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Middle meningeal artery embolization with surgical evacuation improves outcomes in chronic subdural hematoma: a multi-institutional and multinational database study

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ABSTRACT:

Background Middle meningeal artery embolization (MMAE) is emerging as a promising adjunctive treatment in patients with chronic subdural hematomas (cSDH). This study presents real world multicenter data comparing outcomes in cSDH patients undergoing surgical treatment alone or combined with MMAE.

Methods This multi-institutional, multinational, retrospective, propensity-matched study utilized the TriNetX platform to compare outcomes in patients undergoing surgical evacuation and MMAE versus surgery alone for cSDH. The outcomes included inpatient readmission, need for repeat surgery, and mortality at 6 months following treatment.

Results Among 253 108 patients with cSDH, 14 568 underwent surgical evacuation and 711 underwent surgical evacuation with MMAE. Patients who underwent surgical evacuation alone had higher odds of unplanned readmission, need for repeat surgery, and mortality at 6 months, both before and after propensity score matched analysis.

Conclusion Patients undergoing MMAE with surgical evacuation for cSDH had reduced mortality along with reduced rates of readmission and reoperation, suggesting MMAE as a valuable adjunct in managing cSDH.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Previous studies and ongoing clinical trials have demonstrated the potential benefits of middle meningeal artery embolization (MMAE) in managing chronic subdural hematomas (cSDH). While MMAE has been shown to reduce recurrence and improve outcomes when combined with surgery, it is not yet a universally adopted adjunctive treatment in clinical practice.

WHAT THIS STUDY ADDS

⇒ This study provides robust, real-world, multi-institutional, and multinational data comparing outcomes of patients with cSDH undergoing surgery alone to those receiving surgery combined with MMAE. The findings show that MMAE improves clinical outcomes by reducing unplanned readmission rates, the need for repeat surgeries, and mortality at 6 months post-treatment.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ This research supports the integration of MMAE as an adjunct to surgical evacuation for cSDH, potentially leading to changes in clinical guidelines and practice. As further studies validate these findings, adoption of the procedure is likely to increase. Since MMAE is not a time-sensitive emergency procedure (like mechanical thrombectomy), this adoption could occur rapidly. Therefore, it is important for institutions to prepare for the potential addition of this procedure to the neurovascular workload.

INTRODUCTION

A chronic subdural hematoma (cSDH) is one of the most common causes of neurosurgical admissions in patients aged over 65 years[1] and is a sentinel health event often leading to a cascade of disability and repeat admissions.[2] Recent randomized clinical trials have shown a favorable treatment effect of middle meningeal artery embolization (MMAE) over standard of care.[3–5] The typical surgical management options include craniotomy with burr hole drainage or craniectomy, and more recently less invasive percutaneous drain systems.[2 6]

The nationwide 30-day readmission rate following craniotomy is 21.7% (10 643 out of 49 013 patients).[7] Similarly, the nationwide 30-day readmission rate following burr hole craniotomy is 24.5% (675 out of 2753 patients).[8] Retreatment rates for both craniotomy and burr hole craniotomy are relatively low, with patients in the burr hole cohort showing a slightly higher rate of retreatment compared with the craniotomy cohort (8.4% vs 6.6%, P<0.001). The majority (>95%) of retreatments occurred within 90 days of the initial treatment.[9] There is considerable variability in success rates reported for subdural evacuation port system (SEPS) placement. Mooney *et al*[10] reported a recurrence rate of 25% (22/86), a need for repeat surgery in 36% (31/86), and a mortality rate of 4% (3/86). Other studies have reported better outcomes. For example, Flint *et al*[11] compared bedside SEPS

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to burr hole drainage for cSDH and found a higher 6-month reoperation rate with SEPS (15.6%) compared with burr hole drainage (9.1%). In contrast, Safain *et al*[12] found no difference in reoperation or recurrence rates between the procedures.

In the light of emerging evidence supporting MMAE as an adjunctive procedure, this study presents a multi-institutional, multinational, retrospective, propensity score matched analysis using the TriNextX database, comparing outcomes in patients undergoing surgical treatment with MMAE to those receiving surgery alone for cSDH. The primary outcome measures were unplanned inpatient readmission rates, the need for repeat surgical evacuation, and mortality within 6 months following treatment. We hypothesize that patients receiving adjunctive MMAE will have lower odds of readmission, repeat surgery, and mortality compared with those treated with surgery alone.

METHODS

Our study was conducted using the TriNetX platform (Cambridge, MA) (https://trinetx.com/). This manuscript adheres to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines.

Study population and inclusion criteria

We identified patients with subdural hematoma aged over 18 years from the TriNetX server, covering the period from January 1, 2018, to December 09, 2024, using the following International Classification of Diseases 10th revision (ICD-10) codes: I62.02 (non-traumatic subacute subdural hemorrhage), I62.00 (non-traumatic subdural hemorrhage, unspecified), and I62.03 (non-traumatic chronic subdural hemorrhage) (table 1).

Patients who underwent MMAE were identified using ICD-10-PCS (Procedure Coding System) code: 03LG3DZ (occlusion of intracranial artery with intraluminal device, percutaneous approach). Patients who underwent surgical evacuation were identified using ICD-10-PCS codes: 00C43ZZ (extirpation of matter from intracranial subdural space, percutaneous approach), 009400Z (drainage of intracranial subdural space with drainage device, open approach), 009430Z (drainage of intracranial subdural space with drainage device, percutaneous approach), 00C40ZZ (extirpation of matter from intracranial subdural space, open approach), 00C44ZZ (extirpation of matter from intracranial subdural space, percutaneous endoscopic approach), 00940ZZ (drainage of intracranial subdural space, open approach), 00944ZZ (drainage of intracranial subdural space, percutaneous endoscopic approach), 009440Z (drainage of intracranial subdural space with drainage device, percutaneous endoscopic approach), and 00943ZZ (drainage of intracranial subdural space, percutaneous approach). We used a similar approach to Rai *et al*.[13]

After defining the patients with subdural hematoma, and those who underwent surgery and MMAE, we created two mutually exclusive subgroups (table 1). The first group consisted of patients who were treated with surgery alone, and the other group consisted of patients who were treated with surgery and MMAE within 30 days of diagnosis.

Table 1 Definition of ICD-10 and ICD-10-PCS codes used to derive study population and outcome analysis

ICD-10 and ICD-10-PCS codes	Definition
Chronic subdural hematoma	
ICD10: I62.02	Non-traumatic subacute subdural hemorrhage
ICD10: I62.00	Non-traumatic subdural hemorrhage, unspecified
ICD10: I62.03	Non-traumatic chronic subdural hemorrhage
Surgical evacuation	
ICD10PCS: 00C43ZZ	Extirpation of matter from intracranial subdural space, percutaneous approach
ICD10PCS: 009400Z	Drainage of intracranial subdural space with drainage device, open approach
ICD10PCS: 00C44ZZ	Extirpation of matter from intracranial subdural space, percutaneous endoscopic approach
ICD10PCS: 00943ZZ	Drainage of intracranial subdural space, percutaneous approach
ICD10PCS: 00944ZZ	Drainage of intracranial subdural space, percutaneous endoscopic approach
ICD10PCS: 009440Z	Drainage of intracranial subdural space with drainage device, percutaneous endoscopic approach
ICD10PCS: 00940ZZ	Drainage of intracranial subdural space, open approach
ICD10PCS: 00C40ZZ	Extirpation of matter from intracranial subdural space, open approach
ICD10PCS:009430Z	Drainage of intracranial subdural space with drainage device, percutaneous approach
Middle meningeal artery embolization	
ICD10PCS: 03LG3DZ	Occlusion of intracranial artery with intraluminal device, percutaneous approach

ICD-10, International Classification of Diseases 10th revision; ICD-10-PCS, ICD-10 Procedure Coding System.

Data source

TriNetX is a federated research network comprising over 120 healthcare organizations in the USA, providing real-time access to de-identified healthcare records. It encompasses more than 275 million patients, with data directly retrieved from the electronic health record (EHR) management systems of participating organizations. These organizations include large academic centers that operate both tertiary care and satellite outpatient offices. The model integrates new patients, observations, and results daily, all harmonized to standard terminologies like ICD-10 and LOINC, requiring no data wrangling at the point of care. Clinical variables are extracted directly through a built-in natural language processing system from clinical documents. Robust quality assurance is implemented at the time of extraction from EHRs before data inclusion in the database. The interface only provides aggregate counts and statistical summaries to protect personal health information, ensuring that data remain de-identified at all levels of retrieval and dissemination.

TriNetX has received a waiver from the Western Institutional Review Board as it solely provides de-identified information. At our institution, the West Virginia Clinical and Translational Science Institute (WVCTSI) manages the TriNetX platform and facilitates access for end-users. TriNetX serves as a global federated health research network that offers access to electronic medical records—including diagnoses, procedures, medications, laboratory values, and genomic information—across large healthcare organizations (HCOs). This report utilized data from a network of 90 HCOs grouped under 'Research'.

Study outcomes

The outcomes of the study included need for inpatient admission, need for repeat surgery, and mortality within 6 months following treatment.

Statistical analysis

All analyses were conducted using the TriNetX platform. Univariate analyses were performed using the χ^2 test and Student's t-test.

Propensity score matching was conducted in a 1:1 ratio, using age, sex, race, diabetes, hypertension, ischemic heart disease, smoking, alcohol, type of subdural hematoma, chronic or subacute, and prior use of antiplatelet or anticoagulation agents as covariates.

The 1:1 matching was executed based on propensity scores generated using greedy nearest neighbor algorithms with a caliper width of 0.1 pooled standard deviations. Balance on covariates was assessed using standardized mean differences, with absolute values >0.1 considered indicative of residual imbalance. A two-sided $\alpha<0.05$ was defined a priori for statistical significance. Odds ratios (OR) with 95% confidence intervals (95% CI) were calculated for all analyses. The TriNetX platform utilizes input matrices of user-identified covariates to conduct logistic regression analysis, generating propensity scores for individual subjects. Additionally, TriNetX randomizes the order of rows to eliminate bias associated with nearest neighbor algorithms.

RESULTS

Baseline characteristics

A total of 253 108 patients with cSDH were identified. Among these, 14 568 patients underwent surgical evacuation and 711 underwent surgical evacuation with MMAE. The baseline characteristics are summarized in table 2. Most patients in our cohort were male (n=9845, 64.4%).

Table 2 Study demographics before and after propensity score matching

	Before matching				After matching			
Characteristics	Surgery cohort (n=14 568)	Surgery+MMAE cohort (n=711)	P value	Std diff	Surgery cohort (n=706)	Surgery+MMAE cohort (n=706)	P value	Std diff
Demographics								
Age (years)	67.7±15.8	70.7±13.0	<0.001	0.21	70.5±13.5	70.7±13.0	0.804	0.013
Male	9341 (64.3%)	504 (70.9%)	<0.001	0.14	495 (70.1%)	500 (70.8%)	0.771	0.016
Female	4381 (30.1%)	185 (26.0%)	0.019	0.09	199 (28.2%)	184 (26.1%)	0.369	0.048
Black or African American	1701 (11.7%)	71 (10.0%)	0.164	0.06	81 (11.5%)	71 (10.1%)	0.391	0.046
White	9219 (63.4%)	430 (60.5%)	0.113	0.06	453 (64.2%)	430 (60.9%)	0.206	0.067
American Indian or Alaska Native	52 (0.4%)	10 (1.4%)	<0.001	0.11	10 (1.4%)	10 (1.4%)	1	<0.001
Asian	998 (6.9%)	75 (10.5%)	<0.001	0.13	58 (8.2%)	72 (10.2%)	0.198	0.069
Native Hawaiian or other Pacific Islander	117 (0.8%)	11 (1.5%)	0.034	0.07	10 (1.4%)	10 (1.4%)	1	<0.001
Unknown race	1843 (12.7%)	97 (13.6%)	0.451	0.03	77 (10.9%)	97 (13.7%)	0.105	0.086
Other race	608 (4.2%)	26 (3.7%)	0.493	0.03	27 (3.8%)	26 (3.7%)	0.889	0.007
Unknown ethnicity	2502 (17.2%)	110 (15.5%)	0.23	0.05	95 (13.5%)	110 (15.6%)	0.257	0.06
Not Hispanic or Latino	10 889 (74.9%)	556 (78.2%)	0.047	0.08	569 (80.6%)	551 (78.0%)	0.237	0.063
Hispanic or Latino	1147 (7.9%)	45 (6.3%)	0.13	0.06	42 (5.9%)	45 (6.4%)	0.74	0.018
Diagnosis								
Prior TIA or stroke	1132 (7.8%)	86 (12.1%)	<0.001	0.14	81 (11.5%)	84 (11.9%)	0.804	0.013
Hypertension	8423 (57.9%)	517 (72.7%)	<0.001	0.31	513 (72.7%)	512 (72.5%)	0.952	0.003
Acute myocardial infarction	938 (6.5%)	55 (7.7%)	0.176	0.05	52 (7.4%)	55 (7.8%)	0.763	0.016
Chronic ischemic heart disease	3394 (23.3%)	216 (30.4%)	<0.001	0.16	209 (29.6%)	214 (30.3%)	0.771	0.015
Diabetes mellitus	3671 (25.3%)	243 (34.2%)	<0.001	0.2	229 (32.4%)	240 (34.0%)	0.534	0.033
Smoking	2656 (18.3%)	197 (27.7%)	<0.001	0.23	187 (26.5%)	193 (27.3%)	0.719	0.019
Alcohol	949 (6.5%)	39 (5.5%)	0.27	0.04	39 (5.5%)	39 (5.5%)	1	<0.001
Obesity	2209 (15.2%)	166 (23.3%)	<0.001	0.21	168 (23.8%)	164 (23.2%)	0.802	0.013
Chronic kidney disease	2224 (15.3%)	148 (20.8%)	<0.001	0.14	146 (20.7%)	147 (20.8%)	0.948	0.003
Atrial fibrillation and flutter	2654 (18.3%)	167 (23.5%)	<0.001	0.13	154 (21.8%)	166 (23.5%)	0.446	0.041
Asthma	951 (6.5%)	57 (8.0%)	0.122	0.06	47 (6.7%)	55 (7.8%)	0.411	0.044
Medication								
Antiplatelets	4470 (30.7%)	260 (36.6%)	0.001	0.12	251 (35.6%)	260 (36.8%)	0.618	0.027
Anticoagulants	5989 (41.2%)	453 (63.7%)	<0.001	0.46	444 (62.9%)	448 (63.5%)	0.825	0.012
Follow-up data								
Mean follow-up (days)	132.98±67.86	128.27±64.26			138.27±65.37	128.38±64.28		
Median follow-up (days)	180 (114)	180 (115)			180 (97)	180 (115)		

MMAE, middle meningeal artery embolization; Std diff, standardized difference; TIA, transient ischemic attack.

Unplanned inpatient readmission rates

Patients treated with surgery alone had higher odds of unplanned inpatient readmissions compared with those treated with surgery and MMAE (OR 1.22, 95% CI 1.05 to 1.43, P=0.01, 52.1% vs 47.1%).

Similarly, following propensity score-matched analysis, patients treated with surgery alone (376 of 706 (53.3%) vs 329 of 706 (46.6%)) had higher odds of unplanned inpatient readmissions compared with those treated with surgery and MMAE (OR 1.31, 95% CI 1.06 to 1.61, P=0.01).

Repeat surgical evacuation

Patients treated with surgery alone had higher odds of needing repeat surgical procedures within 6 months compared with those who received surgery and MMAE (OR 1.44, 95% CI 1.08 to 1.92, P=0.01, 10.5% vs 7.5%).

In the propensity score-matched analysis, similar outcomes were observed. Patients treated with surgery alone (81 of 706 (11.5%) vs 56 of 706 (7.9%)) had higher odds of needing repeat surgical procedures within 6 months compared with those who received surgery and MMAE (OR 1.50, 95% CI 1.05 to 2.15, P<0.05).

Mortality

Patients treated with surgery alone had higher odds of 60-day mortality compared with those who received surgery and MMAE (OR 2.09, 95% CI 1.60 to 2.74, P<0.001, 16.4% vs 8.6%).

In the propensity score-matched analysis, similar outcomes were observed where patients treated with surgery alone (108 of 706 (15.3%) vs 60 of 706 (8.5%)) had higher odds of 60-day mortality compared with those who received surgery and MMAE (OR 1.94, 95% CI 1.39 to 2.72, P<0.001).

DISCUSSION

This multicenter, multinational study demonstrates that patients undergoing surgical evacuation alone for the management of cSDH have significantly higher odds of unplanned inpatient readmission, needing repeat surgery, and reduced mortality at 6 months compared with those who undergo surgical evacuation with MMAE.

Currently, more than 15 randomized controlled trials are underway in North America and Europe, investigating MMAE as either a standalone therapy or an adjunct to surgery or medical treatment, and three have demonstrated a clear treatment benefit of adjunctive MMAE over standard of care.[3–5] It is important to note that most trials are conducted in tertiary care settings, which may not reflect the capabilities of smaller hospitals that lack the same level of expertise, state-of-the-art angiographic suites, and embolization materials. Our study, by capturing data across various institutions, interventionalists, and countries, provides real-world outcomes.

The scope of MMAE could be significant as the estimated eligible population exceeds that of large vessel strokes.[13] The positive clinical trials will certainly lead to increased adoption of this procedure, and since MMAE is not a time sensitive emergent procedure (like mechanical thrombectomy), this adoption could be rapid. Thus, it is important for institutions to prepare for the potential addition of this procedure to the neurovascular workload.

This study's findings corroborate existing knowledge based on small cohort retrospective studies, indicating that patients receiving MMAE with surgical evacuation have better outcomes than those treated with surgery alone, reducing unplanned readmission rates, the need for repeat surgeries, and mortality at 6 months post-treatment.

This study has several limitations. The inherent challenges of database research include variability in data definitions and coding, limited clinical information, and a lack of imaging data to assess subdural hematoma thickness, density, and intrinsic membranes. Furthermore, clinical outcome data, such as functional outcomes, were not available. Nonetheless, the inclusion of data from 120 healthcare organizations globally, encompassing 711 patients who underwent surgical evacuation with MMAE, enhances the generalizability of our findings and presents the largest sample to date.

In conclusion, patients receiving MMAE with surgical evacuation exhibit significantly lower odds of unplanned readmission, requiring repeat surgery, and reduced mortality compared with those treated with surgery alone.

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Contributors Methodology: DAL, AB, SB, SB, ATR. Formal analysis: DAL. Investigation: DAL, ABB, SB, SB, ATR. Resources: DAL, ATR. Writing—original draft: DAL. Writing—review and editing: DAL, ABB, SB, SB, ATR. Guarantor: DAL. All authors have read and agreed to the published version of the manuscript.

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Competing interests None declared.

Patient consent for publication Not applicable.

Ethics approval This study utilized data from the TriNetX network, a HIPAA-compliant federated healthcare database. As the analysis involved only de-identified patient data, no ethics committee approval was required

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