Outcomes of middle meningeal artery embolization for treating chronic subdural hematoma.

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ABSTRACT

The study evaluates chronic subdural hematoma (cSDH) middle meningeal artery (MMA) embolization efficacy and safety. A prospective interventional study was conducted in Viet Duc Hospital from November 2021 to April 2024. All consecutive cSDH MMA embolization patients were included. Clinical and imaging data were collected before and one month after treatment. The study included 31 42-cSDH patients. Of these, 25.8% had hematoma evacuation, 83.9% were treated with surgery and embolization, and 16.1% with embolization alone. 92.9% of procedures used polyvinyl alcohol particles. The success rate was 92.9% and complications 7.1%. Asymptomatic external carotid artery vasospasm and MMA rupture occurred. Functional improvement occurred in 91.7% of patients one month after treatment. Significantly lower mean modified Rankin Scale (mRS) score (0.2±0.7 *vs*. 1.7±0.9; P=0.000) and higher proportion of patients with ≤2 mRS score (95.8% *vs*. 74.1%) were observed after treatment. Hematoma thickness decreased significantly (P=0.00) from 21.5±7.9 mm to 8.3±4.1 mm. The midline shift decreased significantly from 7.4±5.0 mm to 0.7±1.2 mm (P=0.00). Just one patient (4.2%) needed surgery. MMA embolization alone or with surgery appears to treat cSDH safely and effectively.

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Introduction

Chronic subdural hematoma (cSDH) is a collection of blood and blood breakdown products that accumulate in the space between the dura and arachnoid maters (known as the subdural space) for at least 2-3 weeks. This condition is usually caused by trauma, intracranial hypotension, or coagulation disorders. CSDH is a prevalent neurological condition, particularly in the elderly population.[1] It can significantly diminish the quality of life and even decrease life expectancy, with a one-year mortality rate of up to 32%.[2] However, with timely diagnosis and appropriate treatment, the prognosis can be good.

Chronic subdural hematomas tend to persist and gradually increase in size over time. This occurs due to a chronic inflammatory response of the dura mater that leads to fibrin secretion and neocapillary formation in the membranes.[3] The diagnosis of cSDH is based mainly on clinical symptoms and imaging examinations, with non-contrast brain computed tomography scanning being the most commonly used imaging test.

Various treatment strategies are currently available that aim to effectively and permanently resolve symptoms and eliminate hematomas. Of these, surgery is the most widely used method, which is effective in quickly resolving symptoms, but the recurrence rate is still a concern.[4] Some drugs are used for medically treating cSDH; they include atorvastatin, dexamethasone, antifibrinolytic agents, angiotensin-converting enzyme inhibitors, and goreisan. However, the effectiveness of these drugs is unclear and the required surgery rate varies greatly, ranging from 15% to 90%.[5] In addition, some of these drugs can cause serious complications, such as Cushing's syndrome, gastric ulcers, mental disorders, myocardial infarction, and glaucoma. In recent years, middle meningeal artery (MMA) embolization has emerged as a promising new method of treating cSDH that is both effective and safe. Embolization blocks the blood supply to the membranes of the hematoma, limits continuous leakage from the neocapillaries, and promotes reabsorption of the hematoma over time. However, there are no published studies on this issue in Vietnam. Therefore, we conducted an investigation to evaluate the outcomes of MMA embolization of cSDH.

Materials and Methods

Patient selection

This study enrolled patients with cSDH, either occurring for the first time or recurring, who were treated with MMA embolization at the Radiology Department of Viet Duc Hospital. The study was conducted from November 2021 to April 2024. The decision to perform embolization, either alone or combined with surgery, was based on consultation between surgeon, neurointerventionist, and patient. The general criteria for considering MMA embolization were as follows: patients with mild symptoms could undergo embolization to relieve symptoms and reduce the risk of hematoma development; embolization could be used as an adjunct to surgery to reduce the risk of recurrence and reoperation; patients at high surgical risk or unable to undergo surgery due to old age, cachexia, or multimorbidity. Exclusion criteria included cSDH development with underlying conditions such as brain tumor, arachnoid cyst, or spontaneous intracranial hypotension; non-convexity cSDH; life expectancy less than six months; severe kidney disease; and allergy to contrast agent. The prospective interventional study was approved by the ethics committee of Hanoi Medical University (696/GCN-HDDDNCYSH-DHYHN).

Middle meningeal artery embolization protocol

Before the procedure, the neurointerventionist thoroughly examined and explained the purpose, procedure, and risks of complications to patients and their families. Patients or their relatives had to sign a consent agreement if they accepted the procedure.

During the procedure, the patient was under either local anesthesia or general anesthesia, and heparin 500 IU was continually injected. The interventionist punctured an artery with an 18G needle according to the standard Seldinger technique and then inserted a 0.035 guidewire into the artery. After withdrawing the needle, a 5F or 6F sheath was inserted into the artery following the guidewire. Then, the guidewire and catheter were moved to the common carotid artery ipsilateral to the treated hematoma. Digital subtraction angiography (DSA) of the external and internal carotid arteries was performed to evaluate the anatomy of the MMA, dangerous collaterals, and anatomical variations. This was followed by the performance of DSA of the contralateral carotid arteries. The guidewire and catheter were placed into the external carotid artery, rather than into the internal carotid artery, in order to minimize thrombotic complications. The interventionist withdrew the guidewire, inserted the microguidewire and microcatheter (1.8-2.2F) into the lumen of the catheter, and then withdrew the microguidewire. Selective angiography of the MMA and its branches was performed to identify the branches feeding the hematoma and the presence of dangerous collaterals. If no dangerous collateral was detected, embolization material was used to occlude the MMA, either in its trunk or in its frontal and parietal branches. However, if a dangerous collateral was present, the microcatheter was placed away from these anastomoses or the branches were embolized with coils before injecting embolization material into the remaining branches. Finally, angiography of the MMA and the entire external carotid artery was performed again.

Data collection

Data were prospectively collected using a predesigned research form. The information obtained included demographics (age and gender), history of prior subdural hematoma surgery, coagulation disorders, thrombocytopenia, functional assessment according to the modified Rankin Scale (mRS) upon admission, and the recent treatment approach (embolization alone or combined with surgery). Hematoma characteristics before treatment included location, laterality, thickness (the longest distance from the inner edge of the hematoma to the inner surface of the skull measured on an axial slice), and midline shift (the longest distance from the septum pellucidum to the midline measured on an axial slice). Details on the procedure included the following: duration, endovascular access point, MMA diameter (measured 5-10 mm from the origin of the MMA), embolization material, catheter position before embolization, presence of lacrimal branch, dangerous collaterals with ophthalmic artery, and technical success. The procedure was considered successful if the DSA after the intervention showed occlusion of the MMA branch feeding the hematoma membrane, no hypervascularity around the hematoma, normal circulation of the remaining arteries (Figure 1), and no procedure-related complications. In contrast, cases were considered technical failures if the MMA could not be cannulated successfully, or if dangerous anastomoses prevented the interventionist from performing the embolization after micro-catheterization. Procedural complications included any embolization-associated adverse events, such as infection, new neurological deficits, seizures, intracranial bleeding, cerebral infarction, pseudoaneurysm, carotid artery dissection, retroperitoneal hematoma, allergy to contrast agent, pulmonary embolism, myocardial infarction, and death. Clinical and radiographic outcomes one month after treatment included the percentage of patients requiring surgery/reoperation and showing an improvement in mRS, hematoma thickness, and midline shift (Figure 2).

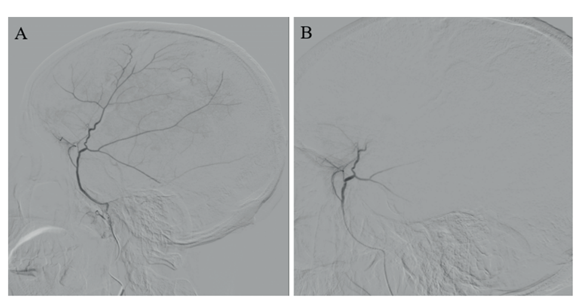

Figure 1. Selective angiography of the middle meningeal artery before embolization (A) and after successful intervention (B).

Statistical analysis

Categorical variables are given as percentages, while quantitative variables are given as mean ± standard deviation. For normally distributed variables, paired means were compared using a t-test, whereas the Wilcoxon test was used for nonnormally distributed variables. The Mann-Whitney U test was used to compare the means of variables between two nonnormally distributed independent samples. All data were analyzed using IBM Statistical Package for the Social Sciences software, version 20.0 (IBM Corp., Armonk, N.Y., USA). A P-value of less than 0.05 indicated statistical significance.

Results

Patient characteristics

Our study consisted of 31 patients with cSDH who were treated with MMA embolization, either alone or in combination with surgery. The patients' characteristics on admission are shown in Table 1. Patient ages ranged from 35 to 84 years, with a mean age of 68±10 years. On presentation, the mean mRS score was 1.7±0.9. The proportion of patients with an mRS score of 1, 2, and 3 was 58.1%, 16.1%, and 25.8%, respectively.

Chronic subdural hematoma characteristics

Table 2 shows the characteristics of cSDH before treatment. Eleven patients (35.5%) had bilateral hematomas, and a total of 42 hematomas were treated with MMA embolization.

Middle meningeal artery embolization characteristics

Table 3 shows the details of the MMA embolization procedure. The duration of the procedure ranged from 12.3 to 101 minutes, with a mean of 30.7±21.3 minutes. The mean diameter of embolized (42 arteries) and unembolized (20 arteries) MMAs were 1.8±0.2 mm and 1.5±0.1 mm, respectively. The technical success rate was 92.9%; however, three procedures (7.1%) had complications, including two MMA ruptures and one external carotid artery vasospasm.

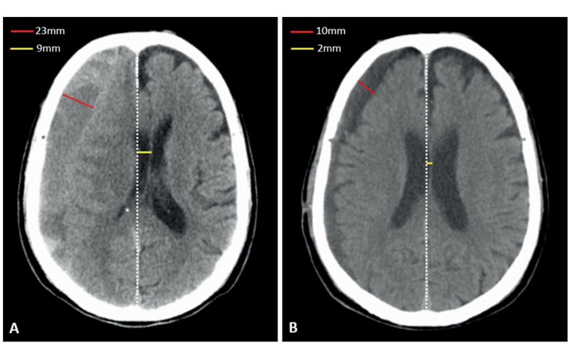

Figure 2. Non-contrast head computed tomography scans of a patient with chronic subdural hematoma on the right side (A) before treatment and (B) after treatment. Hematoma thickness and midline shift both decreased after the intervention.

Outcomes oe month after treatment

The mean length of hospital stay of 31 patients was 8.2±6.6 days, with the shortest stay being 3 days and the longest being 38 days. One month after treatment, 24 patients returned for follow-up examinations. Their clinical and radiographic outcomes are presented in Tables 4 and 5, respectively. The majority of patients (91.7%) showed functional improvement, with only 2 patients (8.3%) showing no change and none becoming worse. The percentages of patients with an mRS score of 0, 1, 2, and 3 were 87.5%, 8.3%, 0%, and 4.2%, respectively. The mean mRS score after treatment (0.2±0.7) was significantly lower than that before treatment (1.7±0.9) (P=0.00). The proportion of patients with an mRS score of ≤2 increased from 74.1% before treatment to 95.8% after treatment. However, one patient (4.2%) experienced worsening bilateral cSDHs and severe headaches, which required surgery.

Table 1. Patient characteristics.

Variable	Patients (%) N=31
Age, years (mean ± SD)	68.0±10.0
Gender	
Male	27 (87.1)
Female	4 (12.9)
Previous subdural hematoma evacuation	
Yes	8 (25.8)
No	23 (74.2)
Thrombocytopenia upon admission	
Yes	2 (6.5)
No	29 (93.5)
Coagulation disorders upon admission	
Yes	2 (6.5)
No	29 (93.5)
mRS upon admission, score (mean±SD)	1.7±0.9
Recent treatment approach	
MMA embolization alone	5 (16.1)
Hematoma evacuation before MMA embolization	25 (80.6)
MMA embolization before hematoma evacuation	1 (3.3)

SD, standard deviation; mRS, modified Rankin scale; MMA, middle meningeal artery.

Table 2. Chronic subdural hematoma characteristics before treatment.

Variable	Hematomas (%) N=42
Location	
Entire convexity	41 (97.6)
Frontal	1 (2.4)
Other	0 (0)
Laterality	
Right	9 (29)
Left	11 (35.5)
Bilateral	11 (35.5)
Hematoma thickness, mm (mean±SD)	21.5±7.9
Midline shift (N=31)	
No	3 (9.7)
Yes	28 (90.3)

SD, standard deviation.

Table 3. Procedure details.

Variable	Procedures (%) N=42
Endovascular access point	
Femoral artery	41 (97.6)
Radial artery	1 (2.4)
Embolized MMA diameter, mm (mean ± SD)	1.8±0.2
Embolization materials	
Polyvinyl alcohol particles	39 (92.9)
Combined materials	3 (7.1)
Catheter position before embolization	
Frontal and parietal branches	18 (42.9)
MMA bifurcation	22 (52.4)
MMA origin	2 (4.8)
Dangerous collaterals with ophthalmic artery	
Yes	2 (4.8)
No	40 (95.2)
Lacrimal branch	
Yes	16 (38.1)
No	26 (61.9)
Technical success	
Yes	39 (92.9)
No	3 (7.1)
Complication	
MMA rupture	2 (4.8)
External carotid artery vasospasm	1 (2.3)

SD, standard deviation; MMA, middle meningeal artery.

Table 4. Clinical outcomes one month after treatment.

Variable	Patients (%) N=24
mRS, score (mean±SD)	0.2±0.7
Change in mRS one month after treatment compared to before treatment	
Improvement	22 (91.7)
No difference	2 (8.3)
Worsening	0 (0)
Required surgery	
Yes	1 (4.2)
No	23 (95.8)
Mortality	0 (0)

mRS, modified Rankin scale; SD, standard deviation.

Table 5. Radiographic outcomes one month after treatment.

Variable	Hematomas (%) N=33
Hematoma thickness, mm (mean ± SD)	8.3±4.1
Change in hematoma thickness one month after treatment compared to before treatment	
Complete resolution	3 (9.1)
No difference	0 (0)
Improvement	28 (84.8)
Worsening	2 (6.1)
Improvement in hematoma thickness	
Complete resolution	3 (9.1)
Hematoma thickness decreased by ≥50%	19 (57.6)
Hematoma thickness decreased by <50%	9 (27.3)
Midline shift, mm (mean ± SD) (N=24)	0.7±1.2
No	17 (54.8)
Yes	7 (22.6)

SD, standard deviation.

One month after treatment, hematoma thickness (8.3±4.1 mm) was significantly reduced compared to before treatment (21.5±7.9 mm) (P=0.00). The majority of cSDHs decreased by at least 50% in thickness (57.6%) or completely regressed (9.1%). However, bilateral hematomas (6.1%) increased in size. After treatment, 54.8% of the patients did not show a midline shift while the remaining patients showed a slight displacement of 1-3 mm. The midline shift after treatment (0.7±1.2 mm) was significantly reduced compared to before treatment (7.4±5.0 mm) (P=0.00).

Discussion

Chronic subdural hematoma is a common neurological disease that frequently affects older individuals, with an incidence rate of 1.72-20.6/100,000 people per year. This condition increases significantly in people over the age of 65.[6] Our study comprised 31 patients, with a mean age of 68±10 years, of whom 90% were aged ≥60 years.

Several treatment strategies are currently available, with the primary goals of symptom relief and effective, long-term hematoma resolution. Surgery remains the most widely used method, but the recurrence rate continues to be a concern. In our study, 25.8% of the patients had a previous hematoma evacuation. The high recurrence rate is a major challenge for treatment, increasing the burden on patients and their families, prolonging the length of hospital stay, increasing costs, and reducing treatment efficacy. In addition, most patients are elderly and have multiple morbidities, which increase the risk of surgical complications or the likelihood of being unable to undergo surgery. In recent years, MMA embolization has emerged as a new treatment method. Embolization blocks the blood supply to the hematoma membranes, limits persistent leakage from the neocapillaries, and promotes hematoma reabsorption over time.[7] In our study, most patients (83.9%) received surgery in combination with embolization. Surgery resolves symptoms quickly and effectively, and adjunctive embolization reduces the risk of recurrence. Five patients (16.1%), who presented with mild headaches, underwent MMA embolization as a standalone treatment to relieve their symptoms and prevent hematoma development.

Chronic subdural hematoma may occur on one or both sides of the head. In cases of bilateral hematoma, MMA embolization can be performed on each side separately or both sides simultaneously, depending on the patient's clinical condition. In this study, 11 patients with bilateral subdural hematomas (35.5%) underwent simultaneous MMA embolization on both sides.

The mean diameter of MMAs on the same side as the hematoma was significantly larger (1.8±0.2 mm) than that of MMAs on the side without the hematoma (1.5±0.1 mm) (P=0.00), consistent with the findings of Pouvelle *et al.*[8] and Takizawa *et al*.[9] This may be because the artery supplies blood to the neovessels in hematoma membranes. Furthermore, a diameter less than 1.5 mm is considered a prognostic factor that can predict both clinical and imaging failure.[10]

In our study, polyvinyl alcohol (PVA) particles were used in 39 procedures (92.9%). PVA particles can migrate to and occlude the distal branches of the MMA, cover a large area, and prevent new distal collaterals. PVA particles are more cost-effective than liquid embolics. However, the particles are not radiopaque, making it difficult to monitor and control abnormal reflux. To overcome these problems, the particles are mixed with contrast agents, but it is still difficult to determine the degree of their distant penetration and vascular occlusion. Moreover, the amount of injected particles is limited by the small size of the microcatheter. The remaining three procedures (7.1%) used PVA particles in combination with other materials such as coils and glue (N-butyl cyanoacrylate). Unlike PVA particles, liquid embolics can be easily observed on DSA due to their radiopacity, potentially dangerous reflux control, and increased safety. In addition, large quantities of liquid embolics can be injected under stable pressure. However, they cannot penetrate far and are mainly effective in occluding the proximal part of the MMA. Liquid embolics are also more expensive than PVA particles. Most of our patients were treated with PVA particles, which were both effective (the technical success rate was 92.9%) and cost-effective. Some studies did not find significant differences between liquid materials and PVA particles in radiation dose, procedure duration, technical failure rate, and required surgery rate.[11,12]

We observed promising results one month after treatment. Based on clinical assessment, 91.7% of our patients showed functional improvement and none of them became worse. The mean mRS decreased, and the proportion of patients with an mRS score of ≤2 increased significantly compared to before treatment. On imaging, the cSDH thickness and midline shift were both lower than before treatment. Most hematomas decreased in thickness by at least 50% or completely regressed (66.7%), with no midline shift (54.8%). These results are consistent with the findings reported by Kan *et al*., who also found significant improvements in cSDH thickness and mRS score after treatment ($P<0.05$).[13] However, according to Gomez-Paz *et al.,* embolization may not be suitable for patients with moderate or severe symptoms as it takes at least two weeks to achieve clear effects. In such cases, surgery is the preferred choice to quickly resolve symptoms caused by hematoma.[14]

Six patients, who had a previous subdural hematoma evacuation, showed clinical and radiographic improvements similar to those in Hashimoto *et al.,*[7] Tempaku *et al.*,[15] and Link *et al.*[16] The follow-up of 20 patients who were treated with adjunct MMA embolization showed a decrease in hematoma thickness in all patients, with 19 showing improved mRS scores. These results suggest that the combination of embolization and surgery is an effective strategy for cSDH and can prevent recurrence, as also shown by Shotar *et al.*[17] and Lam *et al.*[18] Some studies comparing the efficacy of embolization alone or in combination with surgery and surgery alone revealed that embolization resulted in higher hematoma resorption and lower recurrence rates compared to surgery alone.[19,20]

In our study, the recurrence rate was 4.2%, affecting only one patient, which is comparable to the results from studies across the world.[21-24] One patient had bilateral cSDHs, which were initially treated with embolization alone. However, after a month, both hematomas increased in thickness, and the patient continued to experience severe headaches. Consequently, surgery was performed to remove the hematomas.

MMA embolization is a minimally invasive procedure that is highly beneficial to elderly patients with comorbidities. One of its advantages over surgery is that it does not require general anesthesia, which reduces the risk of cardiovascular and respiratory complications. All patients in our study underwent local anesthesia, which reduced procedure-related complications. Furthermore, patients do not need to stop taking anticoagulants or antiplatelet drugs before the procedure, thereby minimizing the risk of thrombosis.[25,26]

In our study, the complications included MMA rupture and external carotid artery vasospasm. The complication rate was 7.1%, which was notably higher than those reported by some authors (1.2-3.6%).[20,22,27] This difference may be attributable to variations in sample size. The case of MMA rupture was self-controlled during the injection of PVA particles. Another case also had an MMA rupture that was occluded by coils. The remaining case was of asymptomatic external carotid artery vasospasm, with no further intervention needed. The patient's clinical condition was stable during the procedure and hospital stay. Although visual complications (transient double vision) and facial paralysis have been reported in the literature,[13,17] our patients did not experience these complications.

Embolization material can penetrate and occlude the ophthalmic artery, which is a highly dangerous complication. Therefore, the ophthalmic artery originating from the MMA or collaterals between the MMA and the ophthalmic artery through the orbital or lacrimal branches are considered dangerous anatomical variations. Neurointerventionists must be thoroughly observant when performing the procedure. One patient in our study had the left ophthalmic artery originating from the ipsilateral MMA (Figure 3). During the procedure,

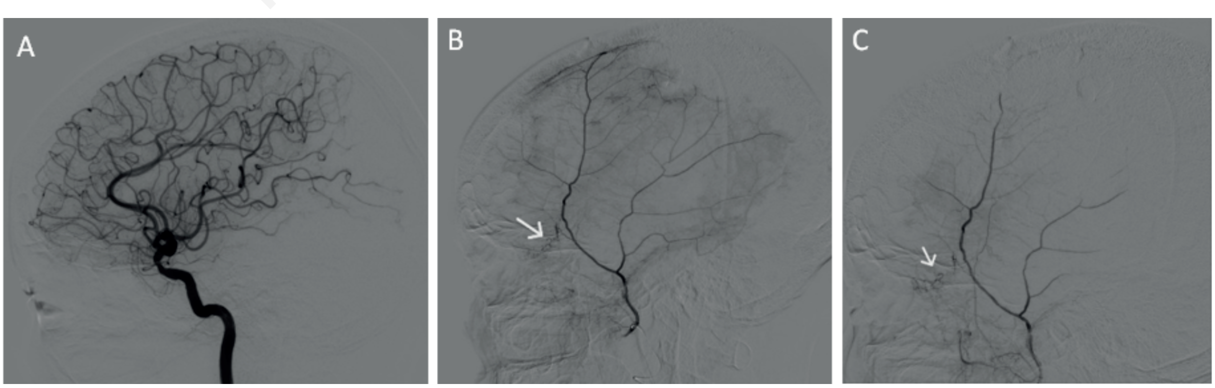

Figure 3. The left ophthalmic artery originates from the ipsilateral middle meningeal artery. A) The ophthalmic artery is not visible on digital subtraction angiography of the internal carotid artery; B) the ophthalmic artery originates from the anterior branch of the middle meningeal artery on selective angiography of the middle meningeal artery before embolization; C) the ophthalmic artery is preserved after the intervention.

a 2.2F microcatheter was placed away from this origin to preserve the branch. Then, PVA particles sized 150-250 micrometers were slowly injected to avoid reflux causing visual complications. After the intervention, the patient did not experience any complications. We also found that in two cases (4.8%), the MMA was dangerously anastomosed with the ophthalmic artery; therefore, the microcatheter was placed away from these collaterals before embolizing the goal vessels. No complications occurred.

Our study has some limitations that need addressing. Firstly, the study was conducted at a single center with a small sample size. Secondly, the follow-up duration was short and some patients were lost to follow-up, which made it impossible to evaluate the long-term efficacy of MMA embolization of cSDH. Thirdly, the study did not include control groups to compare embolization and conventional methods, such as surgery, medical treatment, and monitoring, for their effectiveness. Finally, PVA particles were used in almost all procedures, which makes it difficult to compare different embolization materials for their efficacy.

Conclusions

Our study found that the success rate of MMA embolization for treating cSDH was 92.9%, with a complication rate of 7.1%. The complications included MMA rupture and asymptomatic external carotid artery vasospasm. One month after treatment, the majority of patients showed functional improvement, with hematoma thickness and midline shift decreasing significantly. Only one patient (4.2%) required surgery. Therefore, the study demonstrated that MMA embolization, either alone or in combination with surgery, can be a safe and effective method of treating cSDH.

References

1. Yang W, Huang J. Chronic subdural hematoma: epidemiology and natural history. Neurosurg Clin N Am 2017;28:205-10.
2. Blaauw J, Jacobs B, Hertog HM den, et al. Mortality after chronic subdural hematoma is associated with frailty. Acta Neurochir 2022;164:3133-41.
3. 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.
4. Ivamoto HS, Lemos HP, Atallah AN. Surgical treatments for chronic subdural hematomas: a comprehensive systematic review. World Neurosurg 2016;86:399-418.
5. Fiorella D, Arthur AS. Middle meningeal artery embolization for the management of chronic subdural hematoma. J Neurointerv Surg 2019;11:912-5.
6. Yang W, Huang J. Chronic subdural hematoma: epidemiology and natural history. Neurosurg Clin N Am 2017;28:205-10.
7. Hashimoto T, Ohashi T, Watanabe D, et al. Usefulness of embolization of the middle meningeal artery for refractory chronic subdural hematomas. Surg Neurol Int 2013;4:104.
8. Pouvelle A, Pouliquen G, Premat K, et al. Larger middle meningeal arteries on computed tomography angiography in patients with chronic subdural hematomas as compared with matched controls. J Neurotrauma 2020;37:2703-8.
9. Takizawa K, Sorimachi T, Ishizaka H, et al. Enlargement of the middle meningeal artery on MR angiography in chronic subdural hematoma. J Neurosurg 2016;124:1679-83.
10. Salem MM, Kuybu O, Nguyen Hoang A, et al. Middle meningeal artery embolization for chronic subdural hematoma: predictors of clinical and radiographic failure from 636 embolizations. Radiology 2023;307:e222045.
11. Krothapalli N, Patel S, Fayad M, et al. Outcomes of particle versus liquid embolic materials used in middle meningeal artery embolization for the treatment of chronic subdural hematoma. World Neurosurg 2023;173:e27-e36.
12. Shehabeldin M, Amllay A, Jabre R, et al. Onyx Versus particles for middle meningeal artery embolization in chronic subdural hematoma. Neurosurgery 2023;92:979-85.
13. Kan P, Maragkos GA, Srivatsan A, et al. Middle Meningeal artery embolization for chronic subdural hematoma: a multi-center experience of 154 consecutive embolizations. neurosurgery. 2021;88:268-77.
14. Gomez-Paz S, Akamatsu Y, Salem MM, et al. Upfront middle meningeal artery embolization for treatment of chronic subdural hematomas in patients with or without midline shift. Interv Neuroradiol 2021;27:571-6.
15. Tempaku A, Yamauchi S, Ikeda H, et al. Usefulness of interventional embolization of the middle meningeal artery for recurrent chronic subdural hematoma: Five cases and a review of the literature. Interv Neuroradiol 2015;21:366.
16. Link TW, Schwarz JT, Paine SM, et al. Middle Meningeal Artery Embolization for Recurrent Chronic Subdural Hematoma: A Case Series. World Neurosurg 2018;118:e570-e574.
17. Shotar E, Meyblum L, Premat K, et al. Middle meningeal artery embolization reduces the post-operative recurrence rate of at-risk chronic subdural hematoma. J Neurointerv Surg 2020;12:1209-13.
18. Lam A, Selvarajah D, Htike SS, et al. The efficacy of postoperative middle meningeal artery embolization on chronic subdural hematoma - A multicentered randomized controlled trial. Surg Neurol Int 2023;14:168.
19. Ng S, Derraz I, Boetto J, et al. Middle meningeal artery embolization as an adjuvant treatment to surgery for symptomatic chronic subdural hematoma: a pilot study assessing hematoma volume resorption. J NeuroInterv Surg 2020;12:695-99.
20. Srivatsan A, Mohanty A, Nascimento FA, et al. Middle meningeal artery embolization for chronic subdural hematoma: meta-analysis and systematic review. World Neurosurg 2019;122:613-9.
21. Waqas M, Vakhari K, Weimer PV, et al. Safety and effectiveness of embolization for chronic subdural hematoma: systematic review and case series. World Neurosurg 2019;126:228-36.
22. Court J, Touchette CJ, Iorio-Morin C, et al. Embolization of the Middle meningeal artery in chronic subdural hematoma - A systematic review. Clin Neurol Neurosurg 2019;186:105464.
23. Di Cristofori A, Remida P, Patassini M, et al. Middle meningeal artery embolization for chronic subdural hematomas. A systematic review of the literature focused

on indications, technical aspects, and future possible perspectives. Surg Neurol Int 2022;13:94.
24. Ironside N, Nguyen C, Do Q, et al. Middle meningeal artery embolization for chronic subdural hematoma: a systematic review and meta-analysis. J Neurointerv Surg 2021;13:951-7.
25. Joyce E, Bounajem MT, Scoville J, et al. Middle meningeal artery embolization treatment of nonacute subdural hematomas in the elderly: a multiinstitutional experience of 151 cases. Neurosurg Focus 2020;49:E5.
26. Cannarsa GJ, Olexa J, Chryssikos T, et al. Stand-alone middle meningeal artery embolization for treatment of giant chronic subdural hematoma in elderly frail patients: a case series. Neurosurgery 2021;89:S6.
27. Jumah F, Osama M, Islim AI, et al. Efficacy and safety of middle meningeal artery embolization in the management of refractory or chronic subdural hematomas: a systematic review and meta-analysis. Acta Neurochir (Wien) 2020; 162:499-507.