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Middle Meningeal Artery Embolization for Chronic Subdural Hematoma: Rationale, Technique, and Results

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Learning Objectives: *After participating in this CME activity, the neurosurgeon should be better able to:*

1. *Describe the incidence, prevalence, and pathophysiology of chronic subdural hematoma.*
2. *Distinguish among conventional treatment options and the challenges associated with them.*
3. *Explain endovascular approaches to and anatomic variants of the middle meningeal artery.*
4. *Characterize common embolization agents, their benefits and drawbacks, and the evidence for middle meningeal artery embolization in patients with chronic subdural hematoma.*

Chronic subdural hematoma (cSDH) is a common neurosurgical condition that has a poor natural history. With an inhospital mortality of 16.7%, 1-year mortality of 32%, and only 21.1% of admitted patients returning home, cSDH remains a disabling and deadly disease. The incidence of cSDH greatly increases with age, with some estimates being as high as 18 per 100,000 individuals between the ages of 71 and 80 years. With an aging population and increased use of antiplatelet and anticoagulation medications, the incidence of cSDH is expected to exceed 60,000 new cases per year by the year 2030.

Management strategies for cSDH vary widely and are subject to provider and institutional preferences. Traditional management avenues for cSDH have involved conservative management and open surgery. Conservative management has included observation, the use of corticosteroids, statins, osmotically active agents, platelet-activating factor inhibitors, and plasminogen activator inhibitors. Statins, in particular, have been demonstrated to be beneficial for patients with cSDH in recent randomized clinical trials. Surgical management includes options such as twist drill craniostomy at the bedside and open surgical drainage via burr holes or formal craniotomy. In a randomized clinical trial performed in 2009, the use of drains after burr hole drainage was associated with reduced recurrence and mortality at 6 months, thereby justifying the use of drains after burr hole drainage of cSDH.

In general, patients who are asymptomatic or have minor symptoms with smaller hematoma volumes typically warrant conservative management, whereas patients with more severe symptoms and larger hematoma volumes require operative intervention. The success rate of each method in resolving the hematoma is variable, although surgical intervention is generally favorable in this regard and offers the advantage of an immediate decompressive effect. However, the recurrence rate of cSDH even after surgical evacuation is variable and may be as high as 37% by some estimates.

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Category: Cerebrovascular

Key Words: Chronic subdural hematoma, Embolization, Management, Middle meningeal artery

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Reoperations due to recurrent hematoma, depending on the surgical technique used, range from 11.7% to 28.1%.

Many patients with cSDH are elderly or have comorbid conditions requiring the use of anticoagulants or antiplatelets, which may complicate cranial intervention or preclude surgical intervention entirely. Furthermore, if patients are symptomatic and a decision is made to pursue operative measures, antiplatelet and/or anticoagulation is often discontinued for weeks, leading to increased occurrence in thromboembolic events. With an increased understanding of cSDH pathophysiology and increasing advances in endovascular technology, embolization of the middle meningeal artery (MMA) has become an attractive option in treating cSDH. Indeed, the ability of MMA embolization to treat cSDH has been reported with favorable results. Here, we review the rationale, methodology, and preliminary results of MMA embolization for treating cSDH.

Rationale

An understanding of the pathophysiology of cSDH provides the underlying premise for embolizing the MMA as a form of treatment. In general, a cyclical process of inflammation, angiogenesis, and capillary leakage results in high recurrence rates of cSDH. The inciting event that causes the initial accumulation of subdural blood is most commonly venous bleeding into the potential subdural space that results in splitting of the internal and external dural membranes. After accumulation of blood products, various proinflammatory factors signal an influx of immune cells resulting in dural collagen synthesis, which thickens the inner dural membrane. As a result of the inflammatory and remodeling process, fragile capillaries form within the inner dural membrane, which are prone to bleeding and exudation of fluid containing various inflammatory factors. This in turn results in continued inflammation, which stimulates more angiogenesis and bleeding from fragile neocapillaries, thereby inducing a positive membrane-forming feedback cycle that occurs every 2 to 3 weeks. In essence, this continuous recurrent bleeding from nascent capillaries within the inner dural membrane outpaces the rate at which blood products are resorbed, thereby resulting in a chronic, and oftentimes recurrent SDH.

With an appreciation for the cyclical nature of cSDH, many therapeutic strategies under investigation involve disrupting this process and altering the relative rate of membrane bleeding to blood resorption. Such methods include increasing the inward osmotic forces within the capillaries (with a diuretic such as mannitol), inhibiting activation of fibrinolytic enzymes, or inhibiting angiogenesis. Though ongoing, the results of preliminary studies of conservatively oriented agents such as these are rather variable. The primary arterial blood supply for the leaky inner dural membrane is the MMA. Disruption of arterial supply to the inner membrane with embolization of the MMA is theorized to alter the kinetics of cSDH recurrence by reducing bleeding, and thus favoring resorption of blood product.

Increasing research results support embolization of the MMA as an effective strategy to reduce cSDH recurrence after surgery, as primary treatment of small asymptomatic cSDH when anticoagulation or antiplatelet therapy cannot be stopped. In this endovascular procedure, the MMA is embolized and occluded to decrease the blood supply to the "leaky" membranes. The cSDH is very slowly reabsorbed, reducing the mass effect to the brain over a period of weeks to months. Our current management algorithm in managing patients with cSDH is outlined in Figure 1.

Technique

MMA Access and Anatomic Considerations

Use of the MMA in cSDH transarterial treatment focuses in successfully negotiating the sharp turns of the artery, as it enters the skull base through the foramen spinosum, establishing a very proximal microcatheter position to the

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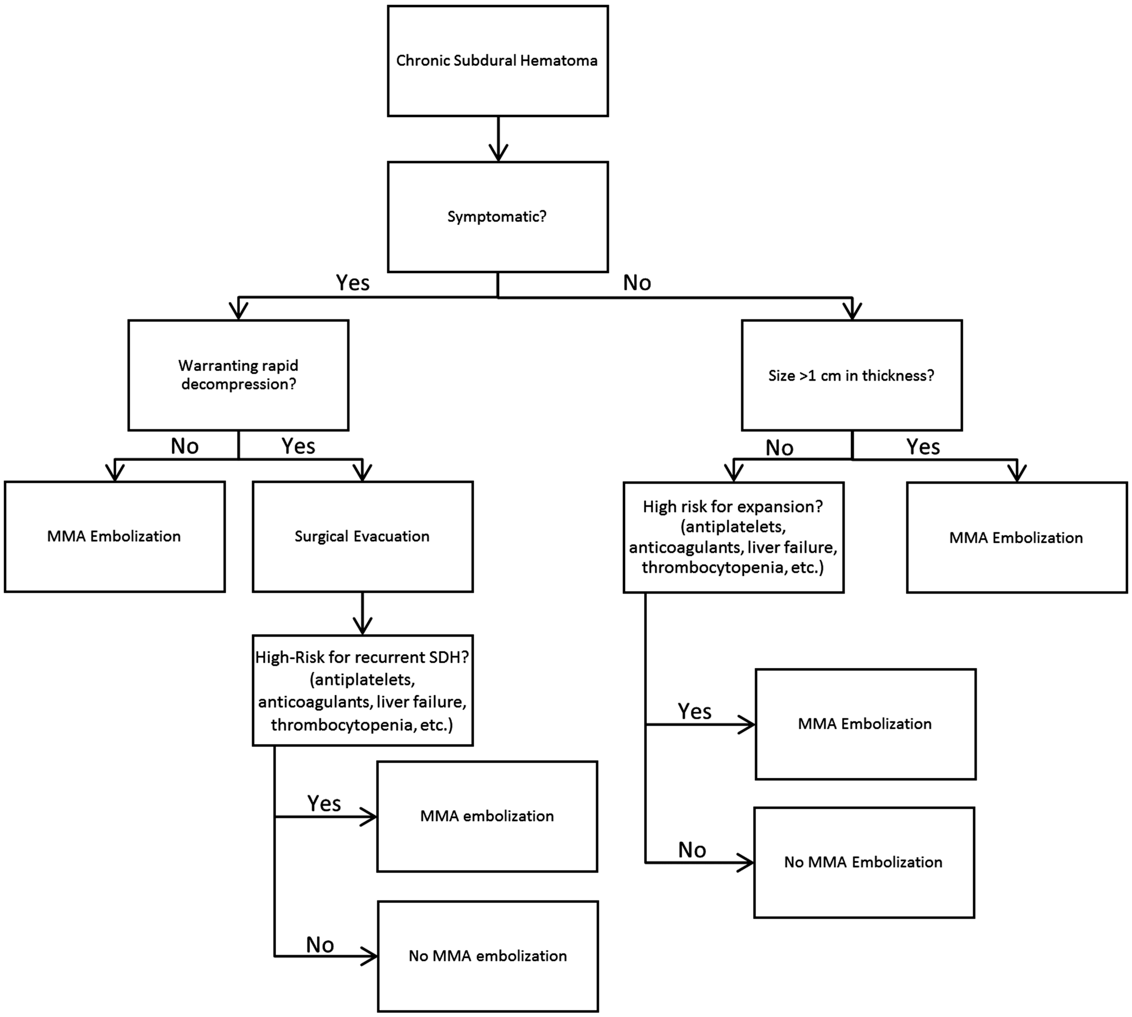

Figure 1. Our institutional algorithm for management of patients with cSDH.

target (inner dural membrane of the hemisphere convexity) and keeping a safe distance from branches that supply the orbit and the facial nerve. The use of detachable tip microcatheters and balloon microcatheters can greatly enhance the safety of MMA embolization with a liquid embolic agent (Onyx) in cSDH via the MMA as in dural arteriovenous fistula cases.

Through either transfemoral or transradial access, a guide catheter is navigated into the external carotid artery or distal common carotid artery. From there a microcatheter is navigated through the external carotid, into the internal maxillary artery and then into the MMA. Once in the main trunk of the MMA, superselective angiography is performed to visualize the branching pattern of the MMA, in addition to confirming absence of any dangerous collateral vessels.

From anterior to posterior, the trunk of the MMA classically gives rise to the sphenoidal, frontal, parietal, and petrosquamosal branches. Depending on the size and location of the SDH, either the MMA proximal to the bifurcation of the frontal and parietal branches is selectively catheterized or the individual parietal and frontal branches are selectively catheterized and individually injected with the embolizing agent. The optimal position of the microcatheter before embolization is above the sphenoid ridge so as to avoid reflux of embolic material into meningo-ophthalmic collaterals or the petrous branch of the MMA.

Although the classical anatomic distribution of MMA branches is present in the large majority of patients, 2 crucially important anatomic variations must be evaluated before embolization. In a small percentage of patients, the contents of the ipsilateral orbit are supplied by a meningo-opthalmic artery that originates from the MMA and travels through the superior orbital fissure into the orbit to supply the entirety of the orbit, including the central retinal artery (Figure 2A). Although this anomaly has been estimated to be present in less than 1% of the population, its presence may preclude embolization of the MMA due to the potential for reflux into the meningo-ophthalmic artery and risk of visual damage. It is important to realize that, even when not visible angiographically, this anastomosis is always present and can be filled with embolic material if the microcatheter is in a wedged position or if liquid embolic materials are used.

A relatively more common variant that is encountered is an MMA that arises from the ophthalmic artery to supply a frontal branch or the entirety of the MMA distribution (Figure 2B). In the latter cases, embolization of the MMA would require catheterization of the ophthalmic artery, which likely adds unacceptable risk to the procedure.

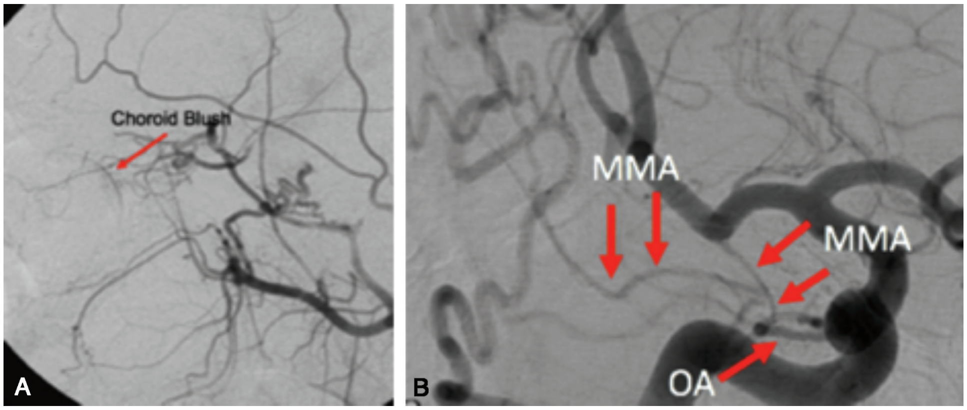

Figure 2. Important anatomic variations in the MMA in context of embolization. *A*, ECA DSA showing choroid blush, indicative that a meningo-ophthalmic branch of the MMA supplies the orbit, including the globe. *B*, CCA injection showing MMA arising entirely from the OA, precluding MMA embolization. CCA, common carotid artery; DSA, digital subtraction angiography; ECA, external carotid artery; OA, ophthalmic artery.

Embolization Agent Selection

There are 2 main types of agents which have been used for MMA embolization: polyvinyl alcohol (PVA) micro zparticles and liquid embolic agents. When injected into the MMA, PVA particles will travel distally resulting in occlusion. PVA has been the most extensively studied embolic agent to date and is relatively inexpensive, and it is our embolic agent of choice in patients with cSDH. Drawbacks to PVA exist, one of which is that PVA can eventually be resorbed, potentially resulting in reconstitution of flow in the MMA, but this should not be an issue in patients with cSDH where temporary and not necessarily persistent occlusion may interrupt “the vicious cascade” initiated by the original bleed. Proper use of PVA makes this embolic agent very safe, as PVA particles greater than 150 μm in diameter, unlike liquid embolic agents, do not pass through dangerous anastomoses, which usually have smaller diameter.

Liquid embolic agents, including *n*-butyl cyanoacrylate and Onyx, have also been used for this purpose, but we do not think they should be first choices in this intervention. Although liquid embolic agents are permanently opaque (which allows ready visualization of distal occlusion of MMA branches), these agents are more expensive and more prone to result in reflux into important branches and dangerous anastomoses.

Another disadvantage of liquid embolic agents compared with PVA is that embolization with Onyx can be very painful and may require the patient to be placed under general anesthesia. Meanwhile, PVA can be done with local sedation only. In our practice we have noticed that a substantial proportion of elderly patients with cSDH suffer from some degree of postsedation or postanesthesia delirium and by performing these procedures with PVA and with local sedation this risk is mitigated. Case examples are provided in Figures 3 and 4.

Early Results of MMA Embolization for Chronic Subdural Hematoma

To date, no randomized clinical trials have been completed comparing the efficacy of MMA embolization to traditional surgical techniques for management of cSDH, although several are currently ongoing. Despite the lack of randomized trials, preliminary studies and our preliminary experience have suggested efficacy of MMA embolization. Ban et al. reported on a series of 72 patients with cSDH who were treated with MMA embolization (27 with MMA embolization as the sole treatment, and 45 with MMA embolization being performed before hematoma evacuation) and compared their outcomes to a historical group of 469 patients with cSDH that were treated conventionally (67 patients with conservative management and 402 with surgical evacuation). At 6-month follow-up, none of the 27 patients treated exclusively with MMA embolization required additional surgical evacuation and all 27 patients had hematoma volumes less than 10 mm; this was in contrast to the conservatively managed group in which 83.6% of patients required surgical rescue. In patients who

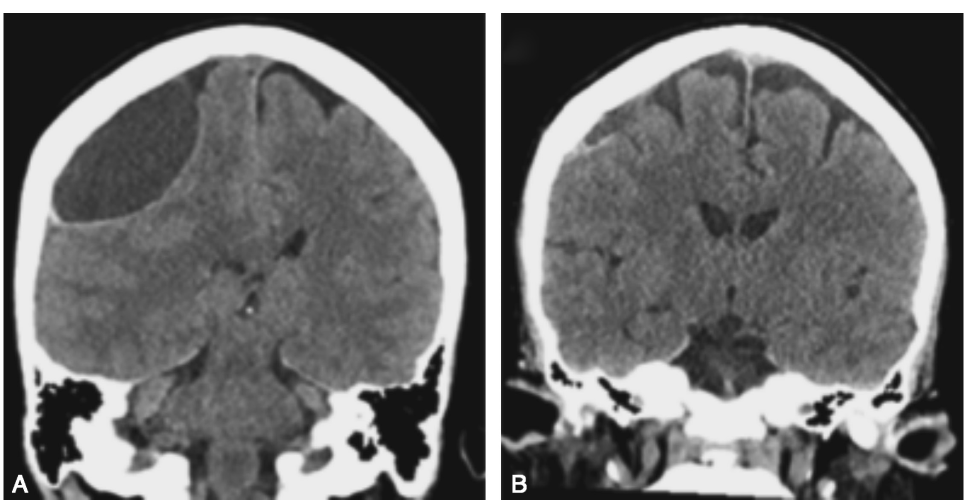

Figure 3. A 67-year-old woman with a history of myelofibrosis presented with mild left hemibody weakness. *A*, Initial CT scan showed a large, right-sided cSDH. The patient’s platelet count was 32,000. She was unresponsive to platelet replacement, so platelets were unable to be replaced to a threshold of 75,000. Therefore, the patient was not a candidate for surgical evacuation, and she was treated with MMA embolization. *B*, At 4 months of follow-up, the patient had experienced gradual improvement in weakness with near-complete resolution of the hematoma.

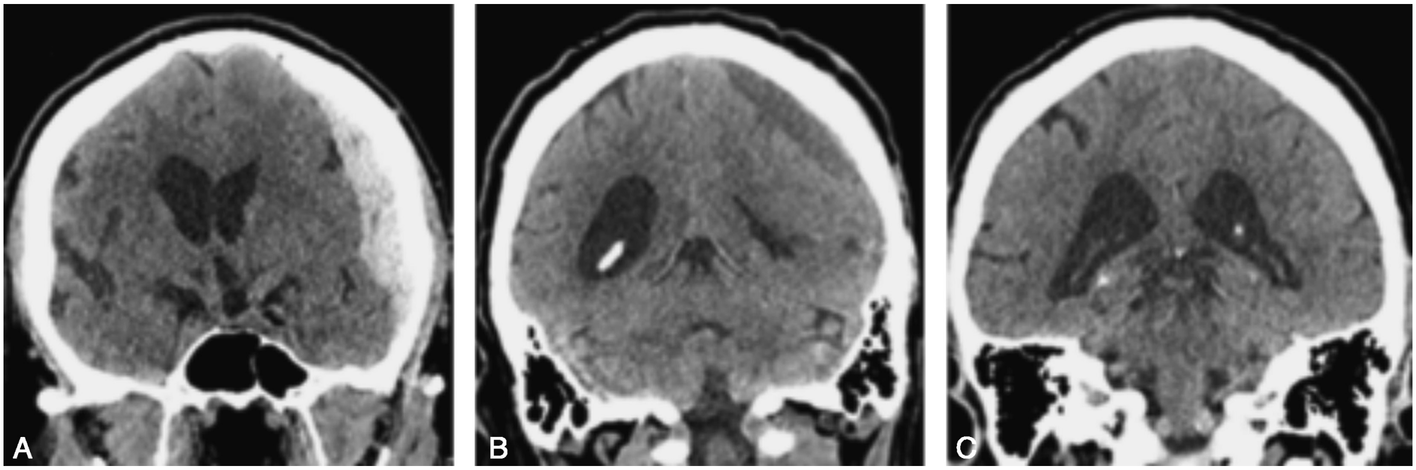

Figure 4. An 80-year-old man on warfarin presented with a left-sided subdural hematoma after falling. *A*, Frontotemporal craniotomy evacuation was performed. The patient was discharged to his facility but was readmitted with word-finding difficulties and mental status change. *B*, Head CT scan revealed the presence of a new cSDH. The patient was treated with MMA embolization. *C*, One-month follow-up imaging after MMA embolization demonstrated complete resolution of the hematoma.

underwent MMA embolization before surgical evacuation, 1 of 45 patients (2.2%) required reoperation, although this particular patient had documented head trauma as a result of a motor vehicle accident. This was in comparison to 73 of 402 patients (18.2%) who did not have preoperative embolization before hematoma removal who needed reoperation. In total, 71 of 72 (98.6%) patients treated with embolization had a "successful" outcome, compared with 340 of 469 (72.5%) managed with conventional methods.

Kim also reported a case control study in which 20 patients who underwent perioperative MMA embolization and hematoma evacuation were compared with 23 patients treated with hematoma evacuation without MMA embolization. In patients treated with MMA embolization, only 1 recurrence was evident (5%) compared with 8 recurrences (34.7%) in the evacuation-only group.

Link et al. reported a single-arm case series of 60 patients treated with MMA embolization, 42 of which were treated without prior surgical evacuation, 10 perioperatively to evacuation, and 8 were treated for cSDH recurrence following evacuation. Of the 50 patients treated nonprophylactically (those treated with MMA embolization without prior surgery or as a result of occurrence after surgery), 91.1% were stable or showed a decrease in size and did not need to undergo surgical evacuation.

Several systematic reviews and meta-analyses have been performed to determine the efficacy and safety of MMA embolization for cSDH. Srivatsan et al. analyzed the pooled data from 3 case control studies and found that recurrence rate was significantly lower in patients with MMA embolization compared with the conventional surgery cohort (2.1% vs 27.7%). Furthermore, pooled data from 6 single-arm case studies were analyzed, and a composite hematoma recurrence rate of 3.6% was found for patients who had undergone MMA embolization, which was lower than the recurrence rate of cSDH treated with conventional surgery in the published literature. Similar results were found by a systematic review and meta-analysis performed by Haldrup et al., who found that patients treated for recurrent cSDH with MMA embolization had a recurrence rate of 2.4%. Patients treated for primary cSDH with MMA embolization had a slightly higher rate of recurrence of 4.1%.

Taken together, these studies demonstrate that MMA embolization is likely superior to conservative management of cSDH. Moreover, MMA embolization used in conjunction with conventional surgical evacuation likely results in significantly decreased rates of recurrence. Although some evidence suggests that MMA embolization may in fact be better than surgical evacuation when rapid brain decompression is not needed, randomized trials are needed for appropriate assessment.

Conclusion

As with any currently investigated and proposed procedure that has the potential to incur additional cost and/or risk, it will be of pivotal importance to properly select patients who could significantly benefit from embolization at minimal risk. Although demographics and clinical features are expected to play a predominant role in patient selection, imaging features on standard axial and perfusion studies, such as the presence of hyperdense, densely septated pseudomembranes, or ones with increased blood flow or metabolic activity, are expected to steer rigorous selection of patients for embolization either as an exclusive or adjunctive cSDH treatment option in the future.

Readings

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1. The incidence of cSDH increases with age.

True or False?

2. Randomized clinical trials have demonstrated that use of statins is beneficial for patients with chronic subdural hematoma.

True or False?

3. The use of drains after burr hole drainage for cSDH has not been demonstrated to reduce recurrence or mortality.

True or False?

4. The pathophysiology of cSDH involves a cycle of inflammation, fragile capillary formation, and rupture, which leads to further inflammation.

True or False?

5. The meningo-ophthalmic artery is an anatomic variant that supplies all or parts of the orbit, including the retina, so reflux of embolic material into this artery could result in blindness in some patients.

True or False?

6. A patient with cSDH is considered for MMA embolization. Her MMA on the affected side arises from the ipsilateral ophthalmic artery. As long as the appropriate size microcatheter is used to cannulate the ophthalmic artery, embolization is safe.

True or False?

7. Open surgical management of subdural hematoma is preferable to embolization of the MMA in that emergent decompression may be achieved.

True or False?

8. To date, no randomized clinical trials comparing embolization of the MMA to conventional methods have been completed, although several are ongoing.

True or False?

9. The incidence of cSDH is likely to decrease in the future.

True or False?

10. The published literature demonstrates that embolization of the MMA reduces the rate of recurrence of cSDH compared with conventional measures.

True or False?