (22.2%)

Follow-up and clinical outcomes

Mean length of follow-up after embolization (Table 3) was 5.2 months (interquartile range: 0.3, 5.7) and 7.7 months when patients who died from non-neurologic causes and patients who are still being followed are excluded; 24 (53%) of patients had at least 3 months of follow-up after treatment; 8 (18%) patients had complete imaging resolution of the treated cSDH during follow-up and were discharged from our service at a mean of 3.2 months.

A total of 3 patients (6.6%) met the primary outcome of interest and underwent unplanned surgical drainage following MMAE. One patient had undergone SEPS drainage followed by MMAE and then required repeat burr hole drainage eight weeks later due to large recurrence (Figure 1). The second patient underwent left-sided burr hole drainage and subsequent MMAE presented two weeks later with residual SDH and received repeat left-sided burr hole drainage. The third patient received SEPS drainage followed by MMAE and then required

Table 2. Technical specifics and results for MMAE using coils.

Procedural factors	*N* (%) or mean (IQR)
Anesthesia	
Local anesthesia only	2 (4.4%)
Conscious sedation	31 (68.8%)
General anesthesia	12 (26.6%)
Arterial access	
Femoral	14 (31.1%)
Radial	32 (71.1%)
Embolization laterality	
Right side	14 (31.1%)
Left side	8 (17.7%)
Bilateral	23 (51.1%)
Procedural length (minutes)	
All procedures	52.3 (35.8,57.3)
Unilateral MMAE	41 (33.5,54.5)
Bilateral MMAE	64 (43.2,67.1)
Fluoroscopy time (minutes)	
All procedures	34.33 (34,46)
Unilateral MMAE	31 (20,45)
Bilateral MMAE	37 (34,44)
Successful occlusion of target MMA	100%
Coils implanted	
Axium coils (number of cases)	12 (26.6%)
Mean number of coils per side treated	3 (IQR 2,4)
Nester coils (number of cases)	33 (73.3%)
Mean number of coils per side treated	3 (IQR 2.9,3.1)
Procedural complications	
Severe	0 (0%)
Minor	0 (0%)

Table 3. Outcome data after MMAE.

Outcome	*N* (%) or mean (IQR)
Average length of follow-up (months)	5.2(0.3,5.7)
Follow-up outcomes	
Patients with complete or near complete resolution of SDH	22 (48.8%)
Death or transition to hospice	7 (15.5%)
Still being monitored with future follow-up (mean 15 weeks)	15 (33.3%)
Lost to follow-up	1 (2.2%)
Primary outcome: need for unplanned retreatment	
Group 1	***N* = 22**
No further intervention	21 (95.5%)
Unplanned surgical intervention required	1 (4.5%)
Group 2	***N* = 21**
No further intervention	20 (95.2%)
Unplanned surgical intervention required	1 (4.7%)
Group 3	***N* = 2**
No further intervention	2 (100%)
Unplanned surgical intervention required	0 (0%)
All patients	***N* = 45**
No further intervention	42 (93.3%)
Unplanned surgical intervention required	3 (6.6%)
Imaging follow-up	
2–4 week brain imaging	***N* = 37**
Resolved	0 (0%)
Improvement in size/shift	24 (64.8%)
Unchanged size/shift	9 (24.3%)
Worsened size/shift	4 (10.8%)
6–8 week brain imaging	***N* = 23**
Resolved	6 (26.1%)
Improvement in size/shift	15 (65.2%)
Unchanged size/shift	1 (4.3%)
Worsened size/shift	1 (4.3%)
3–6 month brain imaging	***N* = 7**
Resolved	2 (28.6%)
Improvement in size/shift	4 (57.1%)
Unchanged size/shift	0 (0%)
Worsened size/shift	1 (14.3%)

left-sided burr hole drainage for reaccumulation two weeks later. Due to persistent SDH, he received a repeat left-sided burr hole drainage one week later.

No patient suffered periprocedural or delayed complications related to the procedure. Seven (16%) of patients either transitioned to hospice care or expired after the MMA embolization (mean 44.6 days after the procedure), none of which was directly due to the treated cSDH or the procedure: two from myocardial infarction (10 and 59 days after MMAE), two from leukemia (2 and 12 days), one from flash pulmonary edema (27 days), one from a new embolic stroke (137 days), and one from an unknown cause at nursing facility 65 days after MMA thought to be a respiratory event. All other patients were alive at the time of manuscript composition and had not undergone further intervention for their cSDH.

There were three additional patients that underwent neurosurgical intervention following MMAE that did not meet our primary endpoint. One patient had a fall resulting in an acute SDH necessitating craniotomy for evacuation, and a second had a fall with a contralateral cSDH who then underwent SEPS placement. Both of these patients are continuing to be followed by our service as outpatients and are doing well clinically. The third patient had MMAE due to enlarging R SDH after burr holes and went on to have a craniotomy for evacuation of a subdural empyema related to burr hole surgical site infection.

Discussion

This single-institution study is the largest to date evaluating the safety and efficacy of stand-alone coil MMAE in the treatment of cSDH. Of the 45 patients who underwent MMAE, only three required unplanned surgical evacuation (6.6%). One patient had undergone SEPS drainage followed by MMAE and then required repeat burr hole drainage eight weeks later due to large recurrence (Figure 1). The second patient received burr hole drainage prior to MMAE but required repeat burr hole drainage two weeks later due to residual. The third patient received burr hole drainage two weeks post MMAE and repeat burr hole drainage three weeks post MMAE due to persistent disease. All 45 patients underwent successful coil embolization of the MMA with coils placed in the anterior branch across foramen spinosum into the extracranial trunk, with 23/45 (51%) undergoing successful bilateral embolization. All ten patients (22.2%) who underwent elective MMAE were treated under conscious sedation and then discharged to home the same day. Importantly, the procedure was well tolerated in all individuals and no severe or minor procedural complications were identified. No patients developed a new deficit or required urgent surgical drainage. Overall these findings suggest that coil embolization alone appears safe and effective and has favorable retreatment rates compared to procedures in which particulate embolysate is used.

Traditionally, the gold standard approaches to management of cSDH include bedside craniostomy, multiple burr hole craniostomy, and open craniotomy for evacuation of SDH. Ducruet et al., in a meta-analysis of over 5400 procedures, quoted the recurrence rate for cSDH as 28.1% for bedside twist drill craniostomy, 19.4% for open craniotomies, and 11.7% for burr hole craniostomies.[5] Other studies have quoted even higher recurrence rates of up to 30%.[15] Notably, high and mixed density hematomas were closely related to a high incidence of recurrence.[16]

MMAE has emerged as a novel treatment modality both as primary and adjunctive treatment for patients with cSDH with a comparative reduction in hematoma size and reduction in recurrence rate as compared to craniotomy and craniostomy procedures. In a meta-analysis of nine studies, Srivatsan et al. reported significantly lower recurrence rate in MMAE versus surgical treatment.[17] MMAE may be of

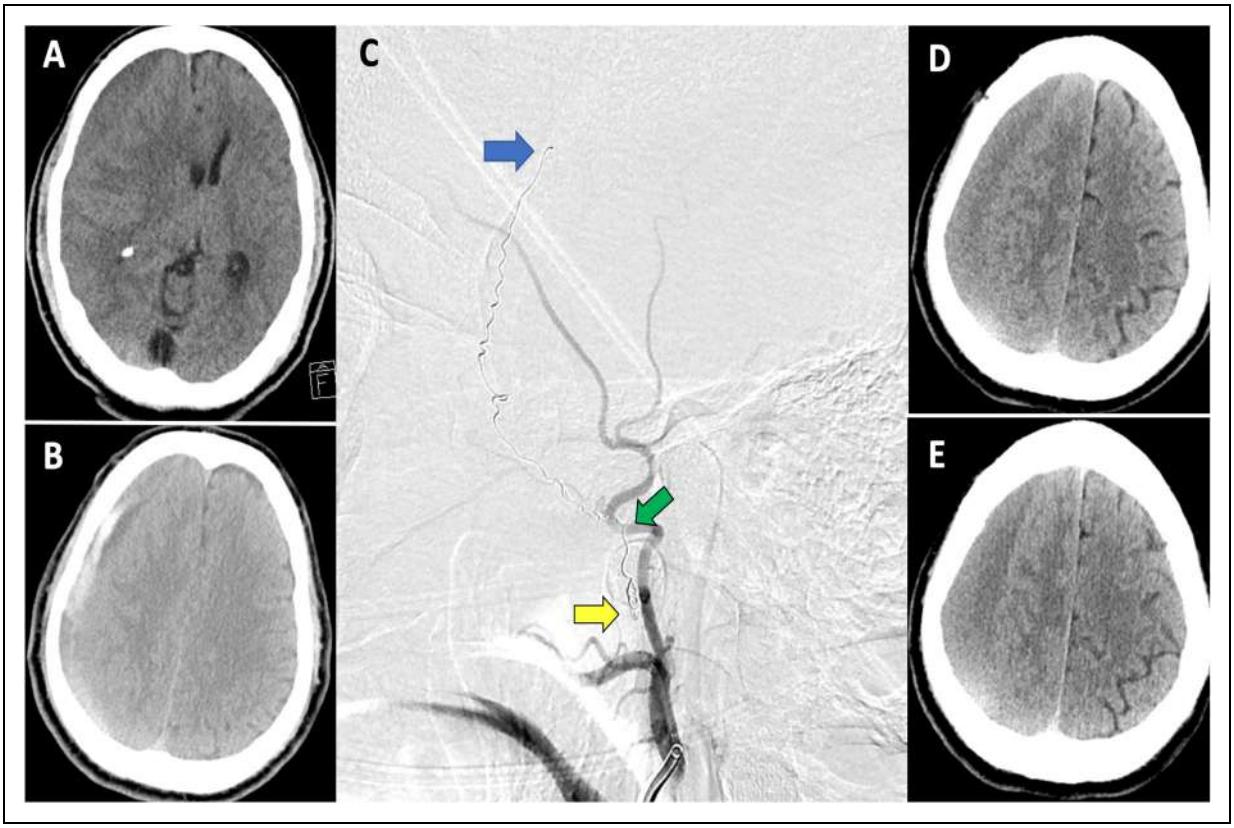


Figure 1. Patient with recurrence of cSDH necessitating unplanned surgical drainage after MMAE. Patient presented with a right cSDH with midline shift (A) and underwent SEPS drainage, with residual collection, neomembranes, and acute blood products in the collection (B). MMAE was performed successfully with coils implanted into the frontal branch (top most arrow), extending past foramen spinosum (middle arrow) and into proximal extracranial MMA (bottom arrow) with complete occlusion of the MMA on angiography (C). Two weeks after MMAE patient presented asymptomatic with enlargement of the cSDH (D). Patient had severe headaches and left leg weakness on eight-week visit (E) and burr hole drainage was performed.

particular utility in patients requiring continued anticoagulation or with thrombocytopenia who would be high risk for either enlargement without intervention or undergoing surgical evacuation. Figure 2 depicts a representative example of a patient with severe thrombocytopenia (platelet count of 19×10^3 μL in the setting of leukemia on chemotherapy) who underwent successful, coil-only MMAE for treatment of large, mixed density subdural hematoma with an excellent result. There were no minor or major procedural complications. Additionally, it is worth noting that on a routine, two-week post-procedure, follow-up CT head there was slight increase in hematoma volume and mass effect, which then improved at subsequent follow-up 6 weeks post-procedure. At six weeks, patient had near total resolution of the subdural hematoma and did not require any further interventions despite her persistent thrombocytopenia.

While MMAE has been shown to be safe and efficacious, there is much debate as to the most effective and safe embolization strategy.[10,12,18] MMAE is most commonly performed with PVA particulates, liquid embolysates such as Onyx or n-BCA, particulate embolysate with adjunctive coiling, or coils alone. Liquid embolics are thought to achieve deeper distal penetration into the neomembrane microvascular capillary bed, diminishing the potential for ongoing supply from collateral channels. However, inadvertent reflux of particulates into important structures can cause visual loss or facial nerve palsy. In many instances, proceduralists utilize liquid embolic agents for capillary penetration followed by coiling of the main MMA trunk to plug proximal flow.[10,12,19,20]

Despite the potential benefits of achieving more distal penetration, liquid and PVA embolic agents have not been shown to be superior to coils and may be associated with higher risk of complication. In a retrospective study of 97 patients evaluating Onyx versus particles for MMAE, Shehabeldin et al. reported the need for unplanned surgical rescue was 10.2% and 16.7%, respectively.[12] Further, when comparing coil embolization versus PVA embolization with adjunctive coiling, Khorasanizadeh et al. reported a similar rate of rescue surgery (8.3% vs. 8.5%), similar percentage of reduction in cSDH volume (68.3% vs. 71.8%) and rate of ≥50% reduction in volume (81.8% vs. 76.3%) when comparing coils alone to coils and particles.[18] Results from the present study are consistent with these findings and suggest that stand-alone coiling may be sufficient for cSDH growth prevention, even in high-risk patients such as those requiring ongoing systemic anticoagulation or with severe thrombocytopenia.

Coil embolization has distinct advantages over embolization with liquid embolics. Firstly, as coiling can be accomplished without roadmap imaging, causes only

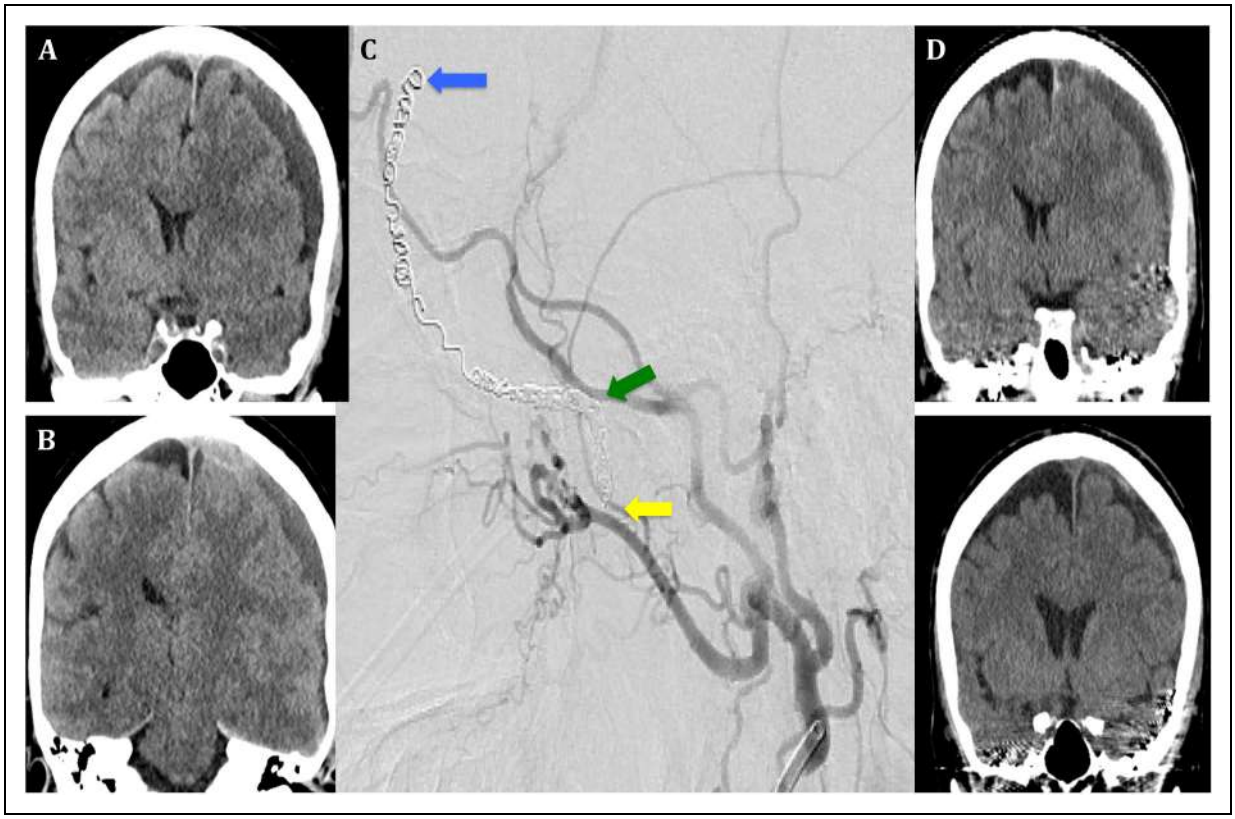


Figure 2. Patient with severe thrombocytopenia (platelet count of 19×10^3 uL at the time of procedure) with large mixed density subdural hematoma measuring 1.5cm with 1cm of midline shift who underwent successful coil only middle meningeal artery embolization as the primary treatment and achieved an excellent result. Initial CT head prior to intervention is shown in A and B. (C) Coils implanted into the frontal branch (top arrow), extending past the foramen spinosum (middle arrow), and into the proximal extracranial MMA (bottom arrow) with complete occlusion of the MMA on angiography. (D) A CT head obtained as part of routine follow-up two weeks after MMA embolization, which shows slight increase in size of the subdural hematoma, now measuring 1.6cm in maximal thickness with 1.1cm of MLS. (E) Near resolution of the subdural hematoma six weeks after intervention without need for additional procedures.

mild discomfort, and can be performed safely even with patient movement, general anesthesia is not usually required. In fact, patient movement may make superselective MMA catheterization challenging due to the acute angle that this vessel arises from the internal maxillary artery, but once the microcatheter is in the MMA, patient movement is no longer problematic as coiling can be easily performed on native fluoroscopy regardless of head motion. In the present series, early procedures were performed under general anesthesia; however, we have now converted to conscious sedation or no sedation for all MMAE (the last two-thirds of patients all underwent successful MMAE under conscious sedation or no sedation). Liquid embolic agents require close visualization to ensure reflux does not occur (which can be difficult to assess if there is patient movement) and certain liquid embolic agents are quite painful, making conscious sedation suboptimal. Additionally, coiling is a fairly simple procedure that is not technically demanding or challenging in most patients. We have adopted the use of Nester coils (Cook Medical), which are lower cost, pushable coils with small thrombogenic fibers that are highly effective in occluding arteries as an additional cost-saving measure. Usually, only 2–4 coils are necessary to achieve complete occlusion of the MMA with no intracranial supply as well as to completely occlude the anterior branch of the intracranial MMA to prevent any collateral flow from the orbit. Overall total procedure length using this strategy was less than 1 h in the majority of patients and no complications were identified.[14,21,22] Finally, stand-alone coiling under conscious sedation, particularly with low-cost pushable coils and without need for admission, may provide cost-savings over other strategies.

This study has a number of limitations, most notably its retrospective, single-institution design. While this is the largest series of stand-alone coiling for MMAE, the small cohort limits the power of this study. All MMAE were performed by the senior author of this study at a single center, limiting its generalizability to other centers that may have alternate indications for MMAE or different cSDH management strategies. The sample is heterogeneous and subject to selection bias due to practice preferences and referral pattern of the primary author.

Conclusions

This is the largest single-institution study evaluating the efficacy of stand-alone coil only MMAE in the treatment of cSDH. Our series shows that coil only MMAE is a safe and efficacious treatment strategy for cSDH, even in the

setting of severe thrombocytopenia or with need for ongoing systemic anticoagulation. The present study suggests that particle/liquid embolization may not be necessary and simple coil occlusion of the intracranial and extracranial MMA may be sufficient to prevent cSDH growth and need for surgical drainage. Ultimately larger confirmatory studies will be necessary.

Declaration of conflicting interests

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Ethics approval

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References

1. Uno M, Toi H and Hirai S. Chronic subdural hematoma in elderly patients: is this disease benign? *Neurol Med Chir (Tokyo)* 2017; 57: 402–409.
2. Yadav YR, Parihar V, Namdev H, et al. Chronic subdural hematoma. *Asian J Neurosurg* 2016; 11: 330–342.
3. Désir LL, D'Amico R, Link T, et al. Middle meningeal artery embolization and the treatment of a chronic subdural hematoma. *Cureus* 2021; 13: e18868.
4. Goyal RK, Nayak B, Maharshi R, et al. Management of chronic subdural hematoma: burr hole versus twist drill—A prospective study. *Asian J Neurosurg* 2018; 13: 319–323.
5. Ducruet AF, Grobelny BT, Zacharia BE, et al. The surgical management of chronic subdural hematoma. *Neurosurg Rev* 2012; 35: 155–169.
6. Msheik A, Gerges T, Al Mokdad Z, et al. Revolutionizing treatment for chronic subdural hematoma: promising outcomes with middle meningeal artery embolization. *Cureus* 2023; 15: e39733.
7. Edlmann E, Giorgi-Coll S, Whitfield PC, et al. Pathophysiology of chronic subdural haematoma: inflammation, angiogenesis and implications for pharmacotherapy. *J Neuroinflammation* 2017; 14: 108.
8. Link TW, Boddu S, Paine SM, et al. Middle meningeal artery embolization for chronic subdural hematoma: a series of 60 cases. *Neurosurgery* 2019; 85: 801–807.
9. Catapano JS, Ducruet AF, Nguyen CL, et al. Middle meningeal artery embolization for chronic subdural hematoma: an institutional technical analysis. *J Neurointerv Surg* 2021; 13: 657–660.
10. Majidi S, Matsoukas S, De Leacy RA, et al. Middle meningeal artery embolization for chronic subdural hematoma using N-butyl cyanoacrylate with D5 W push technique. *Neurosurgery* 2022; 90: 533–537.
11. Mondorf Y, Abu-Owaimer M, Gaab MR, et al. Chronic subdural hematoma–craniotomy versus burr hole trepanation. *Br J Neurosurg* 2009; 23: 612–616.
12. Shehabeldin M, Amllay A, Jabre R, et al. Onyx versus particles for middle meningeal artery embolization in chronic subdural hematoma. *Neurosurgery* 2023; 92: 979–985.
13. Shotar E, Premat K, Lenck S, et al. Angiographic anatomy of the middle meningeal artery in relation to chronic subdural hematoma embolization. *Clin Neuroradiol* 2022; 32: 57–67.
14. Khorasanizadeh M, Shutran M, Garcia A, et al. Middle meningeal artery embolization with isolated use of coils for treatment of chronic subdural hematomas: a case series. *World Neurosurg* 2022; 165: e581–e587.
15. Oh H-J, Lee K-S, Shim J-J, et al. Postoperative course and recurrence of chronic subdural hematoma. *J Korean Neurosurg Soc* 2010; 48: 518.
16. Ko BS, Lee JK, Seo BR, et al. Clinical analysis of risk factors related to recurrent chronic subdural hematoma. *J Korean Neurosurg Soc* 2008; 43: 11–15.
17. Srivatsan A, Mohanty A, Nascimento FA, et al. Middle meningeal artery embolization for chronic subdural hematoma: meta-analysis and systematic review. *World Neurosurg* 2019; 122: 613–619.
18. Khorasanizadeh M, Maroufi SF, Mukherjee R, et al. Middle meningeal artery embolization in adjunction to surgical evacuation for treatment of subdural hematomas: A nationwide comparison of outcomes with isolated surgical evacuation. *Neurosurgery*. 2023. Epub ahead of print. DOI: 10.1227/neu.0000000000002554.
19. Sioutas GS, Vivanco-Suarez J, Shekhtman O, et al. Liquid embolic agents for middle meningeal artery embolization in chronic subdural hematoma: institutional experience with systematic review and meta-analysis. *Interv Neuroradiol* 2023: 15910199231183132.
20. Lee JM, Whang K, Cho SM, et al. Cranial nerve palsy after onyx embolization as a treatment for cerebral vascular malformation. *J Cerebrovasc Endovasc Neurosurg* 2017; 19: 189–195.
21. Wali AR, Himstead A, Bravo J, et al. Helical coils augment embolization of the middle meningeal artery for treatment of chronic subdural hematoma: a technical note. *J Cerebrovasc Endovasc Neurosurg* 2023; 25: 214–223.
22. Chaudhary N and Gemmete JJ. Insights into middle meningeal artery embolization in chronic subdural hematoma: what does not work. *Radiology* 2023; 307: e230405.