Comparative Efficacy and Safety of Coil Versus Onyx Embolization in Middle Meningeal Artery Embolization as an Adjunct to Burr Hole Drainage for Chronic Subdural Hematoma

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AIM: To investigate the differences in efficacy, safety, and health economic outcomes between coils and the Onyx liquid embolic agent in middle meningeal artery embolization (MMAE) as an adjunct to burr hole drainage for chronic subdural hematoma (cSDH).
METHODS: This single-center retrospective cohort study included patients with cSDH who underwent burr hole drainage combined with MMAE between April 2024 and October 2025. Patients were divided into a coil group and an Onyx group based on the embolic material used. Propensity score matching (PSM) was used to balance baseline characteristics across groups. The primary outcome was hematoma volume absorption at 90 days postoperatively. Secondary outcomes included imaging parameters, clinical outcomes, recurrence and reoperation rates, safety events, and health economic indicators.
RESULTS: A total of 184 patients were enrolled, with 66 patients in each group after PSM. Post-matching analyses demonstrated no statistically significant differences between the two groups in hematoma absorption volume at 90 days postoperatively or in other imaging parameters. Regarding clinical outcomes, the proportions of patients with modified Rankin Scale (mRS) scores of 0–2, as well as the recurrence and reoperation rates, were comparable between the groups. In terms of safety, the overall incidence of serious adverse events (SAEs) was comparable; however, cases of facial nerve palsy occurred in the Onyx group, whereas no such complications were observed in the coil group. Perioperative assessments showed that the coil group had a shorter operative time and lower hospitalization costs (all $p < 0.05$), whereas the length of hospital stay did not differ significantly between the groups.
CONCLUSIONS: In the adjunctive treatment of cSDH with burr hole drainage, coils and Onyx liquid embolic agent demonstrate comparable short-term efficacy and overall safety.

Keywords: chronic subdural hematoma; middle meningeal artery embolization; coils; Onyx; propensity score matching

Introduction

Chronic subdural hematoma (cSDH) predominantly affects the elderly population and is characterized by a chronic encapsulated blood collection within the subdural space. With the progressive aging of the population and the widespread use of antithrombotic therapies, its incidence has increased steadily annually [1]. Clinically, burr hole drainage remains the primary surgical treatment for symptomatic cSDH; however, recurrence rates ranging from 10% to 33% are associated with unfavorable patient outcomes and significantly increase the health economic burden [2,3]. In recent years, middle meningeal artery embolization (MMAE) has emerged as a promising minimally invasive therapeutic approach. Its underlying mechanism involves occluding blood flow to the neovasculature within the hematoma membrane, thereby suppressing inflammatory responses and exudation while promoting hematoma absorption [4]. Randomized controlled trials, including Managing Non-acute Subdural Hematoma Using Liquid Materials: a Chinese Randomized Trial of Middle Meningeal Artery Treatment (MAGIC-MT) and Embolization of the Middle Meningeal Artery with Onyx Liquid Embolic System in the Treatment of Subacute and Chronic Subdural Hematoma (EMBOLISE), have demonstrated the efficacy of MMAE in reducing cSDH recurrence rates. In particular, when used as an adjunct to surgical evacuation, MMAE can significantly improve patient outcomes [5,6].

Currently, embolic materials used in MMAE primarily include particles, liquid embolic agents (e.g., Onyx), and coils. Among these, Onyx is widely used due to its favorable dispersibility and permeability [7,8]. However, liquid embolic agents have several notable limitations. First, there is a risk of reflux, and inadvertent migration of the embolic agent into the petrosal branch supplying the fa-

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cial nerve or into anastomotic branches of the ophthalmic artery may result in severe complications, including facial nerve palsy or visual impairment. Second, the procedure is relatively complex and associated with higher treatment costs. Third, the injection process may induce vasospasm or procedure-related pain [9,10]. In contrast, coil embolization, a classic endovascular technique, achieves vascular occlusion primarily through proximal embolization of the main trunk of the middle meningeal artery (MMA) or its major branches. Existing studies have suggested that standalone coil embolization or coils combined with particles provide hematoma absorption rates and clinical outcomes comparable to those achieved with liquid embolic agents in the treatment of cSDH. Because this technique does not require distal microvascular penetration, it may theoretically avoid the risk of cranial nerve injury associated with dangerous vascular anastomoses [11,12].

Although previous studies have explored the use of different embolic materials, most have focused on comparisons between particles and liquid embolic agents, while study populations have often been highly heterogeneous and have not consistently differentiated between standalone embolization and embolization combined with surgical treatment [7,13]. Specifically, for the treatment strategy involving adjunctive burr hole drainage, direct comparative evidence between coils and liquid embolic agents (Onyx) remains limited. Therefore, the present study aims to systematically compare the clinical efficacy, safety, and health economic outcomes of coils versus Onyx in the adjunctive treatment of cSDH following burr hole drainage using a retrospective cohort design with propensity score matching (PSM). The findings aim to provide evidence-based guidance for optimizing the selection of embolic materials in this clinical setting.

Methods

Study Design and Population

This retrospective cohort study consecutively enrolled patients with cSDH who underwent burr hole drainage combined with MMAE between April 2024 and October 2025. Patient selection strictly followed the following criteria:

Inclusion criteria: (1) Age ≥18 years; (2) Computed tomography (CT)-confirmed symptomatic chronic subdural hematoma with mass effect. Symptomatic was defined as the presence of at least one of the following neurological symptoms: headache, nausea/vomiting, short-term cognitive impairment, language disorders or aphasia, gait instability, decreased muscle strength, sensory disturbances, or seizures. Mass effect was defined as the presence of midline shift or local cortical compression and deformation; (3) Patients were independent in activities of daily living before symptom onset, with a preoperative modified Rankin Scale (mRS) score ≤2; (4) Receipt of combined treatment with burr hole drainage and MMAE.

Exclusion criteria: (1) Requirement for craniotomy or emergency hematoma evacuation due to brain herniation or rapid neurological deterioration; (2) Bilateral hematomas in which the symptomatic side could not be determined; (3) Recurrent subdural hematoma; (4) Asymptomatic subdural hematoma; (5) Life expectancy <1 year or the presence of severe comorbidities; (6) Patients who did not undergo MMAE before burr-hole drainage; (7) Incomplete imaging or clinical follow-up data at 90 days postoperatively.

Surgical Methods

All included patients underwent MMAE before burr-hole drainage. Middle meningeal artery embolization: Vascular access was established through femoral or radial artery puncture using the Seldinger technique. A guiding catheter was positioned within the external carotid artery, and a microcatheter was superselectively navigated into the MMA. Patients were divided into two groups based on the embolic material used during the procedure:

Coil Group: The microcatheter was superselectively advanced into the proximal main trunk or a major branch (frontal or parietal branch) of the MMA. Detachable coils were deployed until angiography confirmed stagnation of distal blood flow. This strategy aimed to reduce distal perfusion pressure by occlusion of the proximal vessel while preventing embolic material from entering potentially hazardous intra- and extracranial anastomotic channels.

Liquid Embolic Agent Group (Onyx Group): The microcatheter tip was positioned within the distal MMA, and Onyx (Medtronic, Irvine, CA, USA) was slowly injected under fluoroscopic guidance until the embolic agent permeated the distal branches and capillary bed, with disappearance of the characteristic "cotton-wool" blush on angiography.

Burr hole drainage: The procedure was performed under general or local anesthesia. A burr hole was created at the site of maximal hematoma thickness, the dura was incised, and the hematoma cavity was irrigated. A closed-system drainage catheter was routinely placed postoperatively. The drainage catheter was removed when the drainage volume was <50 mL/24 h and no new or worsening neurological symptoms were observed, typically within 24–48 hours after surgery. A follow-up head computed tomography (CT) scan was routinely obtained after drain removal.

Data Collection and Outcome Measures

Data for this study were collected through a retrospective review of the electronic medical record system. All data were independently extracted and verified by two researchers.

(1) Baseline characteristics: Sex, age, body mass index, smoking history, alcohol consumption, history of hypertension, diabetes mellitus, and trauma, use of antiplatelet agents, anticoagulants, and statins, preoperative modified Rankin Scale (mRS) score, affected side, neurological

symptoms (headache, nausea/vomiting, cognitive impairment, language disorders, gait instability, decreased muscle strength, sensory disturbances, and seizures), and preoperative imaging parameters (hematoma volume, maximal hematoma thickness, and degree of midline shift) were recorded for both groups.

(2) Procedure-related data: The type of embolic material (coils or Onyx), material dosage (number of coils or volume of Onyx), operative time, length of hospital stay, and total hospitalization costs were recorded.

(3) Imaging efficacy endpoints: The primary outcome was the volume of hematoma absorption at 90 days postoperatively (mL), calculated as the difference between the preoperative hematoma volume and the hematoma volume measured at 90 days postoperatively. Secondary imaging endpoints included the hematoma absorption rate (absorption volume / preoperative volume × 100%), reduction in hematoma thickness (mm), improvement in midline shift (mm), and residual hematoma volume (mL) and maximal thickness (mm) at 90 days postoperatively.

(4) Clinical outcome measures: The distribution of mRS scores at 90 days postoperatively was recorded. Functional status at 90 days was assessed using the mRS, and the proportion of patients with an mRS score of 0–2 was recorded.

(5) Definitions of hematoma recurrence/progression and reoperation: Hematoma recurrence/progression was defined as radiological evidence of ipsilateral hematoma reaccumulation or reappearance within 90 days postoperatively, accompanied by new or worsening neurological symptoms. Reoperation was defined as repeat burr hole drainage or craniotomy performed for hematoma evacuation due to hematoma recurrence/progression.

(6) Adverse events: All adverse events (AEs) occurring within 90 days postoperatively were recorded. Serious adverse events (SAEs) were defined as events that were life-threatening, resulted in death or persistent/significant disability, required unplanned hospitalization or prolongation of hospitalization, or required invasive or urgent medical intervention. Events that did not meet these criteria and were transient or manageable with conservative treatment were classified as non-serious adverse events (non-SAEs). AEs were analyzed on a per-patient basis; if a patient experienced multiple events, the patient was counted only once within each category. Consequently, the total number of patients in each category may be lower than the sum of individual adverse events.

Statistical Analysis

Statistical analyses were performed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA) and R software version 4.3.1 (R Foundation for Statistical Computing, Vienna, Austria). The normality of continuous variables was assessed using the Shapiro-Wilk test. Normally distributed continuous variables were expressed as mean ± standard deviation (SD) and compared using the independent-samples *t*-test. Non-normally distributed continuous variables were expressed as median (interquartile range [IQR]) and compared using the Mann-Whitney *U* test. Categorical variables were expressed as frequencies (percentages) and compared using the Chi-square test or Fisher's exact test, as appropriate. To minimize selection bias and potential confounding, propensity score matching (PSM) was performed. Covariates were selected *a priori* based on their established clinical relevance and potential associations with both treatment allocation and postoperative outcomes. A logistic regression model was constructed using treatment group (coils vs. Onyx) as the dependent variable and age, sex, history of antithrombotic drug use, preoperative hematoma volume, preoperative midline shift, and preoperative modified Rankin Scale (mRS) score as covariates to estimate propensity scores. One-to-one nearest-neighbor matching algorithm was applied using a caliper width of 0.2. Covariate balance after matching was evaluated using standardized mean differences (SMDs), with an SMD <0.2 considered indicative of acceptable balance. All statistical tests were two-sided, and p-values < 0.05 were considered statistically significant.

Results

Baseline Characteristics

A total of 184 patients with cSDH were included in this study, of whom 86 underwent coil embolization and 98 underwent Onyx liquid embolization. Prior to PSM, significant differences in baseline characteristics were observed between the two groups. The coil group had a higher median age (p = 0.005), a greater proportion of patients with preoperative antithrombotic drug use (p = 0.028), and a larger baseline hematoma volume (p < 0.001). Following PSM, 66 patients were successfully matched in each group. Overall covariate balance was improved after matching; however, residual imbalance remained in several characteristics, including hypertension, diabetes mellitus, statin use, gait instability, and vascular access, with SMD values > 0.2 (Table 1).

Imaging Efficacy and Clinical Prognosis

Regarding the primary outcome, post-matching analysis demonstrated that hematoma absorption volume at 90 days postoperatively was comparable between the two groups (p = 0.607). For secondary imaging outcomes, no significant differences were observed between the coil and Onyx groups in the average hematoma absorption rate (p = 0.088), reduction in hematoma thickness (p = 0.176), or improvement in midline shift (p = 0.340) (Table 2).

In terms of functional status at 90 days, the proportions of patients with mRS scores of 0–2 were 95.45% in the coil group and 93.94% in the Onyx group, with no statistically significant difference between the groups (p = 1.000). Similarly, no significant differences were observed in hematoma recurrence/progression rates (4.55% vs. 3.03%) or reoper-

Table 1. Baseline characteristics.

Variables	Pre-PSM				Post-PSM			
	Coil group (n = 86)	Onyx group (n = 98)	SMD	*p*-value	Coil group (n = 66)	Onyx group (n = 66)	SMD	*p*-value
Demographic characteristics								
Age (years), median (Q_1, Q_3)	73.00 (69.00, 77.75)	69.00 (65.00, 75.75)	0.360	0.005	72.00 (68.00, 76.00)	72.00 (66.00, 79.75)	0.096	0.895
Male sex, n (%)	63 (73.26)	64 (65.31)	0.173	0.315	45 (68.18)	40 (60.61)	0.159	0.467
BMI (kg/m^2), mean ± SD	24.16 ± 3.24	24.39 ± 2.93	0.073	0.619	24.00 ± 3.02	24.56 ± 2.86	0.188	0.282
Smoking history, n (%)	31 (36.05)	36 (36.73)	0.014	1.000	25 (37.88)	23 (34.85)	0.063	0.856
Alcohol consumption, n (%)	26 (30.23)	32 (32.65)	0.052	0.847	21 (31.82)	22 (33.33)	0.032	1.000
Medical history								
Hypertension, n (%)	54 (62.79)	55 (56.12)	0.136	0.442	45 (68.18)	38 (57.58)	0.221	0.280
Diabetes mellitus, n (%)	25 (29.07)	23 (23.47)	0.128	0.487	20 (30.30)	13 (19.70)	0.247	0.228
History of head trauma, n (%)	57 (66.28)	66 (67.35)	0.023	1.000	42 (63.64)	43 (65.15)	0.032	1.000
Medication history								
Antithrombotic drug use, n (%)	37 (43.02)	26 (26.53)	0.352	0.028	27 (40.91)	22 (33.33)	0.157	0.471
Statin use, n (%)	33 (38.37)	29 (29.59)	0.186	0.271	26 (39.39)	19 (28.79)	0.225	0.271
Neurological symptoms								
Headache, n (%)	60 (69.77)	71 (72.45)	0.059	0.812	47 (71.21)	46 (69.70)	0.033	1.000
Nausea and/or vomiting, n (%)	22 (25.58)	23 (23.47)	0.049	0.872	17 (25.76)	18 (27.27)	0.034	1.000
Short-term cognitive impairment, n (%)	33 (38.37)	32 (32.65)	0.120	0.512	26 (39.39)	21 (31.82)	0.159	0.467
Language disorders/aphasia, n (%)	16 (18.60)	15 (15.31)	0.088	0.690	12 (18.18)	11 (16.67)	0.040	1.000
Gait instability, n (%)	39 (45.35)	41 (41.84)	0.071	0.741	32 (48.48)	25 (37.88)	0.215	0.292
Decreased muscle strength, n (%)	37 (43.02)	39 (39.80)	0.066	0.769	29 (43.94)	29 (43.94)	0.000	1.000
Sensory disturbances, n (%)	13 (15.12)	14 (14.29)	0.023	1.000	10 (15.15)	7 (10.61)	0.136	0.603
Preoperative functional status and imaging characteristics								
mRS score, n (%)			0.026	0.984			0.131	0.753
0	43 (50.00)	50 (51.02)			34 (51.52)	31 (46.97)		
1	30 (34.88)	34 (34.69)			23 (34.85)	23 (34.85)		
2	13 (15.12)	14 (14.29)			9 (13.64)	12 (18.18)		
Affected side, n (%)			0.029	0.962			0.061	0.862
Left	46 (53.49)	51 (52.04)			33 (50.00)	35 (53.03)		
Right	40 (46.51)	47 (47.96)			33 (50.00)	31 (46.97)		
Vascular access, n (%)			0.214	0.196			0.276	0.163
Transfemoral access	46 (53.49)	42 (42.86)			35 (53.03)	26 (39.39)		
Transradial access	40 (46.51)	56 (57.14)			31 (46.97)	40 (60.61)		
Hematoma volume (mL), median (Q1, Q3)	77.00 (62.25, 92.75)	66.00 (58.00, 76.00)	0.535	<0.001	72.00 (60.00, 84.00)	72.00 (59.25, 82.75)	0.164	0.502
Maximum hematoma thickness (mm), mean ± SD	19.38 ± 4.00	18.29 ± 3.82	0.280	0.059	19.71 ± 4.26	18.91 ± 3.89	0.195	0.264
Midline shift (mm), mean ± SD	8.56 ± 2.94	8.12 ± 2.70	0.157	0.289	8.30 ± 2.76	8.53 ± 2.73	0.085	0.626

Abbreviations: BMI, body mass index; mRS, modified Rankin Scale; PSM, propensity score matching; SMD, standardized mean difference; SD, standard deviation.

Table 2. Radiographic and clinical outcomes at 90 days postoperatively.

Outcome measures	Coil group (n = 66)	Onyx group (n = 66)	*p*-value
Radiographic outcomes			
Reduction in Hematoma volume (mL), mean ± SD	63.67 ± 17.77	62.17 ± 15.57	0.607
Hematoma absorption rate (%), median (Q_1, Q_3)	87.58 (81.28, 93.72)	90.14 (85.45, 93.04)	0.088
Residual hematoma volume (mL), median (Q_1, Q_3)	8.00 (5.25, 12.00)	7.00 (4.00, 10.75)	0.157
Reduction in hematoma thickness (mm), mean ± SD	12.59 ± 5.27	11.39 ± 4.84	0.176
Residual maximum hematoma thickness (mm), median (Q_1, Q_3)	6.95 (5.20, 9.55)	7.00 (5.30, 9.12)	0.884
Improvement in midline shift (mm), median (Q_1, Q_3)	5.70 (4.00, 7.27)	5.70 (4.23, 8.78)	0.340
Residual midline shift (mm), median (Q_1, Q_3)	2.30 (1.52, 3.40)	2.00 (1.42, 2.98)	0.167
Functional and clinical outcomes			
Functional status at 90 days (mRS 0–2)			1.000
mRS 0, n (%)	35 (53.03)	32 (48.48)	
mRS 1, n (%)	19 (28.79)	20 (30.30)	
mRS 2, n (%)	9 (13.64)	10 (15.15)	
Hematoma recurrence/progression, n (%)	3 (4.55)	2 (3.03)	1.000
Reoperation, n (%)	3 (4.55)	2 (3.03)	1.000

ation rates (4.55% vs. 3.03%). Overall, no statistically significant between-group differences were observed in these short-term clinical outcomes when the two embolic materials were used as adjuncts to burr-hole drainage for cSDH.

Safety Evaluation

Within 90 days postoperatively, the overall incidence of adverse events (AEs) did not differ significantly between the two groups ($p = 0.347$). The incidence of SAEs was identical in both groups (16.67% each). In terms of embolization-related complications, facial nerve palsy occurred in three patients in the Onyx group, while no such events were observed in the coil group. The incidence of all other individual SAEs was low. Likewise, no significant difference was observed in the overall incidence of non-SAEs between the two groups ($p = 0.215$) (Table 3).

Health Economic and Perioperative Outcomes

Regarding embolic material utilization, the median number of coils used in the coil group was 4.00 (3.00, 5.00), whereas the median volume of Onyx used in the Onyx group was 2.25 mL (1.72, 2.98). Compared with the Onyx group, the coil group demonstrated significant advantages in procedural efficiency and medical costs, as reflected by a shorter operative time and lower total hospitalization costs (Table 4).

Discussion

This study retrospectively compared the clinical efficacy and safety of coils versus Onyx liquid embolic agent as adjuncts to burr hole drainage for cSDH using PSM. The results demonstrated that patients in both groups achieved comparable outcomes across key measures, including radiographic improvement at 90 days postoperatively, functional outcomes, and recurrence rates. In terms of safety, although no statistically significant differences were observed between the two groups, cases of facial nerve palsy occurred in the Onyx group, whereas no such events were identified in the coil group, suggesting a potentially more favorable safety profile for coils. Furthermore, the coil group exhibited a shorter operative time and lower total hospitalization costs, reflecting better procedural efficiency and lower hospitalization costs. These findings suggest that, in the setting of adjunctive surgical treatment, proximal occlusion using coils represents a safe, efficient, and cost-effective therapeutic option.

The optimal embolic material for MMAE remains controversial in the academic community. Liquid embolic agents are often considered the preferred option because they can penetrate the distal capillary network of the MMA, theoretically providing more complete occlusion of the blood supply to the hematoma membrane [7]. However, the findings of the present study indicate that stand-alone coil embolization of the main trunk or major branches, when combined with burr hole drainage, can achieve therapeutic outcomes comparable to those of Onyx. This finding is consistent with findings from recent multicenter studies. Salem et al. [14] analyzed 1070 MMAE procedures and reported no significant differences among particles, Onyx, and n-BCA in surgical rescue rates, radiographic success, or major complications. Khorasanizadeh et al. [12] further supported this perspective by demonstrating that stand-alone coil embolization is as effective as combined particle embolization in reducing hematoma volume. The underlying mechanism may be related to the dependence of cSDH persistence on the elevated perfusion pressure generated by MMA-derived blood flow. By occluding the proximal vessel with coils, although the distal vascular network is not directly embolized, distal hydrostatic pressure may be sufficiently reduced to disrupt the pathological cycle of recurrent microhemorrhage originating from the neovasculature of the hematoma membrane. Consequently, the hematoma

Table 3. Adverse events and safety outcomes within 90 days postoperatively.

Event	Coil group (n = 66)	Onyx group (n = 66)	*p*-value
Total AEs, n (%)	18 (27.27)	23 (34.85)	0.347
SAEs			
Total SAEs, n (%)	11 (16.67)	11 (16.67)	1.000
Facial nerve palsy, n (%)	0 (0.00)	3 (4.55)	
Intracranial hemorrhage, n (%)	2 (3.03)	1 (1.52)	
Intracranial infection, n (%)	1 (1.52)	1 (1.52)	
Puncture-site/incision infection, n (%)	1 (1.52)	2 (3.03)	
Newly-onset seizures, n (%)	1 (1.52)	3 (4.55)	
Pneumonia/severe pulmonary infection, n (%)	4 (6.06)	2 (3.03)	
Cardiovascular events, n (%)	1 (1.52)	0 (0.00)	
Deep vein thrombosis (DVT), n (%)	1 (1.52)	0 (0.00)	
non-SAEs			
Total non-SAEs, n (%)	7 (10.61)	12 (18.18)	0.215
Postoperative headache, n (%)	2 (3.03)	7 (10.61)	
Nausea and/or vomiting, n (%)	2 (3.03)	4 (6.06)	
Urinary retention, n (%)	3 (4.55)	1 (1.52)	

Abbreviations: SAEs, serious adverse events; non-SAEs, non-serious adverse events; AEs, total adverse events.

Table 4. Perioperative outcomes and health economics.

Outcome measure	Coil group (n = 66)	Onyx group (n = 66)	*p*-value
Operative time (min), mean ± SD	47.05 ± 11.14	52.10 ± 11.01	0.010
Length of hospital stay (days), median (Q_1, Q_3)	10.00 (7.25, 12.00)	10.00 (7.00, 11.75)	0.766
Total hospitalization costs (RMB), median (Q_1, Q_3)	49,895.73 (47,656.24, 52,387.04)	52,131.93 (48,515.59, 56,243.26)	0.039

Exchange rate: 1 USD ≈ 7.2 RMB (average during the study period, April 2024 - October 2025).

may transition from a progressive state to spontaneous absorption [12,15]. Moreover, all patients in the present study underwent burr hole drainage, which itself clears a substantial volume of inflammatory factor-rich hematoma fluid and reduces intracranial pressure, potentially further diminishing differences in efficacy among embolic materials with varying capacities for distal penetration [16]. Nevertheless, coil embolization has inherent limitations. Its mechanism primarily relies on proximal occlusion of the main trunk and does not permit penetration of the neocapillary network within the hematoma membrane to the extent achieved by liquid embolic agents. Consequently, low-grade inflammatory exudation mediated by distal abnormal vessels may theoretically persist. Additionally, in cases of complex MMA anatomy with multiple feeding branches or a very short main trunk, coils may not provide adequate embolization and may require the supplementary use of particles or liquid embolic agents [17,18].

Safety remains a core consideration in MMAE procedures. In the present study, three cases of facial nerve palsy occurred in the Onyx group compared with none in the coil group. The MMA has potentially hazardous anastomotic connections with the ophthalmic artery and the greater petrosal nerve branch of the facial nerve. During Onyx injection, reflux or excessive diffusion may result in inadvertent migration into these small anastomotic vessels, leading to severe complications such as facial nerve palsy or visual impairment [19]. Perng et al. [11] reported that stand-alone coil embolization effectively minimizes the risk of unintended vascular occlusion because it does not involve diffusion of a liquid embolic agent, thereby providing a more controlled mechanical occlusion. Khorasanizadeh et al. [12] likewise recommended that when dangerous anastomoses are identified angiographically or when distal superselective catheterization is not feasible, stand-alone coil embolization should be considered the preferred strategy to reduce the risk of cranial nerve injury. The findings of the present study further support this view, indicating that coils may provide a greater safety margin in patients with complex vascular anatomy or high-risk anastomotic branches.

As the incidence of cSDH continues to increase, treatment costs and procedural efficiency have become increasingly critical considerations in clinical decision-making. In the present study, operative time was significantly shorter in the coil group than in the Onyx group ($p = 0.010$), and total hospitalization costs were significantly lower ($p = 0.039$). These differences may be attributed primarily to the relatively straightforward deployment of coils, which do not require the complex preparation and prolonged slow injection associated with Onyx. Furthermore, the Onyx injection process often requires repeated angiographic assessments to monitor for reflux, thereby increasing fluoroscopy time and

contrast agent utilization [20]. Therefore, given the comparable efficacy observed in this study, coil embolization may help reduce operative time and medical expenditures, particularly in settings with limited healthcare resources.

This study has certain limitations. First, as a single-center retrospective study, although PSM was employed to reduce selection bias and improve the comparability of prespecified covariates, some residual imbalance remained, and unmeasured confounding factors (e.g., surgeon experience, timing of embolization, and hematoma fluid characteristics) could not be completely excluded. Second, this study focused specifically on the setting of adjunctive burr hole drainage; therefore, the findings may not be fully generalizable to patients undergoing stand-alone MMAE for cSDH. Third, the follow-up period was limited to 90 days. Although this period was sufficient for evaluating short-term radiographic absorption and postoperative complications, long-term outcomes, including hematoma recurrence, functional recovery, and recanalization of embolized vessels, require further investigation through extended follow-up studies. Finally, subgroup analyses according to specific coil types were not performed. Furthermore, although MMAE was performed before burr-hole drainage in all included patients, the exact interval between the two procedures was not consistently documented in the retrospective records. In addition, anesthesia modality was not systematically recorded, and itemized cost data were unavailable for a more detailed health economic analysis. Future large-scale prospective randomized controlled trials are warranted to address these limitations and further validate the present findings.

Conclusions

For patients with cSDH undergoing burr hole drainage combined with MMAE, coil embolization, and Onyx liquid embolic agent, the short-term efficacy and overall safety are comparable. Coil embolization offers potential advantages in procedural efficiency while avoiding risks associated with distal embolic penetration. However, because coil embolization primarily involves occlusion of the proximal vessel, the optimal embolization strategy should be determined through a comprehensive evaluation of individual anatomical features and clinical conditions. Such an approach may facilitate personalized treatment selection and help achieve an optimal balance between recurrence prevention and procedural safety.

Availability of Data and Materials

The data and materials in the current study are available from the corresponding author on reasonable request.

Author Contributions

Conception and design: CHL. Administrative support: CHL and FBC. Provision of study materials: PL and CHL. Collection and assembly of data: YHW and PL. Data analysis and interpretation: FBC and YHW. Manuscript writing: All authors. All authors contributed to the critical revision of the manuscript for important intellectual content. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

The study conformed to the provisions of the Declaration of Helsinki. It has been reviewed and approved by the Ethics Committee of Deqing County People's Hospital, with the approval number (LL2026-DRY-K04). Given the retrospective nature of this study, patient-related data were anonymized prior to extraction from electronic medical records. The ethics committee granted a waiver of informed consent.

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Conflict of Interest

The authors declare no conflict of interest.

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