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Reduced recurrence of chronic subdural hematomas treated with open surgery followed by middle meningeal artery embolization compared to open surgery alone: a propensity score–matched analysis

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OBJECTIVE Middle meningeal artery embolization (MMAE) is an emerging endovascular treatment technique with proven promising results for chronic subdural hematomas (cSDHs). MMAE as an adjunct to open surgery is being utilized with the goal of preventing the recurrence of cSDH. However, the efficacy of MMAE following surgical evacuation of cSDH has not been clearly demonstrated. The authors sought to compare the outcomes of open surgery followed by MMAE versus open surgery alone.

METHODS Patients who underwent surgical evacuation alone (open surgery–alone group) or MMAE along with open surgery for cSDH (adjunctive MMAE group) were identified at the authors' institution. Two balanced groups were obtained through propensity score matching. Primary outcomes included recurrence risk and reintervention rate. Secondary outcomes included decrease in hematoma size and modified Rankin Scale (mRS) score at last follow-up. Variables in the two groups were compared by use of the Mann-Whitney U-test, paired-sample t-test, and Fisher's exact test.

RESULTS A total of 345 cases of open surgery alone and 52 cases of open surgery with adjunctive MMAE were identified. After control for subjective confounders, 146 patients treated with open surgery alone and 41 with adjunctive MMAE following open surgery with drain placement were included in the analysis. Before matching, the rebleeding risk and reintervention rate for open surgery trended higher in the open surgery alone than the open surgery plus MMAE group (14.4% vs 7.3%, $p = 0.18$; and 11.6% vs 4.9%, $p = 0.17$, respectively). No significant differences were seen in duration of radiographic or clinical follow-ups or decreases in hematoma size and mRS score at last follow-up. After one-to-one nearest neighbor propensity score matching, 26 pairs of cases were compared for outcomes. Rates of recurrence (7.7% vs 30.8%, $p = 0.038$) and overall reintervention (3.8% vs 23.1%, $p = 0.049$) after open surgery were found to be significantly lower in the adjunctive MMAE group than the open surgery–alone group. With one-to-many propensity score matching, 76 versus 37 cases were compared for open surgery alone versus adjunctive MMAE following open surgery. Similarly, the adjunctive MMAE group had significantly lower rates of recurrence (5.4% vs 19.7%, $p = 0.037$) and overall reintervention (2.7% vs 14.5%, $p = 0.049$).

CONCLUSIONS Adjunctive MMAE following open surgery can lower the recurrence risks and reintervention rates for cSDH.

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KEYWORDS chronic subdural hematoma; open surgery alone; middle meningeal artery embolization following open surgery; outcome; recurrence; endovascular neurosurgery; vascular disorders

Chronic subdural hematoma (cSDH) is one of the most common neurosurgical conditions encountered in routine practice. As life expectancy increases and the population gets older, the incidence of cSDH is expected to rise.[1,2] Surgical interventions such as craniotomy or burr hole drainage are widely considered the gold-standard options. Middle meningeal artery embolization (MMAE) is an emerging endovascular

ABBREVIATIONS cSDH = chronic SDH; GCS = Glasgow Coma Scale; MMAE = middle meningeal artery embolization; mRS = modified Rankin Scale; SDH = subdural hematoma.

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treatment technique with proven promising results for cSDH.[3,4] Because of its established benefits, MMAE is being increasingly applied for treatment of cSDHs. In some centers, MMAE is utilized as an adjunct to open surgery, with the goal of preventing recurrence of cSDH. A few small pilot studies have investigated the efficacy of MMAE following surgical hematoma evacuation.[5–8] However, due to the lack of control and stratification in these studies, a definite benefit has not been established. Moreover, differences in outcomes are often related to differences in baseline characteristics with prognostic significance, such as the size of the cSDH and patient age and comorbidities, all of which may independently affect the outcome profile and confound the results.[3,4,9] Therefore, in patients who underwent treatment for cSDH, we sought to compare outcomes of open surgery followed by adjunctive MMAE to outcomes of conventional treatment with open surgery alone by using propensity score matching analysis, which allows for direct head-to-head outcome comparison while controlling for confounding variables. For this purpose, a cohort of cSDH patients treated with open surgery followed by adjunctive MMAE were compared with a historical cohort of surgically treated cases treated with open surgery alone but that would have been eligible for adjunctive MMAE if this technique had been available at that time.

Methods

Patient Selection and Inclusion Criteria

Patient data were retrospectively reviewed from a prospectively maintained institutional database, and patients treated for cSDH with either open surgery alone or open surgery followed by MMAE were identified. The open surgery–alone group included cases treated with burr holes or craniotomy between 2006 and 2021. The adjunctive MMAE group included patients who underwent MMAE after open surgery during the same admission or patients who had MMAE within 1 month after open surgery. Patients who had salvage MMAE treatment for signs of recurrence/rebleeding after open surgery were excluded. Institutional review board approval was obtained before study commencement. Individual patient consent was waived due to the retrospective review of de-identified data. The technique of MMAE involved microcatheterization of one or more MMA branches and embolization with particles, coils, liquid embolic agents, or a combination of those embolization methods.

Data Collection and Statistical Analysis

Data on patient demographics, cSDH characteristics, and outcomes were collected. Retrieved variables included patient age, sex, history of hypertension, diabetes, use of anticoagulation or antiplatelets, presence of symptoms, baseline scores on presentation for the modified Rankin Scale (mRS) and Glasgow Coma Scale (GCS), history of fall or trauma on presentation, side of SDH, SDH thickness, midline shift, presence of acute or subacute components, placement of drain, radiographic follow-up duration, clinical follow-up duration, rebleeding (recurrence) and need for reintervention, radiographic improvement, clinical improvement, and mRS score at last follow-up. Rebleeding or recurrence of SDH was defined as SDH expansion after intervention or appearance of new acute components that warranted intervention or continuous close clinical and radiographic follow-up. We performed propensity score matching, controlling for age, sex, hypertension, diabetes, mRS score on presentation, SDH thickness, acute or subacute components, and postprocedure anticoagulant and antiplatelet use. First, nearest neighbor one-to-one propensity score matching was applied to obtain balanced samples in the two groups. To increase study power by increasing sample size, we also used one-to-many propensity score matching to have balanced cohorts between the two groups. Baseline demographic and outcome data were then compared between unmatched cohorts as well as matched cohorts. The primary outcomes were SDH recurrence rate and reintervention rate. Secondary outcomes included radiographic improvement of hematoma, mRS score at last follow-up, and clinical improvement at last follow-up. Continuous variables are reported as mean ± standard deviation, and categorical variables as proportions (percentages). The Mann-Whitney U-test and two-tailed paired-sample t-test were used to compare continuous variables, and Pearson's chi-square and Fisher's exact test were used for comparison of categorical variables. Statistical significance was considered at a p value less than 0.05. Statistical analyses were conducted using Stata 16.0 (StataCorp).

Results

Initial Patient Cohorts

A total of 345 open surgery–alone cases and 52 adjunctive MMAE following open surgery cases were identified in the initial cohort. A summary of patient demographic and SDH characteristics between the two groups is presented in Table 1. Outcomes are presented in Table 2. As shown, these two groups had differences in existence of symptoms on presentation, history of hypertension, preprocedure antiplatelet use, and postprocedure antiplatelet use, and the portion of patients with drain placement. No significant differences were seen in other parameters.

Drain placement was performed in 42.3% of the patients in the open surgery–alone group and 80.4% of the patients in the adjunctive MMAE group, an outcome that cannot be simply explained by the differences in other parameters. This variation in drain placement may be related to the subjective selection of patients for drain placement who were judged to be at higher risk for SDH recurrence based on intraoperative findings, which may also increase the likelihood of postoperative MMAE. Thus, to exclude the effect of this potential subjective confounder, the patients who had drains in both groups were selected for further analysis.

Baseline Characteristics and Outcomes of Unmatched Cohorts

In total, 146 patients who underwent open surgery alone with drain placement and 41 patients who underwent open surgery followed by adjunctive MMAE with drain placement were included in the analysis. As summarized in Ta-

TABLE 1. Comparison of patient baseline characteristics between unmatched groups

	Open Op	MMAE After Open Op	p Value
Total no. of pts	345	52	
Female/male ratio	107:238	14:38	0.63
Age, yrs	72.2 ± 12.8	74.2 ± 10.9	0.77
Baseline mRS score			0.29
≤2	270 (78.3%)	37 (71.2%)	
>2	75 (21.8%)	15 (28.8%)	
Presentation			0.003
Symptomatic	341 (98.8%)	47 (90.4%)	
Incidental	4 (1.2%)	5 (9.6%)	
GCS score on presentation			>0.99
>8	336 (97.4%)	51 (98.1%)	
≤8	9 (2.6%)	1 (1.9%)	
Antiplatelet preprocedure	117 (33.9%)	25 (48.1%)	0.047
Anticoagulant preprocedure	71 (20.6%)	12 (23.1%)	0.68
Antiplatelet postprocedure	62 (18%)	18 (34.6%)	0.01
Anticoagulant postprocedure	54 (15.7%)	11 (21.2%)	0.32
Diabetes	73 (21.2%)	14 (26.9%)	0.35
Hypertension	212 (61.5%)	41 (78.9%)	0.02
Falls or trauma history on presentation	214 (62%)	35 (67.3%)	0.46
SDH side			0.97
Rt	167 (48.4%)	25 (48.1%)	
Lt	178 (51.6%)	27 (51.9%)	
Acute or subacute components	267 (77.4%)	39 (75%)	0.70
SDH thickness, mm	18.4 ± 7.2	18.8 ± 6.1	0.77
Midline shift, mm	6.5 ± 4.8	7.1 ± 4.6	0.77
>5	199 (57.7%)	32 (61.5%)	0.60
>10	76 (22%)	13 (25%)	0.63
Drain placement	146 (42.3%)	41 (80.4%)	<0.001
Imaging FU, days	82.1 ± 77.5	100.3 ± 106.3	0.77
Clinical FU, days	83.0 ± 87.7	87.5 ± 67.9	0.28

FU = follow-up; pt = patient.
Values are given as number (%) of patients or mean ± SD unless otherwise indicated.

TABLE 2. Comparison of outcomes between unmatched groups

	Open Op	MMAE After Open Op	p Value*
Total no. of pts	345	52	
Primary outcomes			
Rebleeding/recurrence	57 (16.5%)	3 (5.8%)	0.03
Reintervention	49 (14.2%)	2 (3.8%)	0.02
Reintervention same admission	20 (5.8%)	1 (1.9%)	0.21
Reintervention postdischarge	29 (8.4%)	1 (1.9%)	0.07
Secondary outcomes			
Length of stay, days	7.7 ± 6.0	15.7 ± 14.5	0.001
Radiographic improvement	288 (83.5%)	47 (90.4%)	0.14
Improvement on last clinical FU	310 (89.9%)	43 (82.7%)	0.1
mRS score			>0.99
≤2	294 (85.2%)	45 (86.5%)	
>2	51 (14.8%)	7 (13.5%)	

Values are given as number (%) of patients or mean ± SD unless otherwise indicated.
* One-sided Fisher's exact test.

ble 3, 97.9% of patients in the open surgery–alone group were symptomatic on initial presentation, whereas 90.2% of patients in the adjunctive group were symptomatic on initial presentation (p = 0.04). Patients in the adjunctive MMAE group had a higher prevalence of hypertension (82.9% vs 58.9%, p = 0.005). However, no significant difference was found in age, male versus female sex, baseline mRS score, GCS score on presentation, use of antiplatelets and anticoagulation before and after the procedure, history of diabetes, history of falls or trauma on presentation, side of SDH, acute and subacute components, SDH thickness, presence or absence of midline shift, and midline shift > 5 mm or > 10 mm between the two groups (p > 0.05). Moreover, there were no significant differences between the two groups for imaging and clinical follow-up duration.

Outcomes of unmatched cohorts are summarized in Table 4. Primary outcomes were compared for recurrence of SDH and overall incidence of reintervention. In total, 21 cases (14.4%) from the open surgery–alone group had recurrence of SDH, while 3 cases (7.3%) from the MMAE following open surgery group had recurrence (p = 0.18). The reintervention rate in the open surgery–alone group also trended higher compared with the adjunctive MMAE group (11.6% vs 4.9%, p = 0.17) yet was not statistically significant. When the reintervention rate was broken into salvage intervention during the same hospitalization and reintervention after discharge, no significant difference was found between the two groups (6.9% vs 2.4%, p = 0.26; and 4.8% vs 2.4%, p = 0.44, respectively). Secondary outcomes were compared for radiographic improvement (decrease in SDH thickness) and mRS score at last follow-up. As shown in Table 2, the rate of radiographic improvement at the last follow-up was similar in the open surgery versus adjunctive MMAE groups (88.4% vs 90.2%, p = 0.49). No significant difference between the two groups was found in mRS score at last clinical follow-up (p = 0.58).

Baseline Characteristics and Outcomes of Matched Cohorts

After one-to-one nearest neighbor propensity score matching, 26 pairs of cohorts were obtained for comparison. Baseline patient demographics and SDH characteristics are summarized in Table 5. Outcomes of matched cohorts are shown in Table 6. As illustrated, the recurrence (7.7% vs 30.8%, p = 0.038) and overall reintervention (3.8% vs 23.1%, p = 0.049) rates were found to be significantly

TABLE 3. Comparison of baseline characteristics between unmatched groups with drain placement

	Open Op	MMAE After Open Op	p Value
Total no. of pts	146	41	
Female/male ratio	41:105	11:30	0.87
Age, yrs	74 ± 12.6	75.9 ± 10.7	0.53
Baseline mRS score			0.81
≤2	106 (72.6%)	29 (70.7%)	
>2	40 (27.4%)	12 (29.3%)	
Presentation			0.04
Symptomatic	143 (97.9%)	37 (90.2%)	
Incidental	3 (2.1%)	4 (9.8%)	
GCS score on presentation			>0.99
>8	146 (100%)	41 (100%)	
≤8	0 (0%)	0 (0%)	
Antiplatelet preprocedure	59 (40.4%)	17 (41.5%)	0.90
Anticoagulant preprocedure	24 (16.4%)	11 (26.8%)	0.17
Antiplatelet postprocedure	27 (18.5%)	12 (29.3%)	0.19
Anticoagulant postprocedure	27 (18.5%)	10 (24.4%)	0.39
Diabetes	32 (21.9%)	13 (31.7%)	0.22
Hypertension	86 (58.9%)	34 (82.9%)	0.005
History of falls or trauma on presentation	105 (71.9%)	27 (65.9%)	0.45
SDH side			0.88
Rt	66 (45.2%)	18 (43.9%)	
Lt	80 (54.8%)	23 (56.1%)	
Acute or subacute components	116 (79.4%)	34 (82.9%)	0.83
SDH thickness, mm	18.7 ± 7.2	18.4 ± 6.5	0.80
Midline shift, mm	6.3 ± 4.8	7.0 ± 4.2	0.40
>5	84 (57.5%)	26 (63.4%)	0.59
>10	30 (20.1%)	9 (22%)	0.83
Procedure type			0.42
Craniotomy	92 (63%)	23 (56.1%)	
Burr holes	54 (37%)	18 (43.9%)	
Imaging FU, days	83.7 ± 75.4	101 ± 109.2	0.82
Clinical FU, days	84.1 ± 83.2	83.8 ± 54.9	0.37

Values are given as number (%) of patients or mean ± SD unless otherwise indicated.

TABLE 4. Comparison of outcomes between unmatched groups with drain placement

	Open Op	MMAE After Open Op	p Value*
Total no. of pts	146	41	
Primary outcomes			
Rebleeding/recurrence	21 (14.4%)	3 (7.3%)	0.18
Reintervention	17 (11.6%)	2 (4.9%)	0.17
Reintervention same admission	10 (6.9%)	1 (2.4%)	0.26
Reintervention postdischarge	7 (4.8%)	1 (2.4%)	0.44
Secondary outcomes			
Length of stay, days	7.2 ± 5.1	16.4 ± 14.1	<0.001
Radiographic improvement	129 (88.4%)	37 (90.2%)	0.49
mRS score			0.58
≤2	124 (84.9%)	35 (85.4%)	
>2	22 (15.1%)	6 (14.6%)	

Values are given as number (%) of patients or mean ± SD unless otherwise indicated.
* One-sided Fisher's exact test.

lower in the adjunctive MMAE group compared with the open surgery–alone group. Rates of salvage treatment during the same hospitalization were not significantly different between these two groups (open surgery alone vs adjunctive MMAE following open surgery: 11.5% vs 3.8%, p = 0.305). However, reintervention rates after discharge trended higher in the open surgery–alone group (11.5% vs 0%, p = 0.118). In the comparison of secondary outcomes, radiographic improvement trended higher in the adjunctive MMAE group compared with the open surgery–alone group (92.3% vs 76.9%, p = 0.124). However, no significant difference between the two groups was found in mRS scores at last clinical follow-up (p = 0.363).

With one-to-many propensity score matching, 76 and 37 patients were identified, respectively, for comparison of open surgery alone and adjunctive MMAE following open surgery. Table 7 shows baseline characteristics of the two groups after matching, which yielded 76 patients in the open surgery–alone group and 37 patients in the adjunctive MMAE group. There was a trend toward higher rates of symptomatic presentation in the open surgery–alone group (97.4% vs 89.2%, p = 0.07), but this finding did not reach statistical significance. There was also a nonsignificant trend toward greater antiplatelet usage in the open surgery–alone group (51.3% vs 37.8%, p = 0.18) and greater midline shift in the adjunctive MMAE group (7.4 ± 4.1 vs 6.2 ± 4.9 mm, p = 0.16). The rest of the clinical parameters were well balanced between the two groups.

Table 8 shows the outcomes of the two groups following one-to-many propensity score matching. There was a significantly lower rate of rebleeding or recurrence in the adjunctive MMAE group than the open surgery–alone group (5.4% vs 19.7%, p = 0.037) as well as in patients undergoing reintervention (2.7% vs 14.5%, p = 0.049). Length of stay in the adjunctive MMAE group was significantly longer than that in the open surgery–alone group (16.9 ± 14.6 vs 8.3 ± 5.5 days). There were no significant differences between the two groups in radiographic improvement at last follow-up or mRS score at last follow-up.

Discussion

MMAE is increasingly used to treat cSDH, as both a primary treatment and an adjunct to surgery. The role of adjunctive MMAE after surgery for cSDH has yet to be defined. By using the propensity score to match patients who received adjunctive MMAE after surgery with a cohort of patients who were treated with open surgery alone,

TABLE 5. Comparison of baseline characteristics between one-to-one matched groups

	Open Op	MMAE After Open Op	p Value
Total no. of pts	26	26	
Female/male ratio	6:20	9:17	0.54
Age, yrs	78.6 ± 8.3	74.1 ± 10.9	0.09
Baseline mRS score			0.52
≤2	18 (69.2%)	21 (80.8%)	
>2	8 (30.8%)	5 (19.2%)	
Presentation			0.61
Symptomatic	25 (96.15%)	23 (88.5%)	
Incidental	1 (3.85%)	3 (11.5%)	
GCS score on presentation			>0.99
>8	26 (100%)	26 (100%)	
≤8	0 (0%)	0 (0%)	
Antiplatelet preprocedure	18 (69.2%)	12 (46.2%)	0.16
Anticoagulant preprocedure	5 (19.2%)	9 (34.6%)	0.35
Antiplatelet postprocedure	8 (30.8%)	8 (30.8%)	>0.99
Anticoagulant postprocedure	7 (26.9%)	8 (30.8%)	>0.99
Diabetes	8 (30.8%)	7 (26.9%)	>0.99
Hypertension	19 (73.1%)	19 (73.1%)	>0.99
History of falls or trauma on presentation	15 (57.7%)	15 (57.7%)	>0.99
SDH side			0.78
Rt	13 (50%)	11 (42.3%)	
Lt	13 (50%)	15 (57.7%)	
Acute or subacute components	22 (84.6%)	23 (88.5%)	>0.99
SDH thickness, mm	20.1 ± 8.1	18.9 ± 6.8	0.58
Midline shift, mm	6.6 ± 5.1	7.6 ± 4.0	0.41
>5	15 (57.7%)	18 (69.2%)	0.56
>10	4 (15.4%)	6 (23.1%)	0.73
Procedure type			>0.99
Craniotomy	17 (65.4%)	17 (65.4%)	
Burr holes	9 (34.6%)	9 (34.6%)	
Imaging FU, days	69 ± 69.9	93.8 ± 112.1	0.38
Clinical FU, days	68.7 ± 70.1	68.4 ± 49.0	0.49

Values are given as number (%) of patients or mean ± SD unless otherwise indicated. Two groups were matched for age, sex, baseline mRS score, history of hypertension, diabetes, use of antiplatelets postprocedure, use of anticoagulants postprocedure, presence of acute or subacute components, and SDH thickness.

TABLE 6. Comparison of outcomes between one-to-one matched groups

	Open Op	MMAE After OpenOp	p Value*
Total no. of pts	26	26	
Primary outcomes			
Rebleeding/recurrence	8 (30.8%)	2 (7.7%)	0.038
Reintervention	6 (23.1%)	1 (3.8%)	0.049
Reintervention same admission	3 (11.5%)	1 (3.8%)	0.305
Reintervention postdischarge	3 (11.5%)	0 (0%)	0.118
Secondary outcomes			
Length of stay, days	8.4 ± 5.3	18.7 ± 14.8	0.007
Radiographic improvement	20 (76.9%)	24 (92.3%)	0.124
mRS score			0.363
≤2	20 (76.9%)	22 (84.6%)	
>2	6 (23.1%)	4 (15.4%)	

Values are given as number (%) of patients or mean ± SD unless otherwise indicated. Two groups were matched for age, sex, baseline mRS score, history of hypertension, diabetes, use of antiplatelets postprocedure, use of anticoagulants postprocedure, presence of acute or subacute components, and SDH thickness.
* One-sided Fisher's exact test.

we were able to demonstrate a significantly lower rate of SDH recurrence and reintervention in patients treated with adjunctive MMAE in this single-center series.

In the initial cohort, there were significant differences in the use of drains between the two groups—42.3% of the patients in the open surgery group versus 80.4% of the patients in the adjunctive MMAE group—which could not be simply explained by other measured parameters. There are two possible explanations for this finding. One is that the use of drains increased over time after a randomized controlled study published in 2009 demonstrated the low recurrence and mortality benefit of drain placement.[10] Another explanation is that subjective observations during surgery, such as increased bleeding or membrane formation, predict both drain placement and use of postoperative MMAE. To account for the lack of a specific explanation, we chose to analyze only the group of patients with drain placement to avoid potential subjective confounding, which is often hard to control with objective data. Therefore, the open surgery with drain placement group was matched with the adjunctive MMAE following open surgery with drain placement group by controlling for confounding factors such as age, sex, hypertension, diabetes, mRS on presentation, SDH thickness, acute or subacute components, and postprocedure anticoagulant and antiplatelet use. We conducted propensity score matching twice, once with one-to-one nearest neighbor propensity score matching and a second time with one-to-many nearest neighbor propensity score matching. Notably, the matched groups included similar rates of antiplatelet and anticoagulant administration, as well as an identical proportion of patients with midline shift of at least 5 mm. All the clinical parameters were well balanced between the two groups. The method of one-to-many propensity score matching allowed us to draw conclusions with larger sample sizes and higher statistical power.

Other recent studies have suggested a benefit from MMAE in the management of cSDH. Shotar et al. performed a multivariate regression analysis of a cohort of 89 cSDH patients treated with burr holes plus adjunctive MMAE compared with a historical cohort of 174 patients treated with burr holes alone, with MMAE being performed specifically in cases judged to have a high risk for recurrence.[7] These authors found that embolization was independently associated with a lower risk of reoperation.

TABLE 7. Comparison of baseline characteristics between the one-to-many matched groups

	Open Op	MMAE After Open Op	p Value
Total no. of pts	76	37	
Female/male ratio	18:58	11:26	0.49
Age, yrs	77.5 ± 9.3	75.3 ± 11	0.29
Baseline mRS score			>0.99
≤2	56 (73.7%)	28 (75.7%)	
>2	20 (26.3%)	9 (24.3%)	
Presentation			0.07
Symptomatic	74 (97.4%)	33 (89.2%)	
Incidental	2 (2.6%)	4 (10.8%)	
GCS score on presentation			>0.99
>8	76 (100%)	37 (100%)	
≤8	0 (0%)	0 (0%)	
Antiplatelet preprocedure	39 (51.3%)	14 (37.8%)	0.18
Anticoagulant preprocedure	15 (19.7%)	9 (24.3%)	0.63
Antiplatelet postprocedure	20 (26.3%)	10 (27%)	>0.99
Anticoagulant postprocedure	15 (19.7%)	8 (21.6%)	0.81
Diabetes	24 (31.6%)	11 (29.7%)	0.84
Hypertension	56 (73.7%)	30 (81.1%)	0.48
History of falls or trauma on presentation	48 (63.2%)	23 (62.2%)	>0.99
SDH side			0.78
Rt	35 (46.05%)	16 (43.2%)	
Lt	41 (59.95%)	21 (56.8%)	
Acute or subacute components	63 (82.9%)	30 (81.1%)	0.80
SDH thickness, mm	18.7 ± 7.1	19.2 ± 6.3	0.79
Midline shift, mm	6.2 ± 4.9	7.4 ± 4.1	0.16
>5	44 (57.9%)	24 (64.9%)	0.54
>10	13 (17.1%)	9 (24.3%)	0.45
Procedure type			0.51
Craniotomy	46 (60.5%)	20 (54.1 %)	
Burr holes	30 (39.5%)	17 (45.9%)	
Imaging FU, days	89.5 ± 86.7	108.9 ± 112	0.51
Clinical FU, days	85.4 ± 83.3	83.8 ± 57.3	0.55

Values are given as number (%) of patients or mean ± SD unless otherwise indicated. Two groups were matched for age, sex, baseline mRS score, history of hypertension, diabetes, use of antiplatelets postprocedure, use of anticoagulants postprocedure, presence of acute or subacute components, and SDH thickness.

TABLE 8. Comparison of outcomes between one-to-many matched groups

	Open Op	MMAE After Open Op	p Value*
Total no. of pts	76	37	
Primary outcomes			
Rebleeding/recurrence	15 (19.7%)	2 (5.4%)	0.037
Reintervention	11 (14.5%)	1 (2.7%)	0.049
Reintervention same admission	4 (5.3%)	1 (2.7%)	0.47
Reintervention postdischarge	7 (9.2%)	0 (0%)	0.057
Secondary outcomes			
Length of stay, days	8.3 ± 5.5	16.9 ± 14.6	0.003
Radiographic improvement	65 (85.5%)	33 (89.2%)	0.414
mRS score			0.344
≤2	64 (84.2%)	33 (89.2%)	
>2	12 (15.8%)	4 (10.8%)	

Values are given as number (%) of patients or mean ± SD unless otherwise indicated. Two groups were matched for age, sex, baseline mRS score, history of hypertension, diabetes, use of antiplatelets postprocedure, use of anticoagulants postprocedure, presence of acute or subacute components, and SDH thickness.
* One-sided Fisher's exact test.

Our study had a similar design, but the addition of propensity score matching further strengthens the result by decreasing the risk of bias. In a similar vein, Onyinzo et al. compared 31 cSDH patients who underwent combined treatment with 82 patients who underwent open surgery alone.[6] The results of Onyinzo et al. showed a decreased trend in rescue surgery when MMAE was added to open surgery. However, their study lacks adequate controls for potential confounders.

A recent propensity score–matched comparison of MMAE to both nonoperative management and surgical evacuation by Catapano et al. showed a lower risk of treatment failure and incomplete cSDH resolution for MMAE. The findings of these authors argue against the idea that cSDH cases that resolve after MMAE may have also resolved with observation alone.[3] By contrast, our study focused on the adjunctive use of MMAE after surgery, a group that was not examined in the above study.

One limitation of this study is that the primary outcome of reintervention for cSDH has a subjective component to it as the decision to reoperate is made by the patient's neurosurgeon with full knowledge of whether the patient had already undergone MMAE. For example, a surgeon may choose to observe a patient with a minimally symptomatic recurrent SDH knowing that the patient had undergone MMAE, while the same radiographic appearance and symptoms may prompt surgery in a patient not already treated with MMAE. However, the overall radiographic recurrence rate should not be influenced by this factor. Another limitation is that our study has inherited biases owing to its retrospective design, which warrants future large prospective studies to validate the results. Nevertheless, this is to our knowledge the only study on this topic with large patient cohorts for which controlling was performed for all possible objective confounding factors as well as subjective confounders that would affect the outcome of cSDH management.

Conclusions

In propensity score–matched cohorts of cSDH patients who underwent either open surgery alone or open surgery plus adjunctive MMAE, there was a significantly lower likelihood of cSDH recurrence or need for reintervention in patients who received surgery plus MMAE.

References

1. Yang W, Huang J. Chronic subdural hematoma: epidemiology and natural history. *Neurosurg Clin N Am*. 2017;28(2): 205-210.
2. Balser D, Farooq S, Mehmood T, Reyes M, Samadani U. Actual and projected incidence rates for chronic subdural hematomas in United States Veterans Administration and civilian populations. *J Neurosurg*. 2015;123(5):1209-1215.
3. Catapano JS, Ducruet AF, Nguyen CL, et al. A propensity-adjusted comparison of middle meningeal artery embolization versus conventional therapy for chronic subdural hematomas. *J Neurosurg*. 2021;135(4):1208-1213.
4. Enriquez-Marulanda A, Gomez-Paz S, Salem MM, et al. Middle meningeal artery embolization versus conventional treatment of chronic subdural hematomas. *Neurosurgery*. 2021;89(3):486-495.
5. Kim E. Embolization therapy for refractory hemorrhage in patients with chronic subdural hematomas. *World Neurosurg*. 2017;101:520-527.
6. Onyinzo C, Berlis A, Abel M, Kudernatsch M, Maurer CJ. Efficacy and mid-term outcome of middle meningeal artery embolization with or without burr hole evacuation for chronic subdural hematoma compared with burr hole evacuation alone. *J Neurointerv Surg*. 2022;14(3):297-300.
7. 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(12):1209-1213.
8. 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(7): 695-699.
9. Badhiwala JH, Karmur BS, Wilson JR. Propensity score matching: a powerful tool for analyzing observational nonrandomized data. *Clin Spine Surg*. 2021;34(1):22-24.
10. Santarius T, Kirkpatrick PJ, Ganesan D, et al. Use of drains versus no drains after burr-hole evacuation of chronic subdural haematoma: a randomised controlled trial. *Lancet*. 2009; 374(9695):1067-1073.

Disclosures

Dr. Taussky reports being a consultant for Medtronic, Cernovus, and Avail.

Author Contributions

Conception and design: Ogilvy, Salih. Acquisition of data: all authors. Analysis and interpretation of data: Salih. Drafting the article: Salih, Shutran. Critically revising the article: Ogilvy, Salih, Taussky, Moore. Reviewed submitted version of manuscript: Ogilvy, Salih. Administrative/technical/material support: Ogilvy. Study supervision: Ogilvy.

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