Middle Meningeal Artery Embolization for Chronic Subdural Hematoma: Ready for Primetime?

Andrew C. White, DO
Diagnostic & Interventional Neuroradiology
Radiology of Huntsville
Huntsville Hospital

Disclosures

Sadly, none...

"I'm afraid I can't treat you, Mr. Fisk. I have a conflict of interest."

Objectives

1. Describe MMAE to patients/families.
2. Summarize current evidence-based guidelines for its use in cSDH.
3. Identify which patient subgroups are and are not reasonable candidates for embolization.

SDH: A History

- SDH appear throughout human history
- Chronic SDH (cSDH) as a distinct entity recognized later
- Initially described as inflammatory '*pachymeningitis hemorrhagica interna*' by Virchow
- Later confirmed to be traumatic by Cushing

Epidemiology: Why is this important?

- cSDHs are common
  - 8.2 cases per 100,000 (age >70) per year.
- By 2030, cSDH is predicted to be the most prevalent cranial neurosurgical condition in adults
  - Estimated 60,000 cases/yr in the US
  - Pts living much longer and much more active into their 90s
  - More pts on anticoagulants and antiplatelets
- Mortality rates increase after cSDH, especially with advanced age
  - Median survival after diagnosis ~4 years
    - Decreases significantly for pts aged 85 and older

Epidemiology: Why is this important?

ELSEVIER
World Neurosurgery
Volume 80, Issue 6, December 2013, Pages 889-892

Peer-Review Report

Chronic Subdural Hematoma: A Sentinel Health Event

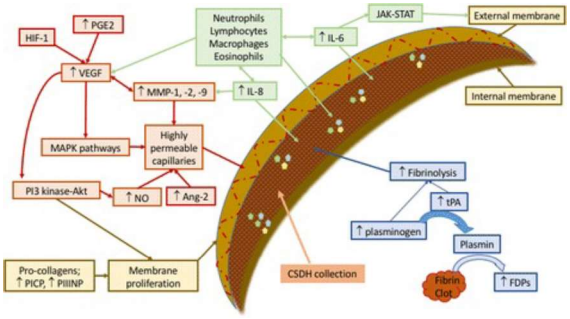
Travis M. Dumont [1], Anand I. Rughani [1], Tara Goeckes [2], Bruce I. Tranmer [1]

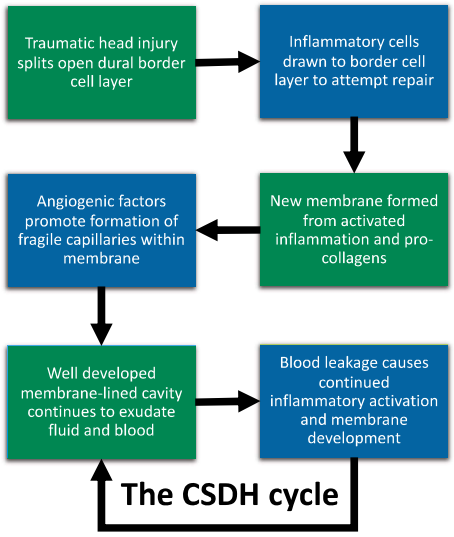
Show more

+ Add to Mendeley Share Cite

https://doi.org/10.1016/j.wneu.2012.06.026 Get rights and content

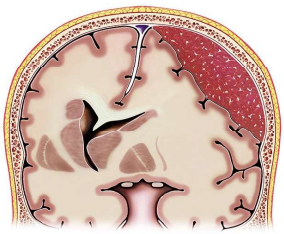
Pathophysiology





Radiology OF HUNTSVILLE
Middle Meningeal Artery Embolization for Chronic Subdural Hematoma
Background • Principles • Evidence

Current Treatment



Asymptomatic vs symptomatic

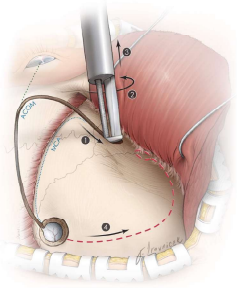
- cSDH > 10 mm, or midline shift > 5 mm
- *'moderate to severe cognitive impairment, or progressive neurological deterioration attributable to the cSDH, in patients with potential for recovery'*

Conservative

- Observation
- Medical: Steroids, **statins**, hyperosmolar therapy, reversal/suspension of AC and AP

Surgical

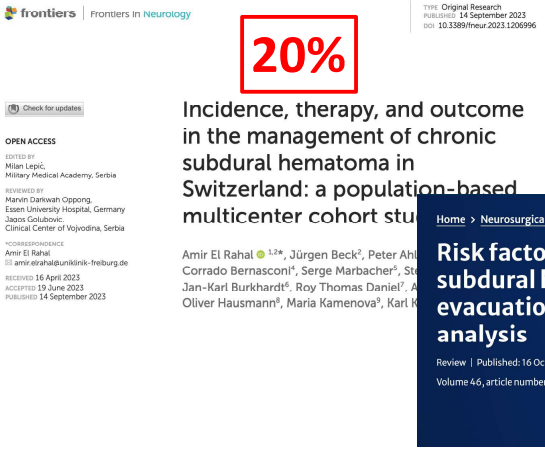
- Burr hole drainage +/- subdural or subgaleal drain placement
- Craniotomy/craniectomy



HUNTSVILLE HOSPITAL

Radiology OF HUNTSVILLE
Middle Meningeal Artery Embolization for Chronic Subdural Hematoma
Background • Principles • Evidence

Current Treatment


frontiers | Frontiers in Neurology

TYPE Original Research
PUBLISHED 14 September 2023
DOI 10.3389/fneur.2023.1206996

Check for updates

OPEN ACCESS

EDITED BY
Milan Lepic,
Military Medical Academy, Serbia

REVIEWED BY
Marvin Darkwah Oppong,
Essen University Hospital, Germany
Jagos Golubovic,
Clinical Center of Vojvodina, Serbia

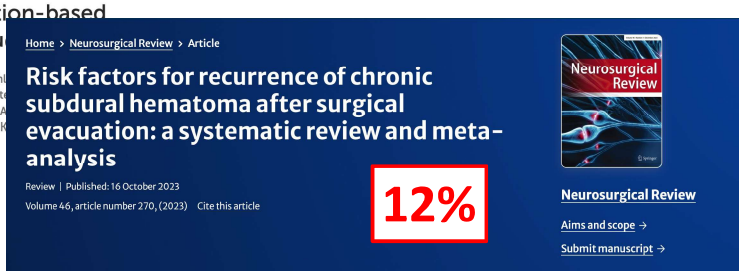
*CORRESPONDENCE
Amir El Rahal
amir.elrahal@uniklinik-freiburg.de

RECEIVED 16 April 2023
ACCEPTED 19 June 2023
PUBLISHED 14 September 2023

20%

Incidence, therapy, and outcome in the management of chronic subdural hematoma in Switzerland: a population-based multicenter cohort stu

Amir El Rahal [1,2]*, Jürgen Beck[2], Peter Ahl
Corrado Bernasconi[4], Serge Marbacher[5], St
Jan-Karl Burkhardt[6], Roy Thomas Daniel[7], A
Oliver Hausmann[8], Maria Kamenova[9], Karl K


Home > Neurosurgical Review > Article

Risk factors for recurrence of chronic subdural hematoma after surgical evacuation: a systematic review and meta-analysis

Review | Published: 16 October 2023
Volume 46, article number 270, (2023) Cite this article

12%

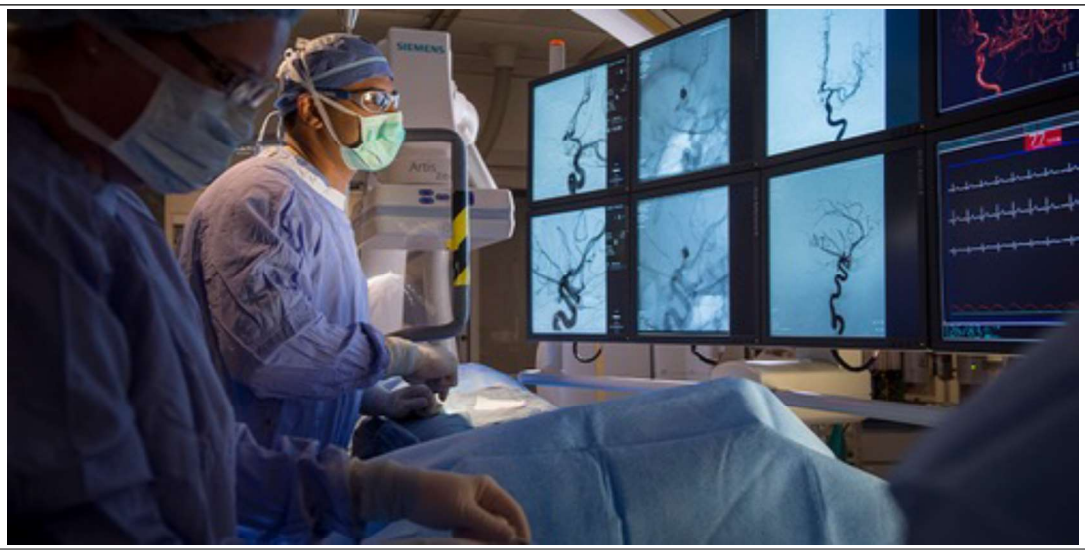
Neurosurgical Review

Neurosurgical Review

Aims and scope →

Submit manuscript →

HUNTSVILLE HOSPITAL



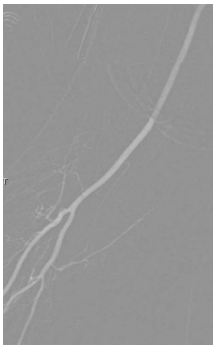
Middle Meningeal Artery Embolization

What is it?

Technique: Arterial access

<u>Femoral access</u>

Ideal for greater than 80% of cases



<u>Radial access</u>

Advantageous in some cases

No significant access site hemorrhage

Technique: Arch Navigation and Carotid Imaging

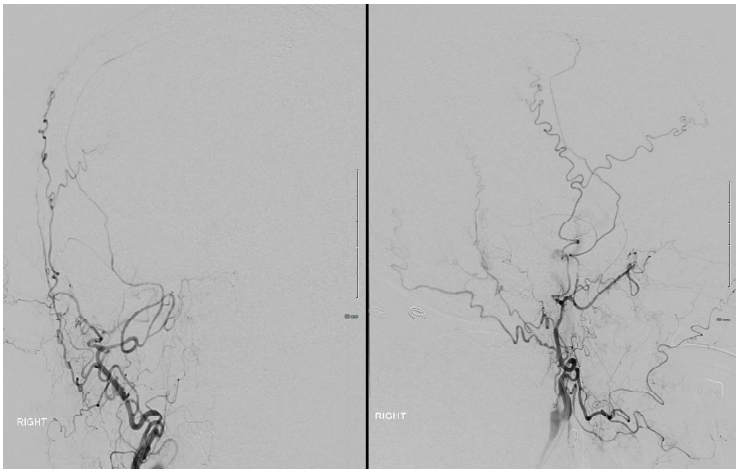
Baseline AP and Lateral views

- Extracranial and proximal intracranial carotid arteries
- Ophthalmic artery origin
- MMA origin

Middle Meningeal Artery Embolization for Chronic Subdural Hematoma
Background • Principles • Evidence

Technique: Selective ECA

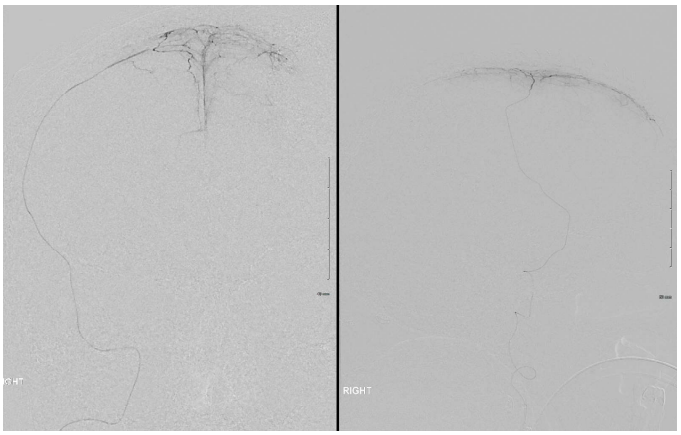
For roadmap navigation



Middle Meningeal Artery Embolization for Chronic Subdural Hematoma
Background • Principles • Evidence

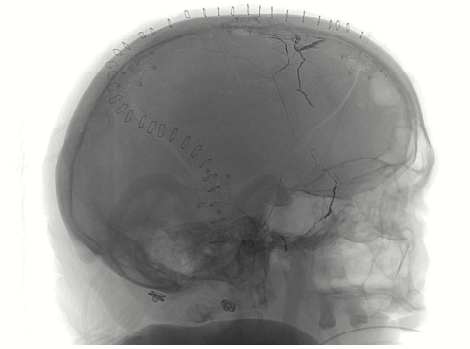
Technique: Selective MMA

Prior to embolic agent injection



Technique: Post-procedure Dyna-CT

To evaluate for non-target embolization and hemorrhagic complications.



Radiology OF HUNTSVILLE
Middle Meningeal Artery Embolization for Chronic Subdural Hematoma
Background • Principles • Evidence

Technique: Embolization

Particle Agents (PVA particles, Embospheres, gelfoam)
- Cheap
- Safe (and fast)
- Painless (sedation only)

Liquid Agents (Onyx, n-bCA, SQUID, PHIL)
- Expensive
- Painful (requires GA)
- Risk of catheter retention (low)
- Permanent

Coils

HUNTSVILLE HOSPITAL

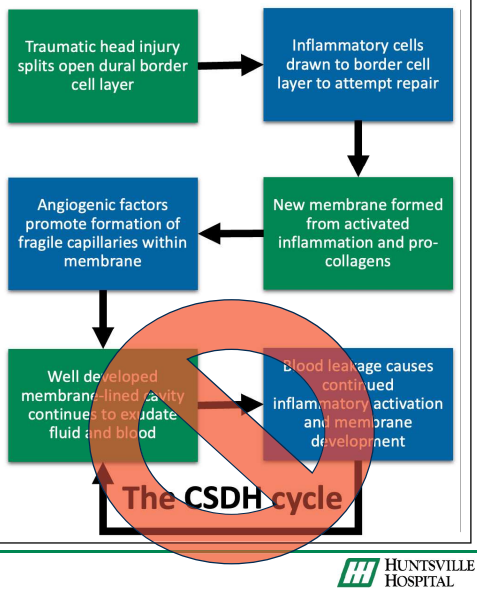
Radiology OF HUNTSVILLE
Middle Meningeal Artery Embolization for Chronic Subdural Hematoma
Background • Principles • Evidence

Why the MMA?

Major blood supply to dura (2/3)

Present and readily accessible in >90% patients

Devascularizing membranes via MMA may favor cSDH reabsorption



HUNTSVILLE HOSPITAL

Is it Safe?

Overall complication rate – 3.79%

Neurologic complications – 1.33%

- Stroke: 0.30%
- MMA rupture: 0.13%
- Vision changes: 0.10%
- Facial nerve injury: 0.07%

Non-neurologic: Access site, AKI, etc.

SNIS 20th annual meeting electronic poster abstracts

E-049 Complications of middle meningeal artery embolization – a systematic review

J Gerstl , M Shafi , S Badikol , N Nawabi , R Mekary , M Sukumaran , A Kappel , A Feroze , T Smith , M Aziz-Sultan

Abstract

Introduction Middle meningeal artery (MMA) embolization is becoming an increasingly established treatment option for chronic subdural hematoma (cSDH). Although several systematic reviews have considered outcomes and/or overall incidence of complications following MMA embolization, no prior review has conducted a comprehensive assessment of overall and specific complications following MMA embolization. The aim of the present systematic review was to establish estimates of incidence for overall and specific complications following MMA embolization.

Methods PubMed, Embase and Cochrane were searched for studies reporting complications following MMA embolization in November 2022. Studies with >5 adult patients undergoing MMA embolization for cSDH were included. Outcomes were categorized according to complication type, including neurological complications, cardiovascular complications, infection, and miscellaneous complications. PRISMA guidelines were followed.

Results A total 389 abstracts were screened of which 128 full texts were reviewed. A final 49 studies containing 3009 patients undergoing MMA embolization were included. No complications or mortalities were reported in 28 studies representing 1352 patients. Across the 49 studies, the incidence of overall complications was 3.79% (114/3009 patients).

Neurological complications were reported in 40 patients (1.33%) including: new onset seizures in 13 patients (0.43%); unspecified stroke in 9 patients (0.30%); aphasia in 4 patients (0.13%); MMA rupture in 4 patients (0.13%); visual changes in 3 patients (0.10%); facial droop in two patients (0.07%); lethargy in one patient (0.03%); imbalance in one patient (0.03%); numbness in one patient (0.03%); headaches in one patient (0.03%); and hemiplegia in one patient (0.03%). Cardiovascular complications were reported in 8 patients (0.27%) including: deep venous thrombosis or pulmonary embolus in two patients (0.07%); fistula in two patients (0.07%); access site hematoma in one patient (0.03%); aortic dissection in one patient (0.03%); femoral artery pseudoaneurysm in one patient (0.03%); and external carotid artery spasm in one patient (0.03%). Infection was reported in 11 patients (0.37%) including: urinary tract infection in three patients (0.10%); pneumonia in three patients (0.10%); and empyema in three patients (0.10%). Other complications reported included: acute kidney injury in three patients (0.10%); catheter herniation in two patients (0.07%); and retained microcatheter in one patient (0.03%). No periprocedural mortalities were reported.

Conclusion The published literature suggests that MMA embolization is a generally well-tolerated procedure, but with a low risk of significant complications, including, but not limited to stroke, seizures, visual obscurations, and facial palsy. Further studies and sub-analyses are needed to fully characterize the incidence of such complications.

Does it Work?

Radiology

Latest Articles | All Issues | Collections | For Authors | Diagnosis Please | Multimedia | Browse by

Home > Radiology > Vol. 286, No. 3

PREVIOUS NEXT

Original Research
Neuroradiology

Middle Meningeal Artery Embolization for Chronic Subdural Hematoma

Seung Pil Ban, Gyojun Hwang, Hyoung Soo Byoun, Tackeun Kim, Si Un Lee, Jae Seung Bang, Jung Ho Han, Chae-Yong Kim, O-Ki Kwon, Chang Wan Oh

Author Affiliations

Published Online: Oct 10 2017 | https://doi.org/10.1148/radiol.2017170053

72 pts underwent MMA embo for cSDH> 10 mm

Historical surgical controls 469 (conventional treatment in 67 and hematoma removal in 402)

27 MMA only, 45 MMA + surgery

No recurrence in the MMA group
1 recurrence in the MMA + surgery group
129 recurrences in historical controls
No complications from MMA embo in this series (excluding 1 recurrence)

ELSEVIER

World Neurosurgery
Volume 118, October 2018, Pages e570-e574

Original Article

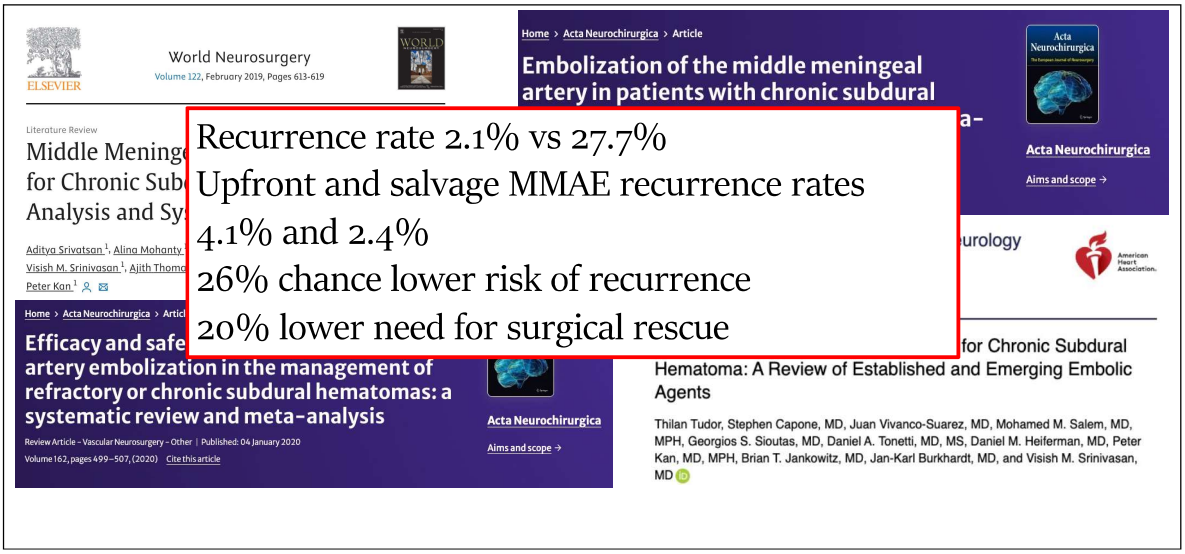
Middle Meningeal Artery Embolization for Recurrent Chronic Subdural Hematoma: A Case Series

Thomas W. Link [1], Justin T. Schwarz [1], Stephanie M. Paine [1], Hooman Kam, Jared Knopman [1]

NEUROSURGICAL FOCUS
Neurosurg Focus 49 (4):E5, 2020

Middle meningeal artery embolization treatment of nonacute subdural hematomas in the elderly: a multiinstitutional experience of 151 cases

Evan Joyce, MD, MS,[1] Michael T. Bounajem, MD,[1] Jonathan Scoville, MD,[1] Ajith J. Thomas, MD,[2] Christopher S. Ogilvy, MD,[2] Howard A. Riina, MD,[3] Omar Tanweer, MD,[3] Elad I. Levy, MD, MBA,[4] Alejandro M. Spiotta, MD,[5] Bradley A. Gross, MD,[6] Brian T. Jankowitz, MD,[7] C. Michael Cawley, MD,[8] Alexander A. Khalessi, MD,[9] Aditya S. Pandey, MD,[10] Andrew J. Ringer, MD,[11] Ricardo Hanel, MD, PhD,[12] Rafael A. Ortiz, MD,[13] David Langer, MD,[13] Michael R. Levitt, MD,[14] Mandy Binning, MD,[15] Philipp Taussky, MD,[1] Peter Kan, MD,[16] and Ramesh Grandhi, MD[1]



Recurrence rate 2.1% vs 27.7%
Upfront and salvage MMAE recurrence rates 4.1% and 2.4%
26% chance lower risk of recurrence
20% lower need for surgical rescue

Radiology OF HUNTSVILLE
Middle Meningeal Artery Embolization for Chronic Subdural Hematoma
Background • Principles • Evidence

Newest Evidence

3 studies, all presented at ISC Feb 2024

EMBOLISE

MAGIC-MT

STEM

International Stroke Conference 2024

HUNTSVILLE HOSPITAL

Radiology OF HUNTSVILLE
Middle Meningeal Artery Embolization for Chronic Subdural Hematoma
Background • Principles • Evidence

EMBOLISE

- IDE study of Onyx (Medtronic) for MMAE in pts w/ symptomatic subacute or chronic subdural hematoma.
- 39 US centers, targeted enrollment up to 600 pts across 2 arms
  - **Mild cSDH (MLS <5 mm, hematoma thickness <15 mm, minor symptoms such as headache), 1:1 randomization**
    - Observation
    - MMAE
  - **Moderate/severe cSDH (MLS >5 mm, hematoma thickness >15 mm, severe symptoms such as motor deficit), 1:1 randomization**
    - Surgery alone
    - Surgery w/ adjunctive MMAE
- Primary endpoint: Rate of hematoma recurrence/progression requiring surgical drainage within 90 days of treatment
- Secondary endpoints
  - Technical success of MMAE
  - Non-inferiority of MMAE cohort compared to control cohort in each study arm in blinded assessment of functional outcomes (based on mRS, # hospital admissions, and change in appearance of cSDH)

HUNTSVILLE HOSPITAL

EMBOLISE

Results

4.1% of patients in the MMA embolization group and in 11.3% in the surgery-alone group (relative risk 0.36; 95% CI 0.11-0.80) → NNT 13.8

MMAE noninferior to surgery alone for deterioration in neurologic function through 90 days (11.9% MMAE vs 9.8% control).

100% success rate of target vessel embolization

Safety: Low rate of serious adverse events related to MMA embolization within 30 days (2.0%)

No significant differences between the groups in the rate of stroke or neurological death within 90 days.

Conclusion: MMAE should be considered for patients presenting with symptomatic subacute/chronic SDH requiring surgery.

MAGIC-MT

- Investigator-initiated but indus ndomized (1:1) controlled trial (n=722) across 31 centers in Ch
- MMAE (Onyx) in patients with .
  - Surgical (Burr hole)
    - MMAE
    - Burr holes alone
  - Conservative
    - MMAE
    - Observation alone
- Exclusions: Craniotomy, pre-tre
  - MMAE had to be performed befo al group
- Primary endpoint: Symptomati SDH or death w/in 90 days.

MAGIC-MT

Results

7.2% MMAE (adjunct or standalone) vs 12.2% Control (Burr holes or conservative)
OR -4.93 (-9.37 to 0.63), p=0.02
NNT 20.3

Significantly fewer serious adverse events within 90 days in the interventional group
6.7% MMAE vs 11.6% control

STEM

- IDE study of Squid (Balt) for MMAE in pts w/ symptomatic subacute or chronic subdural hematoma.
- Industry-supported multi-center prospective randomized clinical trial across 33 centers in the USA, France, and Spain
- 310 patients w/ symptomatic cSDH randomized 1:1 to either standard management (burr hole drainage) or observation, without or without MMAE
- Exclusions: Craniotomy, pre-treatment mRS≥2
- Primary endpoint: cSDH recurrence or progression requiring surgical treatment at 180 days, with other secondary endpoints also at 180 days

Middle Meningeal Artery Embolization for Chronic Subdural Hematoma
Background • Principles • Evidence

STEM

Results

MMAE 15.2% vs standard management alone 39.2%

OR 3.60, 95% CI 1.91 to 6.78, p=0.0001

NNT 4.2

Positive effect of MMAE → standalone MMAE 19.1% vs observation 59.2%

OR 6.10, 95% CI 2.43 to 15.40, p=0.001

MMAE as surgical adjunct 12.3% vs surgery alone 25.4%

OR 2.40, 95% CI 0.97 to 6.03, p=0.058

No difference in safety outcomes between the groups

Huntsville Hospital

Middle Meningeal Artery Embolization for Chronic Subdural Hematoma
Background • Principles • Evidence

Newest Evidence: EMBOLISE, MAGIC-MT, STEM

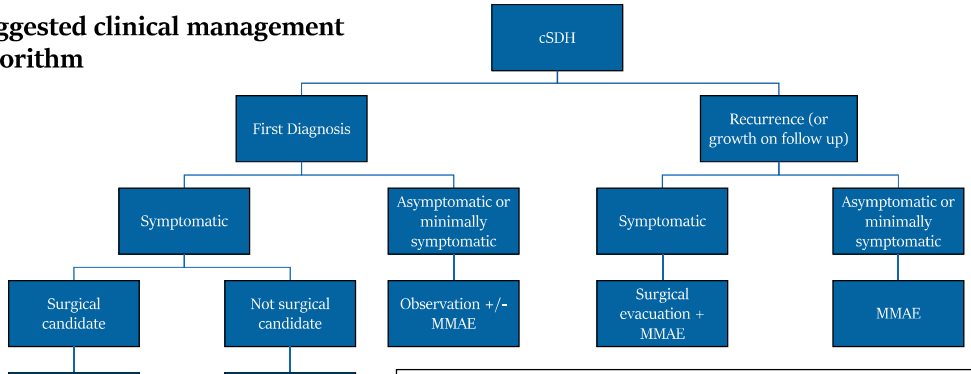
MMAE for cSDH is safe and effective in preventing cSDH recurrence or progression

As a standalone treatment (MAGIC-MT and STEM)

As an adjunctive treatment (EMBOLISE)

Huntsville Hospital

Suggested clinical management algorithm



Additional considerations

- If rapidly worsening clinical symptoms, do not delay surgical evacuation.
- MMAE (bilateral) consideration for all patients at high risk for recurrence.
- Part of the MMAE evaluation should include contrast-enhanced head CT (better visualization of membranes) and MMA measurement (spinosum diameter as surrogate).
- Follow up head CT prior to hospital discharge and at 4 weeks post-embo.

Radiology OF HUNTSVILLE

Middle Meningeal Artery Embolization for Chronic Subdural Hematoma

References

MMAE for cSDH is safe and effective in preventing cSDH recurrence or progression, particularly as an adjunct to surgical treatment, and should be considered routinely in the course of clinical care.

HUNTSVILLE HOSPITAL

Radiology OF HUNTSVILLE

Middle Meningeal Artery Embolization for Chronic Subdural Hematoma

References

1. Liu W, Bakker NA, Groen RJM. Chronic subdural hematoma: a systematic review and meta-analysis of surgical procedures. J Neurosurg. 2014;121:665–673. doi:10.3171/2014.5.JNS132715
2. Xu CS, Lu M, Liu LY, et al. Chronic subdural hematoma management: clarifying the definitions of outcome measures to better understand treatment efficacy: a systematic review and meta-analysis. Ear Rev Med. 2017;21:809–818.
3. Almeswar SA, Farrokhyar T, Hong C, et al. Chronic subdural hematoma management: a systematic review and meta-analysis of 34,829 patients. Ann Surg. 2014;259:448–457. doi:10.1097/SLA.0000000000000355
4. Ivamoto HS, Lemos HP, Atallah AN. Surgical treatments for chronic subdural hematomas: a comprehensive systematic review. World Neurosurg. 2010;86:399–418. doi:10.1016/j.wneu.2015.10.035
5. Xu G, Chen S, Yuan L, Jing Y. Burr-hole irrigation with closed-system drainage for the treatment of chronic subdural hematoma: a meta-analysis. Neurol Med Chir (Tokyo). 2016;56:62–68. doi:10.2176/nmc.ra.2015-0093
6. Jaeah F, Osama M, Idilen AJ, 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. doi:10.1007/s00701-019-04181-3
7. Feghali J, Yang W, Huang J. Updates in chronic subdural hematoma: epidemiology, etiology, pathogenesis, treatment, and outcome. World Neurosurg. 2020;141:339–345. doi:10.1016/j.wneu.2020.06.140
8. Abboud T, Dirsan I, Gibbert C, et al. Influence of antithrombotic agents on recurrence rate and clinical outcome in patients operated for chronic subdural hematoma. Neurochirurgie (Astur). 2018;64:86–91. doi:10.1016/j.neuchi.2017.09.002
9. Dazzat AF, Grobelny BT, Zacharia BE, et al. The surgical management of chronic subdural hematoma. Neurosurg Rev. 2012;35:155–69; doi:10.1007/s10143-011-0334-z
10. Berger V, Vatter H, Oswald A, et al. Chronic subdural haematoma in elderly patients: a retrospective analysis of 322 patients between the ages of 65–94 years. Acta Neurochir (Wien). 2012;154:1549–1554. doi:10.1007/s00701-012-1431-6
11. Ban P, Maraglias G-I, Srivatsan A, et al. Middle meningeal artery embolization for chronic subdural hematoma: a multicenter experience of 154 consecutive embolizations. Neurosurgery. 2021;88:266–277. doi:10.1093/neuros/nyaa379
12. Ernestus RI, Bölcskei P, Lanfermann H, Klug N. Chronic subdural hematomas: surgical treatment and outcome in 104 patients. Surg Neurol. 1997;48:220–225. doi: 10.1016/s0090-3019(97)80031-6
13. Mori K, Maeda M. Surgical treatment of chronic subdural hematoma in 500 consecutive cases: clinical characteristics, surgical outcome, complications, and recurrence rate. Neurol Med Chir (Tokyo). 2001;41:371–381. doi:10.2176/nmc.41.371
14. Yadav YR, Parihar V, Namdev H, Bajaj J. Chronic subdural hematoma. Asian J Neurosurg. 2016;11:258–543. doi:10.4103/1793-5482.145012
15. Matsumoto H, Hanayama H, Okada T, et al. Clinical investigation of chronic subdural hematoma with impending brain herniation on arrival. Neurosurg Rev. 2018;41:447–455. doi:10.1007/s10143-017-0865-9
16. Ban SP, Hwang G, Byun HS, et al. Middle meningeal artery embolization for chronic subdural hematoma. Radiology. 2018;286:992–999. doi:10.1148/radiol.2017171053
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;122:617–629. doi:10.1016/j.wneu.2018.11.167
18. Berghaeuser Pont LME, Dieleman CMF, Dippel DWJ, et al. The role of corticosteroids in the management of chronic subdural hematoma: a systematic review. Eur J Neurol. 2012;19:1397–1403. doi: 10.1111/j.1468-1331.2012.03768.x
19. Sun TF, Boet R, Poon WS. Non-surgical primary treatment of chronic subdural haematoma: preliminary results of using dexamethasone. Br J Neurosurg. 2005;19:327–333. doi:10.1080/02688690500305332
20. Qiu S, Zhao W, Sun C, et al. Effects of atorvastatin on chronic subdural hematoma: a systematic review. Medicine. 2017;96:e7290. doi:10.1097/MD.0000000000007290
21. Poulsen FR, Munthe S, Søe M, Halle B. Perindopril and rosuvastatin in patients with chronic subdural hematoma (PERSEUS trial): protocol for a randomized, double-blinded, placebo-controlled, multicenter trial. Trials. 2014;15:464. doi:10.1186/1745-6215-15-464
22. Thotakura AK, Marabathina NR. Nonsurgical treatment of chronic subdural hematoma with steroids. World Neurosurg. 2015;84:1968–1972. doi:10.1016/j.wneu.2015.08.014
23. Link TW, Boddu S, Paine SM, et al. Middle meningeal artery embolization for chronic subdural hematoma: a series of 60 cases. Neurosurgery. 2019;85:810–817. doi:10.1093/neuros/nyy521
24. Gernbacher J, Kolcan JPG, Jagid J. To drain or not drain: recurrences in chronic subdural hematomas. World Neurosurg. 2016;95:474–480. doi:10.1016/j.wneu.2016.08.069
25. Haridoyo M, Kethuramathan B, Debrahasi B, et al. Embolization of the middle meningeal artery in patients with chronic subdural hematomas: systematic review and meta-analysis. Acta Neurochir (Wien). 2020;162:1777–1784. doi:10.1007/s00701-020-04368-1
26. Chon KH, Lee JM, Koh EJ, Choi HY. Independent predictors for recurrence of chronic subdural hematoma. Acta Neurochir (Wien). 2012;154:1541–1548. doi:10.1007/s00701-012-1396-9
27. Amirjamshidi A, Abouzari M, Rahchiar R, et al. Outcomes and recurrence rates in chronic subdural haematoma. Br J Neurosurg. 2007;21:272–276. doi:10.1080/02688690701272232
28. Paramasivam S, Sudin R. Middle meningeal artery embolization in the management of chronic subdural hematoma: a case report and review of literature. J Cerebrovasc Sci. 2019;1:45. doi:10.4103/jcvs.jcvs_7_20
29. Miranda LB, Braxton E, Hobbs J, Quigley MR. Chronic subdural hematoma in the elderly: not a benign disease. J Neurosurg. 2011;114:75–76. doi:10.3171/2010.8.JNS10398
30. Weigel R, Schmiedek P, Krauss JK. Outcome of contemporary surgery for chronic subdural haematoma: evidence based review. J Neurol Neurosurg Psychiatry. 2003;74:937–943. doi:10.1136/jnnp.74.7.937
31. Kim E. Embolization therapy for refractory hemorrhage in patients with chronic subdural hematomas. World Neurosurg. 2017;107:530–537. doi:10.1016/j.wneu.2017.07.070
32. Abi-Ghanem S, Yehuda M, Carmel NN, et al. Impact of preoperative embolization on the outcomes of carotid body tumor surgery: a meta-analysis and review of the literature. Head Neck. 2016;38(suppl 1):E2386–94. doi:10.1002/hed.24381
33. Killeffer JA, Killeffer FA, Schochet SS. The outer membranous of chronic subdural hematoma. Neurosurg Clin N Am. 2000;11:467–472
34. Jafari N, Gessner L, Kashif JM, et al. The pathogenesis of chronic subdural hematomas: a study on the formation of chronic subdural hematomas and analysis of computed tomography findings. World Neurosurg. 2017;107:376–381. doi:10.1016/j.wneu.2017.07.108
35. Tanaka F, Kaimori M. Histological study of vascular structure between the dura mater and the outer membrane in chronic subdural hematoma in an adult [Article in Japanese]. No Shinkei Geka. 1989;17:431–436
36. Hong HJ, Kim YJ, Yi HJ, et al. Role of angiogenic growth factors and inflammatory cytokine on recurrence of chronic subdural hematoma. Surg Neurol. 2009;72:11–16–discussion 16. doi:10.1016/j.surneu.2008.01.023
37. Kitazono M, Yokota H, Satoh H, et al. Measurement of inflammatory cytokines and thrombomodulin in chronic subdural hematoma. Neurol Med Chir (Tokyo). 2012;52:810–815. doi:10.2176/nmc.52.810
38. Weigel R, Hohenstein A, Schilling L. Vascular endothelial growth factor concentration in chronic subdural hematoma fluid is related to computed tomography appearance and exudation rate. J Neurotrauma. 2014;31:670–673. doi:10.1089/neu.2013.3084
39. Shono T, Inamura T, Morioka T, et al. Vascular endothelial growth factor in chronic subdural haematomas. J Clin Neurosci. 2001;8:414–15. doi:10.1054/jocn.2000.0951
40. Maedai S, Sakurai M, Matsumoto Y. Middle meningeal artery embolization for refractory chronic subdural hematoma. Case report. J Neurosurg. 2000;93:688–688. doi:10.3171/jns.2000.93.4.0688
41. 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. doi:10.4103/2152-7806.116659
42. Mino M, Nishimura S, Hori E, et al. Efficacy of middle meningeal artery embolization in the treatment of refractory chronic subdural hematoma. Surg Neurol Int. 2020;11:78. doi:10.4103/2152-7806.278611
43. Ishihara H, Ishihara S, Kobyama S, et al. Experience in endovascular treatment of recurrent chronic subdural hematoma. Interv Neuroradiol. 2007;13 suppl 1:141–144. doi:10.1177/15910199070130S121
44. Tempake 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;21:366–371. doi:10.1177/1591019915583224
45. Hirai S, Ono J, Okaki M, et al. Embolization of the middle meningeal artery for refractory chronic subdural hematoma. Usefulness for patients under anticoagulant therapy. Interv Neuroradiol. 2004;10 suppl 2:109–114. doi:10.1177/15910594040100S118
46. Link TW, Boddu S, Marcus J, et al. Middle meningeal artery embolization as treatment for chronic subdural hematoma: a case series. Oper Neurosurg (Hagerstown). 2018;15:556–562. doi:10.1093/ons/opy054
47. Motoyama H, Hanayama H, Okuda T, et al. Which surgical procedure is effective for refractory chronic subdural hematoma? Analysis of our surgical procedures and literature review. J Clin Neurosci. 2018;49:40–47. doi:10.1016/j.jocn.2017.11.009
48. 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. doi:10.1016/j.wneu.2018.06.241
49. 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. Published online December 29, 2020. doi: 10.1177/1591019920982816
50. Waqas M, Vakharia K, Vivanco JV, et al. Safety and effectiveness of embolization for chronic subdural hematoma: systematic review and case series. World Neurosurg. 2019;126:e828–e836. doi:10.1016/j.wneu.2019.02.208
51. Shotar E, Meyblum L, Premat K, et al. Middle meningeal artery embolization reduces the post-operative recurrence rate of acute-to-chronic subdural hematoma. J Neurointerv Surg. 2020;12:1209–1213. doi:10.1136/neurintsurg-2020-016048
52. Carnevale J, Schwarz J, Goldberg J, Link TW. Perioperative prophylactic middle meningeal artery embolization for chronic subdural hematoma: a series of 44 cases. Neurosurgery. 2020;67(suppl 1):nyaa447_318. doi: 10.1093/neuros/nyaa447_318
53. Catapano JS, Nguyen CL, Wakim AA, et al. Middle meningeal artery embolization for chronic subdural hematoma. Front Neurol. 2020;11:557233. doi:10.3389/fneur.2020.557233
54. Rinaldo L, Cloft H, Brinjikji W. I-13 Middle meningeal artery embolization for treatment of chronic subdural hematoma: a prospective institutional case series. J Neurointerv Surg. 2021;13:A90. doi:10.1136/neurintsurg-2020-SNIS.145
55. Joyce E, Bosnjak NT, Scoville J, et al. Middle meningeal artery embolization treatment of noncute subdural hematoma in the elderly: a multiinstitutional experience of 141 cases. Neurosurg Focus. 2020;48:E5. doi:10.3171/2020.1.FOCUS205218
56. Bond B, Bond A, Kottah J. Middle meningeal artery embolization for the treatment of chronic subdural hematoma: a systematic literature review (2253). Neurology. 2020;94:15 suppl:2252.
57. Scoville J, Joyce E, Yassoky P, Grandhi R. Primary middle meningeal artery embolization for non-acute subdural hematoma: a multi-institutional retrospective review of particle versus liquid embolic agents. Neurosurgery. 2020;67(suppl 1):nyaa447_309. doi: 10.1093/neuros/nyaa447_309
58. Rajah GS, Waqas M, Dossani RH, et al. Transradial middle meningeal artery embolization for chronic subdural hematoma using Onyx: case series. J Neurointerv Surg. 2021;13:114–118. doi:10.1136/neurintsurg-2020-016185
59. Rudger CA, Shaikh HA, Jankowitz BT. Treatment of chronic subdural hematomas utilizing middle meningeal artery embolization. J Radiol Nurs. 2020;39:298–301. doi:10.1016/j.jradnu.2020.06.005

HUNTSVILLE HOSPITAL