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Review Article

Middle meningeal artery embolization: A scoping review of trends and outcomes by embolization material

Tiffany Chu[1], Ryan Sindewald[2], Lauren E. Stone[3], Arvin R. Wali[3], David Santiago-Dieppa[3]

[1]Department of Neurologic Surgery, Creighton University School of Medicine, Omaha, Nebraska, [2]Department of Neurologic Surgery, University of California San Diego School of Medicine, [3]Department of Neurologic Surgery, University of California San Diego, La Jolla, California, United States.

E-mail: Tiffany Chu - tiffanychu@creighton.edu; Ryan Sindewald - rsindewald@health.ucsd.edu; Lauren E. Stone - lestone@health.ucsd.edu; Arvin R. Wali - awali@health.ucsd.edu; *David Santiago-Dieppa - drsantiagodieppa@health.ucsd.edu

***Corresponding author:**
David Santiago-Dieppa, Department of Neurologic Surgery, University of California San Diego, La Jolla, California, United States.

drsantiagodieppa@health.ucsd.edu

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ABSTRACT

Background: Chronic subdural hematomas (cSDHs), blood collections under the dural layer of the brain, are common in the elderly and frequently linked to trauma and anticoagulation. As the global elderly population increases, the incidence of cSDH is expected to rise, straining healthcare systems. Middle meningeal artery embolization is a minimally invasive alternative to surgery, which could prove especially beneficial for elderly patients with multiple comorbidities or contraindications to surgery. However, the efficacy and patient-related outcomes associated with different embolization materials remain unknown.

Methods: The authors conducted a scoping review of manuscripts published through August 2023 to assess outcomes associated with various embolization materials used in middle meningeal artery embolization for cSDH. Recurrence rates after embolization and complications were the primary outcomes.

Results: The authors analyzed a total of 25 studies, reporting 1579 embolizations in 1362 patients. Embolic materials included particles (35.7%), liquid embolisates (31.5%), coils (3.2%), and combinations of the aforementioned materials (29.6%). Recurrence rates were low (5.1%), and the most common complications were seizures and strokes. The overall mortality was 1.4%, with three procedure-related deaths.

Conclusion: With low recurrence and complication rates, middle meningeal artery embolization is a safe and effective treatment for cSDH. However, due to limitations in data availability, we were not able to link hematoma recurrence or complication rates with the type of embolization material used. To better understand the safety profiles of different materials, further large-scale studies are warranted.

Keywords: Chronic subdural hematoma, Coil, Microsphere, Middle meningeal artery embolization, Particle

INTRODUCTION

Chronic subdural hematomas (cSDHs) are collections of blood beneath the dura covering the brain which triggers a complex inflammatory process resulting in membrane formation, neovascularization, and ultimately brain compression.[34] More common in the elderly populations, cSDHs are multifactorial in origin, with strong associations with trauma as well as antiplatelet/anticoagulation medications and other coagulopathic medical conditions.[25,30] Patient presentation can vary significantly, including focal neurologic deficits, headache, gait abnormalities, altered mental status, seizure, and cognitive impairment, with estimated mortality rates comparable to hip fractures in this population.[4,13] In the United States, cSDH more than doubled from 26.4/100,000 in 2003 to 58.6/100,000 in 2016.[22] These numbers likely underestimate the future impact of cSDH on the healthcare system, as the global population of 80 or older is expected to triple from 2015 to 2050.[22] As such, management of this pathology continues to evolve.

The threshold for surgical management is impacted by radiographic and clinical parameters specific to cSDHs, as well as the patient's overall ability to tolerate a surgical procedure.[30] In 2000, middle meningeal artery embolization (MMA embo) was first reported for the treatment of refractory subdural hematoma.[20] The MMA embo uses endovascular techniques to eliminate the blood supply to neovascular beds feeding the cSDH collection, preventing SDH expansion while providing a minimally invasive, although slower, method of subdural hematoma resolution.[6,14,34] The procedure also reduced subdural hematoma recurrence rates, which is not an uncommon phenomenon in elderly populations, ranging from 0.36% to 37%.[2,6,33] It is projected to become the most common neurosurgical procedure by 2030.[34]

MMA embo technical nuances continue to evolve faster than large studies are able to publish results. Embolization agents, in particular, are heterogenous, including particles of varying diameters (polyvinyl alcohol), liquid embolic agents (N-butyl cyanoacrylate, Onyx), and coils.[30] As newer methods and materials continue to be developed, understanding the relationship between embolization materials and patient outcomes would help elucidate optimal algorithms, providing clinical guidance and direction for further innovation. Smaller case series have been published, providing some guidance with technique and the relationship between clinical picture and optimal embolization material choice. However, to date, no review comparing MMA embolization materials and associated patient outcomes has been published. We sought to assemble a scoping review for patient outcomes associated with specific embolization materials.

METHODS

This scoping review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews guidelines. Approval from the Local Institutional Ethics Committees was not required given the study design.

Search strategy

A comprehensive literature search was performed in the following electronic databases, encompassing all articles published through August 2023: PubMed, Embase, Cochrane, Google Scholar, Oxford Journals, and SCOPUS. The search strategy incorporated keywords and MeSH terms (including abbreviations, variations in plurality, and spelling) pertinent to chronic subdural hematoma, middle meningeal artery embolization, and embolization materials. The following search algorithm was used: "((Chronic subdural hematoma) OR (SDH)) AND ((Middle meningeal artery embolization) OR (MMA embolization)) AND (((n-butyl cyanoacrylate) OR (n-BCA) OR (NBCA)) OR coil OR ((polyvinyl alcohol) OR (PVA)) OR Onyx OR Embosphere OR microsphere OR particle)." Reference lists of selected articles were also reviewed.

Eligibility criteria

A single independent reviewer screened titles and abstracts of all retrieved articles. Full-text articles were obtained for all potentially relevant studies. Each study was evaluated based on predefined inclusion and exclusion criteria. Both retrospective and prospective studies were considered eligible. Case series with more than five patients and at least 6 weeks of follow-up data were included. Patients without cSDH were excluded from the study. Articles lacking information on the type of embolization material used were also excluded from the study. Only peer-reviewed journal articles written in the English language were included; abstracts, posters, and oral presentations were excluded from the study.

Data extraction

Data from the included articles were imported into an Excel spreadsheet. Information extracted included study characteristics (author, study design, study year(s), country, and sample size), patient characteristics (average age and follow-up duration), embolization material(s), and outcome measures (post-craniotomy/burr-hole status, post-embolization recurrence, and complications).

RESULTS

The search was conducted across six electronic databases (PubMed, Embase, Cochrane, Google Scholar, Oxford Journals, and SCOPUS) and yielded a total of 1942 studies. After the removal of duplicates, 735 studies remained for screening based on titles and abstracts. From these, 678 were excluded due to irrelevance. Among the 57 records assessed for eligibility, 32 were excluded for the following reasons: insufficient sample size (n = 16), insufficient follow-up (n = 6), inability to access the full text (n = 8), and articles not written in the English language (n = 2). Ultimately, this systematic review included 25 studies [Figure 1].[1,3,5,8-12,14,16-19,21,23,24,26-31,34-36]

Overview of included studies

This review included data from 22 retrospective case series, two prospective studies, and one randomized controlled trial. In total, 1579 embolizations were performed across

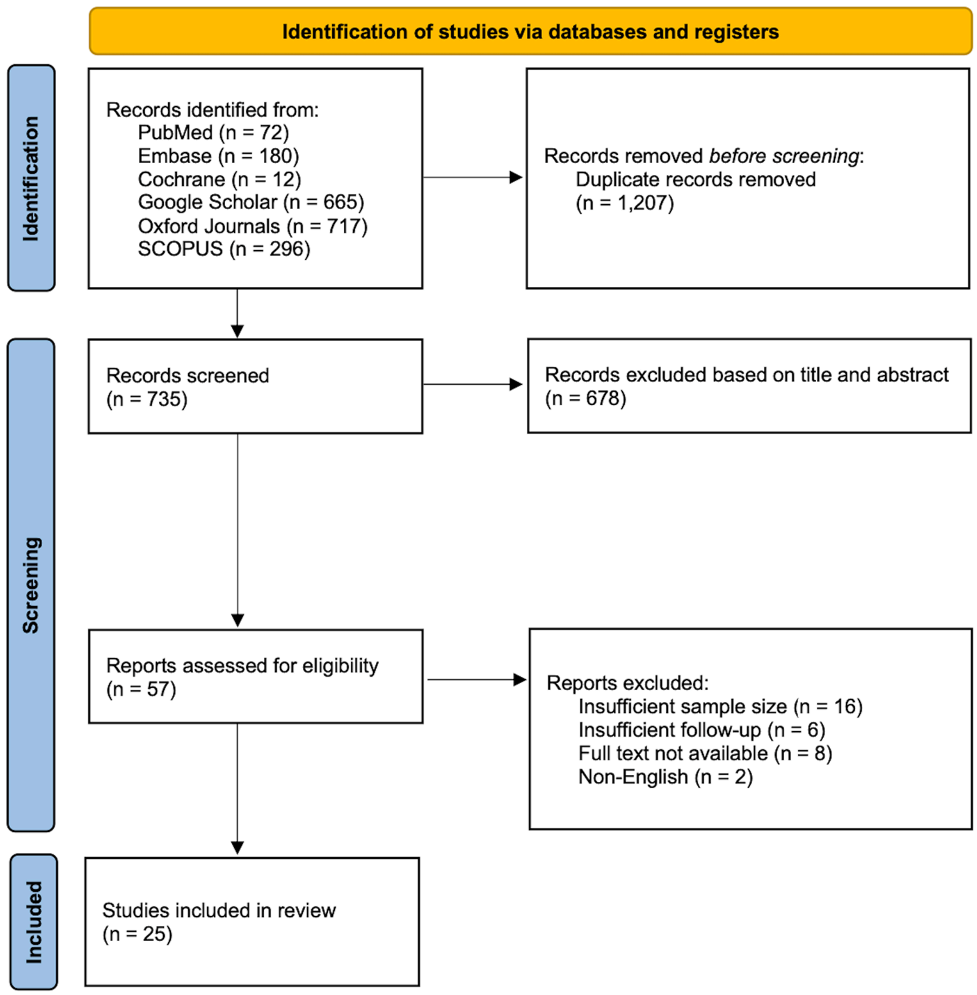

Figure 1: PRISMA flow diagram detailing the number of database searches, records screened, full texts retrieved, and studies included in this review.

1362 patients in 25 studies [Table 1]. The predominant share of studies originated from the United States (*n* = 17, 68%), with others conducted in Japan (*n* = 3, 12%), Australia (*n* = 1, 4.0%), France (*n* = 1, 4.0%), China (*n* = 1, 4.0%), Hong Kong (*n* = 1, 4.0%), and Korea (*n* = 1, 4.0%). Patient enrollment varied significantly across studies, with an average of 54.5 ± 50.7 patients per study. The average age of patients across all studies was 71.8 ± 5.5 years, with an average follow-up period of 4.4 months. In addition, 26.9% of patients underwent surgical evacuation (either through burr holes or craniotomy) before embolization.

Material usage

Of the embolizations performed, 35.7% used particles, 31.5% used liquid embolic agents, 3.2% used coils, and 29.6% utilized a combination of materials. Polyvinyl alcohol (PVA) particles were the most commonly used (61.4%), followed by trisacryl gelatin microspheres (11.7%) and Embosphere® (0.7%). Among liquid embolic agents, Onyx was the most frequently used (41.0%), followed by n-butyl cyanoacrylate (32.6%), Squid-12 (1.1%), and precipitating hydrophobic injectable liquid (0.6%). For those treated with a combination of materials, the most common approach was the use of particles with coils (80.1%).

Outcomes and complications

Excluding one study that did not provide data, the recurrence of hematoma after embolization was low, occurring in 79 cases (5.1%). Overall, complication rates across the studies were generally low. Two studies did not report any complication data, and ten studies indicated no complications. The remaining 13 studies reported complications affecting 0.9–25.0% of their samples. Most complications were neurologic (2.0%), followed by vascular and cardiac etiologies (0.7%) and infections or delayed wound healing (0.3%). The most common neurologic complications included seizures

Table 1: Study design and baseline clinical characteristics.

Author, Year	Country	Study design	Number of patients	Number of cases	Average patient age, years (SD)	Average follow-up, months
Lam *et al*., 2023[16]	Australia	Randomized controlled trial	16	18	64.2	3
Liu *et al*., 2023[18]	China	Retrospective case series	53	53	68.1 (18.1)	6
Shotar *et al*., 2020[31]	France	Retrospective case series	89	104	74 (13)	3
Wong *et al*., 2023[36]	Hong Kong	Retrospective case series	7	8	77 (11)	6
Okuma *et al*., 2019[23]	Japan	Retrospective case series	17	21	76.4 (12.5)	26.3
Saito *et al*., 2019[26]	Japan	Retrospective case series	8	10	79	28.9
Izawa *et al*., 2019[8]	Japan	Retrospective case series	11	14	73.8	11.9
Kim *et al*., 2017[12]	Korea	Retrospective case series	20	26	73.7 (7.1)	3 *
Krothapalli *et al*., 2023[14]	United States	Retrospective case series	116	145	73.2	6
Shehabeldin *et al*., 2023[30]	United States	Retrospective case series	97	97	75.7 (14.4)	3.6
Wali *et al*., 2023[34]	United States	Retrospective case series	8	13	85	3
Link *et al*., 2019[17]	United States	Retrospective case series	49	60	69 (13)	1.5
Ban *et al*., 2018[3]	United States	Prospective	72	91	69.3 (10.5)	6
Majidi *et al*., 2022[19]	United States	Retrospective case series	61	83	62.5 (9)	3 to 6
Khorasanizadeh *et al*., 2022[11]	United States	Retrospective case series	78	94	72	3.0
Scoville *et al*., 2023[29]	United States	Retrospective case series	208	208	NR	3
Schwarz *et al*., 2021[28]	United States	Retrospective case series	41	44	73.3 (11)	12
Al-Mufti *et al*., 2021[1]	United States	Prospective	16	16	72	3
Catapano *et al*., 2021[5]	United States	Retrospective case series	35	41	68 (12)	4
Kan *et al*., 2021[10]	United States	Retrospective case series	138	154	69.8 (14.2)	2
Joyce *et al*., 2020[9]	United States	Retrospective case series	121	151	NR	3
Rajah *et al*., 2020[24]	United States	Retrospective case series	46	52	71.7 (14.4)	2
Samarage *et al*., 2022[27]	United States	Retrospective case series	37	53	76.9 (12.7)	6
Waqas *et al*., 2019[35]	United States	Retrospective case series	8	9	63.6 (10.9)	3.3
Msheik *et al*., 2023[21]	United States	Retrospective case series	10	14	63.4 (16)	2

*Symptomatic patients were followed for up to 6 months. NR: Not reported

(n = 5), strokes (n = 5), transient neurologic deficits (n = 3), facial droop (n = 3), and headaches (n = 3). There were 17 mortalities (1.4%) across all studies: three were procedure-related, seven were unrelated to the procedure, and eight were uncategorized. A detailed list of complications is shown in Table 2.

DISCUSSION

MMA embolization has emerged as a safe and effective means for treating cSDH. Understanding of the applications of the procedure is rapidly developing, with regular introduction of new materials, methods, and potential applications.[32,34] Three primary materials have been produced for MMA embolization: coils, Onyx glue, and polyvinyl alcohol particles. These embolisates can be used individually or in combination. Techniques to improve middle meningeal artery embolization using a combination of embolisates have been demonstrated.[34]

This study found that the two most common individual embolisates reported are particles and liquid embolic agents, followed by combinations of materials. When considering the pathophysiology of chronic subdural hematoma, eliminating the delivery of blood to the friable capillary beds is the ultimate goal. This can be accomplished by distal embolization, achieved with PVA delivery to capillary beds, or proximal embolization, accomplished with coils or Onyx near the foramen spinosum. In this review, very few coil only patients were reported, representing 3.2% of the total cohort. Coils have the distinct advantage of having a low likelihood of migration while also eliminating the risks of distal particle migration to critical structures such as the retina through ophthalmic feeders, which can be present in some patients. In a case series of 45 patients, Iyer *et al*. demonstrated that coil embolization alone appears sufficient within the cohort.[7] In this series, no complications were reported, which may

Table 2: Outcomes of embolization for chronic subdural hematoma.

Author, Year	Embolization material	Post-craniotomy/ Burr Hole MMA	Post-embo recurrence	Complications (n, %)
Lam *et al*., 2023[16]	NBCA (*n*=7), Squid-12 (*n*=5), PHIL (*n*=3), Onyx (*n*=1)	100%	0%	None
Liu *et al*., 2023[18]	PVA followed by NBCA+ethiodized oil	41.5%	3.8%	NR
Shotar *et al*., 2020[31]	TGM alone (*n*=54), TGM+coil (*n*=27), NBCA (*n*=5), coil alone (*n*=5)	100%	4.5%	Partial seizure (1, 1.1%); reversible headache (1, 1.1%); transient diplopia (2, 2.3%); asymptomatic iatrogenic meningomeningeal fistula (1, 1.1%); postprocedural femoral artery occlusion at the puncture site (1, 1.1%)
Wong *et al*., 2023[36]	Onyx	50%	0%	None
Okuma *et al*., 2019[23]	NBCA alone (*n*=12), Embosphere® (*n*=4), NBCA+Embosphere® (*n*=4), coil (*n*=1),	64.7%	NR	None
Saito *et al*., 2019[26]	NBCA alone (*n*=9), NBCA+PVA (*n*=1)	100%	12.5%	None
Izawa *et al*., 2019[8]	PVA (*n*=5), TGM (*n*=9)	100%	0%	Delayed wound healing (1, 9.1%)
Kim *et al*., 2017[12]	PVA	100%	3.8%	Surgical (2, 10%); medical (3, 15%)
Krothapalli *et al*., 2023[14]	PVA (*n*=68), Onyx (*n*=40), NBCA (*n*=8)	0%	1.7%	Ischemic stroke (1, 0.9%)
Shehabeldin *et al*., 2023[30]	Onyx (*n*=49), PVA (*n*=48)	NR	13.4%	NR
Wali *et al*., 2023[34]	PVA+coil	12.5%	0%	None
Link *et al*., 2019[17]	PVA	30.0%	6.7%	Moralities unrelated to the procedure (3, 6.1%)
Ban *et al*., 2018[3]	PVA	2.8%	1.4%	None
Majidi *et al*., 2022[19]	NBCA alone (*n*=55), NBCA+coil (*n*=6)	49.0%	5.0%	Transient neurologic deficit (1, 1.6%)
Khorasanizadeh *et al*., 2022[11]	PVA+coil (*n*=82), coil alone (*n*=12)	8.5%	8.3%	Visual loss due to retinal artery embolization (1, 1.3%); MCA occlusion (1, 1.3%)
Scoville *et al*., 2023[29]	Onyx, NBCA, PVA, Embosphere®	NR	4.9%	Postsurgical infections (2, 1%); worsening headaches (2, 1%); new-onset seizures (2, 1%); MMA rupture (2, 1%); ECA spasm (2, 1%); postprocedural facial drop from Onyx infiltration (2, 1%); stroke due to subdural compression (1, 0.5%); increased lethargy (1, 0.5%); increased balance difficulties (1, 0.5%); intermittent aphasia (1, 0.5%); numbness (1, 0.5%); uncategorized technical complication (1, 0.5%)
Schwarz *et al*., 2021[28]	PVA	40.9% SEPS, 59.1% craniotomy	4.5%	None
Al-Mufti *et al*., 2021[1]	NBCA+ethiodized oil	75%	NR	None

(Contd...)

Table 2: *(Continued).*

Author, Year	Embolization material	Post-craniotomy/ Burr Hole MMA	Post-embo recurrence	Complications (n, %)
Catapano *et al.*, 2021[5]	Onyx (*n*=29), particles and/or coils (*n*=7), NBCA (*n*=5)	2.6%	2.0%	Left MCA stroke (1, 2.9%)
Kan *et al.*, 2021[10]	Onyx, NBCA, coil, PVA, Embosphere®	33.3%	6.5%	Asymptomatic MMA rupture (1, 0.7%); postoperative seizure (1, 0.7%); right-sided facial droop (1, 0.7%); mortalities unrelated to the procedure (4, 2.9%); procedure-related mortalities (2, 1.5%)
Joyce *et al.*, 2020[9]	Onyx, NBCA, coil, PVA, Embosphere®	39.7%	6.0%	Intermittent aphasia (1, 0.8%). delayed seizure (1, 0.8%); delayed infarction (1, 0.8%); mortality (8, 6.6%)
Rajah *et al.*, 2020[24]	Onyx (*n*=43), NBCA (*n*=1)	8.7%	11.4%	Worsening underlying CHF (1, 2.2%); aspiration pneumonia (1, 2.2%)
Samarage *et al.*, 2022[27]	NBCA (*n*=38), coil (*n*=20), PVA (*n*=9), combination (*n*=17)	49.0%	14.0%	Aortic dissection (1, 2.7%); iatrogenic fistula (1, 2.7%); common femoral artery pseudoaneurysm (1, 2.7%)
Waqas *et al.*, 2019[35]	Onyx	25.0%	0%	None
Msheik *et al.*, 2023[21]	Onyx	40.0%	10.0%	None

NBCA: n-butyl cyanoacrylate; PHIL: Precipitating hydrophobic injectable liquid; PVA: Polyvinyl alcohol particles; TGM: Trisacryl gelatin microspheres; SEPS: Subdural evacuation port system, NR: Not reported, MCA: Middle cerebral artery, CHF: Congestive heart failure, MMA: Middle meningeal artery, ECA: External carotid artery

indicate a more favorable complication profile, but more data is required.

Recurrence rates of subdural hematoma and complication profiles differ by embolisate.[29] Radiographic outcomes of particle embolisates in patients receiving middle meningeal artery embolization for prophylactic, recurrent, and upfront treatment of subdural hematoma have been reported to be better than liquid embolisate.[29] One systematic review seems to demonstrate that liquid embolisates are associated with lower recurrence rates, rescue operations, and complications. Complication proportions have not been demonstrated to be different between liquid and particle embolisates; however, coil embolization appears to carry less risk.[7,29] Combination of coil embolization with PVA particles has been demonstrated to have the best overall outcomes.[15]

This study has limitations due to the rapid evolution of middle meningeal artery embolization techniques. To maintain the generalizability of the findings, case series with small sample sizes were excluded, although these studies may contain unique complications or insights. Anatomical variations in patients, such as ophthalmic feeder vessels, can increase the risk of complications, particularly ocular ones. The complication profiles and efficacy of middle meningeal artery embolization based on the location of embolization have not yet been fully characterized, which could offer valuable insights into reducing complication risks and improving outcomes. Recurrence and complication rates for individual embolisates were not reported in the reviewed publications, limiting the ability to characterize and compare individual embolisates. In addition, the development of newer generations of embolic materials may shift the landscape of both efficacy and complication profiles. Emerging techniques, such as using coils to enhance distal delivery of PVA, are also under development and may further impact patient outcomes.[7]

CONCLUSION

Middle meningeal artery embolization is a safe and effective treatment for chronic subdural hematoma. Complication rates are low across all embolisates reported. Further characterization of individual embolisates would be beneficial for choosing the optimal embolization material for any given case. Further large-scale studies with more detailed reporting of complication and recurrence rates by embolisate are warranted.

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