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Predictors of Recurrence and Reintervention in Non-Acute Subdural Hematoma: A Multimodal Analysis of Imagenological, Clinical, Surgical, and Endovascular Factors

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Abstract

BACKGROUND AND PURPOSE

Non-acute subdural hematomas (naSDH), encompassing subacute and chronic subdural hematomas, are a common neurosurgical condition in older adults with substantial recurrence rates after treatment. Management has become increasingly multimodal, combining surgical and endovascular strategies; however, the influence of clinical, radiological, surgical, and technical factors on recurrence and reintervention remains under investigation.

MATERIALS AND METHODS

We conducted a retrospective multicenter cohort study including patients from six high-complexity neurosurgical and neurointerventional referral centers in Colombia between January 2023 and June 2025. Adult patients with symptomatic non-acute subdural hematoma confirmed by CT were included. Hematomas were managed with surgery alone, combined surgery and middle meningeal artery embolization, or embolization alone. Recurrence and reintervention were evaluated as outcomes. Univariable and multivariable logistic regression analyses were performed to identify factors associated with the primary outcomes.

RESULTS

A total of 247 naSDH were analyzed. Recurrence occurred in 51 hematomas (20.6%) and reintervention in 44 (17.8%). In multivariable analysis, smoking (OR 9.59, 95% CI 1.93–47.52), hypertension (OR 5.23, 95% CI 1.14–23.93), increasing age (OR 1.07, 95% CI 1.00–1.16), and greater hematoma thickness (OR 1.20, 95% CI 1.05–1.37) were independently associated with recurrence. Combined surgery with embolization was associated with reduced recurrence (OR 0.44, 95% CI 0.22–0.88). Among surgical variables, post-drain pneumocephalus significantly increased recurrence risk (OR 13.32, 95% CI 2.83–62.65), whereas longer durostomy drainage duration reduced the recurrence (OR 0.51, 95% CI 0.30–0.85). Endovascular technical factors were not independently associated with recurrence.

CONCLUSIONS

Clinical factors showed the strongest association with recurrence. Combined surgery and embolization demonstrated a protective effect, while postoperative pneumocephalus and drainage duration significantly influenced possible outcomes.

INTRODUCTION

Subdural hematomas (SDHs) are extra-axial blood collections located between the dura mater and the arachnoid membrane, most commonly resulting from tearing of bridging veins due to rotational or acceleration-deceleration forces (1) (2). According to their evolution, SDHs are classified into acute (ASDH), subacute (SSDH), and chronic (CSDH), with non-acute SDH encompassing the subacute and chronic phases. Non-acute SDH, particularly CSDH constitutes one of the most frequent neurosurgical conditions in older adults, with reported incidences up of 58.1 per 100,000 person-years in patients aged > 65 years (3), and higher rates in patients with anticoagulation or significant cerebral atrophy (4)

Clinically, non-acute SDH presents with progressive neurological decline, cognitive or functional deterioration, gait instability, headache, and focal deficits, or, in severe cases, herniation and coma (5) (6) (7). Imaging plays a crucial role in diagnosis. (2). Modern radiological classifications such as the extended internal architecture system proposed by Hamou et al. categorize CSDH with CT into hypodense, isodense, hyperdense, sedimented, laminar, bridging, trabecular, and mixed subacute–chronic types, reflecting the dynamic interplay of neomembrane formation, angiogenesis, and recurrent microhemorrhage (8). From an epidemiological perspective, cortical atrophy graded by the Pasquier scale has emerged as an important predisposing and potentially predictive factor, given its role in stretching bridging veins and limiting postoperative brain re-expansion (9).

Non-acute subdural hematomas (naSDH) are prone to recurrence after surgical treatment (10). The literature demonstrates that combined management with middle meningeal artery embolization or exclusive endovascular treatment in patients with symptomatic non-acute subdural hematoma are effective in reducing hematoma recurrence (11). The management depends on the size, location, and clinical impact of the hematoma. Symptomatic or large SDHs typically require surgical evacuation, most commonly via burr-hole craniostomy, and in other cases require placement of a subdural drain.(12) Management via endovascular alternative, includes other variables that modulate treatment efficacy, including embolic agents (include particles, liquid agents, and coils), catheter positioning, anatomical variants, and procedural technical heterogeneity. The use of liquid embolic material was a factor characterized by lower retreatment rates than standard treatment alone (3). Surgical management remains effective but susceptible to recurrence due to multiple variables that include postoperative pneumocephalus, drainage duration (no drain, subdural drain, subgaleae drain), extent of durotomy and membranectomy and type of surgical approach (burr holes, craniotomy)(13) (14). Reintervention has been associated with poorer functional status, reduced quality of life, and an overall increase in the duration of hospitalization (13). This is especially important in the patient centered care because a second surgery impacts the quality of life of the patients and their functional outcomes.

Subdural hematoma recurrence rates after treatment are significant (5), they vary by treatment modality and patient characteristics, necessitating close follow-up. For surgically treated chronic subdural hematoma (cSDH), large meta-analyses and population-based studies consistently report recurrence rates requiring reoperation in the range of 10–14% within the first year, with most recurrences occurring in the first 4–8 weeks post-procedure. (15) A systematic review and meta-analysis of 455 studies (over

100,000 cases) found a pooled recurrence rate of 10.8% (95% CI 10.2–11.5) after surgical evacuation. (16)

Randomized controlled trials (RCT) evaluating adjunctive therapies have demonstrated lower recurrence rates. Middle meningeal artery embolization (MMAE), either as primary or adjunctive therapy, has shown promise in reducing recurrence. In a recent multicenter RCT, symptomatic recurrence or progression within 90 days occurred in 6.7% of patients treated with MMAE versus 9.9% with usual care (difference −3.3 percentage points, 95% CI − 7.4 to 0.8). (17) Repeated or rescue surgery was required in 3.1% of the MMAE group versus 6.4% of the usual care group. Another RCT of adjunctive MMAE reported recurrence or progression leading to repeat surgery in 4.1–4.4% of the MMAE group versus 11.1–11.3% in controls within 90 days (relative risk 0.36–0.40, $p < 0.02$). (10)

Recurrence rates are also influenced by perioperative factors. Early spontaneous cessation of subdural drainage after burr-hole evacuation is associated with higher recurrence (up to 26.5% if drainage ceases within 8 hours, compared to 9.6% if drainage continues for 17–24 hours). (18). Radiological predictors such as cortical atrophy and limited postoperative midline re-expansion independently increase recurrence risk, and risk stratification tools based on these factors can help identify high-risk patients. (19) In this study, we aim to identify the clinical, radiological, surgical and endovascular factors associated with recurrence and the need for reintervention in patients with symptomatic non-acute subdural hematoma.

MATERIALS AND METHODS

We performed a retrospective, multicenter cohort study including patients from six high-complexity neurosurgical and neurointerventional radiology referral centers in Colombia, from January 2023 to June 2025. The study was conducted in accordance with the Declaration of Helsinki and its subsequent revisions. The protocol was approved by the institutional research ethics committees of all participating centers, including the Comité de Ética en Investigaciones (CEI) – Fundación Oftalmológica de Santander (FOSCAL) (approval number 11816/2025; protocol 010005). Given the retrospective design and the use of anonymized clinical data, the requirement for written informed consent was waived. Data were obtained from de-identified institutional databases from each participating center.

Study cohort

Adult patients (≥ 18 years) with a diagnosis of symptomatic non-acute subdural hematoma confirmed by computed tomography (CT) were included. Patients treated conservatively and those with poor baseline functional status (mRS > 3) were excluded to ensure analytic homogeneity. The study population included patients managed with three therapeutic approaches. A total of 247 hematomas were included: 105 were treated with surgery alone, 100 with combined treatment, and 42 with exclusive embolization.: surgery alone, based on medical decision-making or lack of neurointerventional consultation; combined management with surgery and embolization, with embolization performed either before or after surgery;

and embolization alone. In patients treated with embolization alone, neurosurgical evaluation favored conservative management, and middle meningeal artery embolization was performed to reduce the risk of recurrence.

Hematoma measurements

Hematoma dimensions were measured using standard anatomical planes. Thickness was assessed on the coronal view at the point of greatest depth. Length was defined as the maximum anteroposterior extension on axial images, while height corresponded to the greatest craniocaudal dimension. Midline shift was measured on axial images by identifying the anatomical midline and calculating the perpendicular displacement caused by the hematoma. Hematoma delta was calculated by subtracting the initial thickness from the thickness measured at discharge or follow-up, allowing assessment of hematoma reduction or progression over time.

Outcomes

Recurrence was defined as rebleeding confirmed on imaging, identified either by the appearance of a new hemorrhagic component not present on prior studies or by a significant increase in hematoma thickness associated with recurrence of symptoms. Additionally, reintervention was defined as the need for repeat surgical drainage or any additional surgical procedure for subdural hematoma following the initial treatment. In patients managed with embolization alone, reintervention specifically referred to the subsequent requirement for surgical management after the initial embolization. Follow-up was obtained through review of electronic medical records and categorized according to duration into three intervals: up to 3 months (89 patients), less than 6 months (11 patients), and less than 12 months (5 patients). A greater proportion of patients in the endovascular group had follow-up extending beyond 6 months compared with the surgical group.

Statistical analysis

Univariable analysis was conducted. Continuous variables were summarized using measures of central tendency and variability, reporting mean and standard deviation for normally distributed data and median with interquartile range for non-normally distributed data. Data distribution was evaluated using the Kolmogorov–Smirnov test. Categorical variables were expressed as absolute counts and percentages. For bivariate analysis, variables were analyzed after stratification by treatment group. Normally distributed continuous variables were compared using the Student t test, while non-normally distributed variables were assessed using the U Mann–Whitney test. Comparisons of categorical variables were performed using the chi-square test or Fisher exact test, as appropriate, among the three treatment groups. A backward stepwise multivariable model was constructed to evaluate 90-day recurrence. All variables with a p-value < 0.20 in the univariate analysis were initially entered into the preliminary model, and variables were subsequently removed stepwise according to the backward elimination procedure

until the final model was obtained. Patients lost to follow-up were excluded from the analysis. The proportion of missing data was evaluated for each variable and was low (< 5% for most variables). Overall study denominator remained constant across analyses. For variables with missing values, analyses were conducted using the available information without imputation.

RESULTS

Study population and outcomes

A total of 247 naSDH were included in this analysis. During the follow-up period, 51 hematomas (20.6%) experienced recurrence, and 44 hematomas (17.8%) required reintervention. The gender distribution showed 62 female hematomas (25.1%) and 185 male hematomas (74.9%) (Table 1).

Univariable analysis of clinical factors

The univariable analysis revealed several clinical factors associated with recurrence and reintervention. mean age was 78.58 ± 1.36 years in patients with recurrence compared to 73.19 ± 0.89 years in those without recurrence (p = 0.940). For reintervention, mean age was 77.18 ± 1.49 years in patients requiring reintervention versus 73.68 ± 0.87 years in those who did not (p = 0.940).

Smoking history emerged as a significant risk factor, present in 16 hematomas (31.37%) with recurrence versus 33 hematomas (16.84%) without recurrence (p = 0.020). For reintervention, smoking history was present in 17 hematomas (38.64%) requiring reintervention compared to 32 hematomas (15.76%) who did not (p = 0.001). History of seizures was significantly associated with recurrence, occurring in 7 hematomas (13.73%) with recurrence versus 8 hematomas (4.08%) without recurrence (p = 0.010). For reintervention, seizure history was present in 6 patients (13.64%) versus 9 patients (4.43%, p = 0.200) (Table 1).

Hypertension showed a trend toward significance, present in 37 hematomas (72.55%) with recurrence versus 115 hematomas (58.67%) without recurrence (p = 0.070). For reintervention, hypertension was present in 31 hematomas (70.45%) versus 121 hematomas (59.61%, p = 0.180).

Previous use of antiplatelet therapy had an inverse relationship with recurrence, present in 8 hematomas (15.69%) with recurrence versus 53 hematomas (27.04%) without recurrence (p = 0.094). For reintervention, antiplatelet therapy was used in 7 hematomas (15.91%) versus 54 hematomas (26.60%, p = 0.136). Other medical comorbidities including diabetes mellitus with a 35.39% of recurrence versus 30.10 (p = 0.476), coagulation disorders did not show a statistically significant association with recurrence with a limited sample size of patients, in contrast, in history of traumatic brain injury recurrence was present in 37 hematomas (72.55%) vs 119 hematomas (60.71%) (p = 0.119), No significant associations with recurrence were observed for previous anticoagulant use, history of alcoholism, or cerebral atrophy (Table 1).

Table 1
Univariable comparison analysis of factors related to recurrence and reintervention in chronic subdural hematoma

Group of treatment	Recurrence		P-value	Reintervention		P-value
	Yes n = 51 (%) ± SD	No n = 196 (%) ± SD		Yes n = 44 (%) ± SD	No n = 203 (%) ± SD	
Age (mean years)	78.58 ± 1.36	73.19 ± 0.89	0.940	77.18 ± 1.49	73.68 ± 0.87	0.940
Gender						
Female	12 (23.53)	50 (25.51)	0.771	9 (20.45)	53 (26.11)	0.433
Male	39 (76.47)	146 (74.49)		35 (79.55)	150 (73.89)	
Medical History (yes)						
Diabetes mellitus	18 (35.39)	59 (30.10)	0.476	15 (34.09)	62 (30.54)	0.645
Hypertension	37 (72.55)	115 (58.67)	0.070	31 (70.45)	121 (59.61)	0.180
Smoking history	16 (31.37)	33 (16.84)	**0.020**	17 (38.64)	32 (15.76)	**0.001**
Coagulation disorders	2 (3.92)	13 (6.63)	0.470	2 (4.55)	13 (6.40)	0.640
History of traumatic brain injury	37 (72.55)	119 (60.71)	0.119	32 (72.73)	124 (61.08)	0.147
Previous use of anticoagulant	10 (19.61)	43 (21.94)	0.718	9 (20.45)	44 (21.67)	0.858
Previous use of antiplatelet therapy	8 (15.69)	53 (27.04)	0.094	7 (15.91)	54 (26.60)	0.136
History of alcoholism	0 (0)	5 (2.55)	0.249	1 (2.27)	4 (1.97)	0.897
History of cerebral atrophy	12 (23.53)	54 (27.55)	0.563	10 (22.73)	56 (27.59)	0.509
History of seizures	7 (13.73)	8 (4.08)	**0.010**	6 (13.64)	9 (4.43)	**0.200**
Pasquier's Global Cortical Atrophy (GCA) Scale						
0	135 (68.88)	32 (62.75)	0.545	28 (63.64)	139 (68.47)	0.651
1	43 (21.94)	12 (23.53)		10 (22.73)	45 (22.17)	
2	16 (8.16)	7 (13.73)		6 (13.64)	17 (8.37)	

Group of treatment	Recurrence		P-value	Reintervention		P-value
	Yes n = 51 (%) ± SD	**No n = 196 (%) ± SD**		**Yes n = 44 (%) ± SD**	**No n = 203 (%) ± SD**	
3	2 (1.02)	0 (0)		0 (0)	2 (2.99)	
Admission Hematoma measurements (mean -mm)						
Thickness	20.14 ± 0.97	18.16 ± 0.48	**< 0.001**	20.28 ± 1.10	18.20±.0.47	**< 0.001**
Length	124.17 ± 4.60	119.15 ± 2.45	**< 0.001**	121.88 ± 5.01	119.83 ± 2.40	**< 0.001**
Hematoma height	84.28 ± 2.89	86.55 ± 1.74	0.173	83.23 ± 3.18	87.35 ± 1.69	0.173
Midline shift	6.08 ± 0.79	6.59 ± 0.39	**< 0.001**	6.56 ± 0.83	6.47 ± 0.38	**< 0.001**
Hematoma subtype						
Hypodense	11 (21.57)	34 (17.35)	**0.011**	7 (15.91)	38 (18.72)	**0.025**
Isodense	10 (19.61)	35 (17.86)		10 (22.73)	35 (17.24)	
Hyperdense	7 (13.73)	15 (7.65)		7 (15.91)	15 (7.39)	
Sedimented	7 (13.73)	9 (4.59)		5 (11.36)	11 (5.42)	
Laminar	3 (5.88)	2 (1.02)		3 (6.82)	2 (0.99)	
Trabecular	1 (1.96)	12 (6.12)		1 (2.27)	12 (5.91)	
Bridging	1 (1.96)	6 (3.06)		1 (2.27)	6 (2.96)	
Subacute	11 (21.57)	83 (42.35)		10 (22.73)	84 (41.38)	
Laterality						
Right	27 (52.94)	100 (51.02)	0.807	25 (56.82)	102 (50.25)	0.429
Left	24 (47.06)	96 (48.98)		19 (43.18)	101 (49.75)	
Location						
Frontoparietal	7 (13.73)	47 (23.98)	0.143	7 (15.91)	47 (23.15)	0.743
Frontotemporal	0 (0)	10 (5.10)		1 (2.27)	9 (4.43)	
Frontal only	2 (3.92)	7 (3.57)		2 (4.55)	7 (3.45)	
Temporal only	0 (0)	5 (2.55)		1 (2.27)	4 (1.97)	

Group of treatment	Recurrence		P-value	Reintervention		P-value
	Yes n = 51 (%) ± SD	No n = 196 (%) ± SD		Yes n = 44 (%) ± SD	No n = 203 (%) ± SD	
Parietal only	0 (0)	4 (2.04)		0 (0)	4 (1.97)	
Hemispheric	37 (72.55)	112 (57.14)		0 (0)	4 (1.97)	
Parieto-occipital	5 (9.80)	11 (5.61)		2 (4.55)	14 (6.90)	
Type of treatment						
Surgery alone	30 (58.82)	75 (38.37)	**0.030**	24 (54.55)	81 (39.90)	0.179
Surgery + Embolization	15 (29.41)	85 (43.37)		13 (29.55)	87 (42.86)	
Embolization alone	6 (11.76)	36 (18.37)		7 (15.91)	35 (17.24)	
Type of anesthesia						
General	49 (96.08)	163 (83.16)	0.056	41 (93.18)	171 (84.24)	0.296
Conscious sedation	1 (1.96)	26 (12.76)		2 (4.55)	24 (11.82)	
Regional anesthesia	1 (1.96)	8 (4.08)		1 (2.27)	8 (3.94)	
Days of hospital stay (mean)	13.45 ± 1.67	11.37 ± 0.66	**0.014**	13.86 ± 1.90	11.35 ± 0.64	**0.014**

GCA: Pasquier's Global Cortical Atrophy Scale

Treatment modalities

This was significantly associated with recurrence (p = 0.030) (Table 1). Surgery alone was proportionally more frequent in the recurrence group, whereas combined surgery with embolization and embolization alone were more common in the no-recurrence group. In contrast, treatment type was not significantly associated with reintervention (p = 0.179).

Hospital length of stay was significantly longer in patients with recurrence (13.45 ± 1.67 vs. 11.37 ± 0.66 days, p = 0.014) and in those requiring reintervention (13.86 ± 1.90 vs. 11.35 ± 0.64 days, p = 0.014) (Table 1). General anesthesia showed a trend toward association with recurrence (p = 0.056), with higher use in the recurrence group. No significant differences were observed according to anesthesia type overall (Table 1).

Hematoma measurements

Admission hematoma measurements demonstrated significant associations with both outcomes. Patients who experienced recurrence had significantly greater mean hematoma thickness (20.14 ± 0.97 mm vs. 18.16 ± 0.48 mm, $p < 0.001$) and mean length (124.17 ± 4.60 mm vs. 119.15 ± 2.45 mm, $p < 0.001$). Mean hematoma height showed no significant difference (84.28 ± 2.89 mm vs. 86.55 ± 1.74 mm, $p = 0.173$). Notably, mean midline shift showed an inverse relationship with recurrence (6.08 ± 0.79 mm vs. 6.59 ± 0.39 mm, $p < 0.001$)

Similarly, patients requiring reintervention had larger mean hematoma thickness (20.28 ± 1.10 mm vs. 18.20 ± 0.47 mm, $p < 0.001$) and mean length (121.88 ± 5.01 mm vs. 119.83 ± 2.40 mm, $p < 0.001$). Mean hematoma height showed no significant difference (83.23 ± 3.18 mm vs. 87.35 ± 1.69 mm, $p = 0.173$), while mean midline shift was 6.56 ± 0.83 mm in patients requiring reintervention versus 6.47 ± 0.38 mm in those who did not ($p < 0.001$) (Table 1).

Hematoma radiological subtypes

The distribution of hematoma subtypes was significantly associated with both recurrence and reintervention ($p = 0.011$ and $p = 0.025$, respectively) (Table 2). Among the 247 hematomas, subacute was the most frequent subtype (38.06%), followed by hypodense and isodense subtypes (18.22% each).

Recurrence rates varied across subtypes. Laminar hematomas had the highest recurrence rate (60%), followed by sedimented (43.75%) and hyperdense (31.81%) subtypes. Hypodense and isodense hematomas showed intermediate recurrence rates (24.44% and 22.22%, respectively), whereas trabecular (7.96%), bridging (14.2%), and subacute hematomas (11.7%) had lower recurrence rates (Table 2). A similar pattern was observed for reintervention. Laminar hematomas again showed the highest rate (40%), followed by hyperdense (31.81%) and sedimented (31.25%) subtypes. Isodense (22.22%) and hypodense (15.56%) hematomas demonstrated intermediate rates, while trabecular (7.69%) and subacute hematomas (10.63%) had the lowest reintervention rates (Table 2).

Table 2
Hamou et al. Subdural hematoma Radiological classification, recurrence and reintervention rates.

Subtype	All (n = 247) (%)	No Recurrence (n = 196) (%)	Recurrence (n = 51) (%)	Recurrence rate (%)	P-value
Hypodense	45 (18.22)	34 (17.35)	11 (21.57)	**24.44%**	**0.011**
Isodense	45 (18.22)	35 (17.86)	10 (19.61)	**22.22%**	
Hyperdense	22 (8.91)	15 (7.65)	7 (13.73)	**31.81%**	
Sedimented	16 (6.48)	9 (4.59)	7 (13.73)	**43.75%**	
Laminar	5 (2.02)	3 (1.53)	3 (5.88)	**60%**	
Trabecular	13 (5.26)	12 (6.12)	1 (1.96)	**7.96%**	
Bridging	7 (2.83)	7 (3.58)	1 (1.96)	**14.2%**	
Subacute	94 (38.06)	83 (42.35)	11 (21.57)	**11.7%**	
Subtype	**All (n = 247) (%)**	**No Reintervention (n = 203) (%)**	**Reintervention (n = 44) (%)**	**Reintervention rate (%)**	**P-value**
Hypodense	45 (18.22)	38 (18.72)	7 (15.56)	**15.56%**	**0.025**
Isodense	45 (18.22)	35 (17.24)	10 (22.73)	**22.22%**	
Hyperdense	22 (8.91)	15 (7.39)	7 (15.91)	**31.81%**	
Sedimented	16 (6.48)	11 (5.42)	5 (11.36)	**31.25%**	
Laminar	5 (2.02)	3 (1.48)	2 (4.55)	**40%**	
Trabecular	13 (5.26)	12 (5.91)	1 (2.27)	**7.69%**	
Bridging	7 (2.83)	6 (2.96)	1 (2.27)	**14.2%**	
Subacute	94 (38.06)	84 (41.38)	10 (22.73)	**10.63%**	

Univariable and multivariable logistic regression analysis

Logistic regression analysis identified several predictors of recurrence. Advancing age was associated with increased risk (OR 1.05, 95% CI 1.01–1.08, p = 0.005). History of smoking increased the odds of recurrence more than two-fold (OR 2.26, 95% CI 1.12–4.55, p = 0.023), while history of seizures was associated with nearly four-fold increased odds (OR 3.74, 95% CI 1.29–10.86, p = 0.015). Postoperative head trauma emerged as a particularly strong predictor (OR 6.43, 95% CI 1.39–29.86, p = 0.017). General anesthesia showed a trend toward significance (OR 7.52, 95% CI 0.99–56.89, p = 0.051), as did

hypertension (OR 1.86, 95% CI 0.95–3.67, p = 0.072) and previous antiplatelet therapy (OR 0.50, 95% CI 0.22–1.14, p = 0.099) (Table 3).

Combined surgery with embolization was associated with reduced recurrence risk compared to surgery alone (OR 0.44, 95% CI 0.22–0.88, p = 0.021). Embolization alone showed a trend toward significance (OR 0.42, 95% CI 0.16–1.09, p = 0.075) (Table 3).

Among surgical variables, post-drain pneumocephalus significantly increased recurrence risk (OR 3.39, 95% CI 1.64-7.00, p = 0.001). Type of surgery showed no significant association, with craniotomy (OR 1.57, 95% CI 0.70–3.51, p = 0.272), single burr-hole (OR 3.12, 95% CI 0.84–11.55, p = 0.088), and double burr-hole (OR 1.25, 95% CI 0.29–5.25, p = 0.761) showing no significant differences. Days of durostomy drainage showed a protective trend (OR 0.76, 95% CI 0.56–1.05, p = 0.094) (Table 3).

For endovascular variables, the use of cyanoacrylate (OR 0.14, 95% CI 0.02–0.89, p = 0.038) and microparticles (OR 0.08, 95% CI 0.007–0.82, p = 0.034) as embolic materials were associated with significantly reduced recurrence rates. Onyx (OR 0.47, 95% CI 0.12–1.90, p = 0.293), Phil (OR 0.40, 95% CI 0.03–4.68, p = 0.465), and coils (OR 0.75, 95% CI 0.12–4.48, p = 0.753) showed no significant associations. However, due to limited statistical power in this analysis, when embolic materials were regrouped into broader categories (liquids, particles, and coils), no statistically significant association with recurrence was observed. (Table 3).

In the multivariable model, among clinical factors, a history of smoking emerged as the strongest independent predictor of recurrence (OR 9.59, 95% CI 1.93–47.52, p = 0.006), followed by hypertension (OR 5.23, 95% CI 1.14–23.93, p = 0.033). Increasing age was also associated with recurrence, with a modest but statistically significant effect (OR 1.07, 95% CI 1.00–1.16, p = 0.045). Greater hematoma thickness was independently associated with recurrence (OR 1.20, 95% CI 1.05–1.37, p = 0.005).

Treatment with surgery combined with embolization showed a protective association against recurrence of naSDH. Among surgical variables, longer duration of durostomy was associated with reduced recurrence (OR 0.51, 95% CI 0.30–0.85, p = 0.011), whereas the presence of post-drain pneumocephalus was strongly associated with increased recurrence risk (OR 13.32, 95% CI 2.83–62.65, p < 0.001).

Regarding endovascular factors, neither the type of procedure nor the embolic agent demonstrated an independent association with recurrence. These findings may reflect the limited sample size or the absence of an independent association or differences between embolic agents in our cohort. (Table 3).

Table 3
Logistic regression analysis of factors associated with recurrence

Category	Univariable Analysis	Odds Ratio	95% CI	P-value
Clinical factors	Age (years)	**1.05**	1.01–1.08	**0.005**
	History of smoking	**2.26**	1.12–4.55	**0.023**
	History of seizures	**3.74**	1.29–10.86	**0.015**
	Postoperative head trauma	**6.43**	1.39–29.86	**0.017**
	General anesthesia	7.52	0.99–56.89	0.051
	Hypertension	1.86	0.95–3.67	0.072
	Previous antiplatelet therapy	0.50	0.22–1.14	0.099
Hematoma measurements	Thickness	1.14	1.09–1.21	**< 0.001**
	Length	1.01	1.00-1.02	**< 0.001**
	Height	1.01	0.99–1.02	0.073
Type of treatment	Surgery + embolization	**0.44**	0.22–0.88	**0.021**
	Embolization alone	0.42	0.16–1.09	0.075
Surgical variables	Type of surgery: craniotomy	1.57	0.70–3.51	0.272
	Type of surgery: single burr-hole	3.12	0.84–11.55	0.088
	Type of surgery: double burr-hole	1.25	0.29–5.25	0.761
	Days of durostomy drainage	0.76	0.56–1.05	0.094
	Post-drain pneumocephalus	**3.39**	1.64–7.00	**0.001**
Endovascular variables	Embolic material: cyanoacrylate	**0.14**	0.02–0.89	**0.038**
	Embolic material: microparticles	**0.08**	0.007–0.82	**0.034**
	Embolic material: Onyx	0.47	0.12–1.90	0.293
	Embolic material: Phil	0.40	0.03–4.68	0.465
	Embolic material: Coils	0.75	0.12–4.48	0.753
	Liquid	1.74	0.55–5.45	0.34
	Particles	0.17	0.02–1.34	0.09

Category	Univariable Analysis	Odds Ratio	95% CI	P-value
	Coils	2.27	0.56–9.21	0.25
Category	**Multivariable Analysis**	**Odds Ratio**	**95% CI**	**P-value**
Clinical factors	Age (years)	1.07	1.00-1.16	**0.045**
	History of smoking	9.59	1.93–47.52	**0.006**
	Hypertension	5.23	1.14–23.93	**0.033**
	General anesthesia*	13.42	1.93-187.26	0.053
Hematoma measurements	Thickness	1.20	1.05–1.37	**0.005**
Type of treatment	Surgery + embolization	0.23	0.06–0.85	**0.029**
Surgical variables	Days of durostomy drainage	0.51	0.30–0.85	**0.011**
	Post-drain pneumocephalus	13.32	2.83–62.65	**< 0.001**

**Anesthesia was retained in the multivariable model as a potential confounding variable in the association with age.*

DISCUSSION

This study provides real-world multicenter data in our population on factors associated with recurrence and reintervention in naSDH. Few studies have offered a comprehensive analysis integrating the full spectrum of variables involved in patient management, including clinical characteristics, contemporary treatment strategies such as standalone or combined endovascular approaches, and surgery-related factors.

Clinical factors

Advanced age is considered one of the most important risk factors for cSDH, and previous studies have identified distinct clinical presentations in elderly patients compared with younger populations (20). In our cohort, most patients were in the 6th and 7th decades of life. Similarly, male sex has also been associated with a higher probability of developing cSDH as in our series where the majority of patients were male. However, neither age or sex showed a significant association with recurrence or reintervention (Table 1). These findings suggest that both factors may have a stronger role in the initial development of cSDH rather than in the risk of recurrence once the condition has been treated. Despite the well-recognized predominance of advanced age and male sex in the epidemiology of cSDH, similar findings were observed in our naSDH cohort. The role of these demographic variables in postoperative

recurrence remains uncertain, and several studies have reported inconsistent associations between age or sex and recurrence rates. In the large cohort analyzed by Salmanian et al., a clear predominance of elderly and male patients was also observed, while recurrence rates did not significantly differ between these groups. (21)

In the logistic regression analysis, all variables were evaluated using recurrence as the primary outcome, as this group inherently includes patients who required retreatment. Given that the main clinical objective is to prevent recurrence, this approach was considered the most relevant. In the univariable analysis, a history of smoking and seizures were associated with an increased risk of recurrence, while prior hypertension showed a trend toward significance (Table 2). In multivariable analysis history of smoking remained strong risk predictor (OR 9.59, 95% CI 1.93–47.52), P = 0.006) and hypertension became statistical significant (OR 5.23, 95% CI-1.14-23.93, P = 0.033). This finding contrasts with the results reported by Yoon G. et al., who did not observe significant differences in smoking between the analyzed groups (17.8% in the non-recurrence group vs. 32% in the recurrence group). Although a trend toward significance was noted, hypertension was also not identified as a risk factor, which may be related to limited statistical power rather than a true absence of association. Similarly, the use of antiplatelet or anticoagulant medications was not associated with recurrence in their study, consistent with the findings observed in our cohort (Table 1, Table 2). (22). Fewer patients with prior anticoagulant or antiplatelet use were observed in the recurrence and reintervention groups, although neither variable showed a significant association with these outcomes in our cohort. Interestingly, in the univariable analysis, antiplatelet therapy showed a trend toward a protective effect, although this did not reach statistical significance. One limitation of our study is that we did not perform a subanalysis according to the timing of blood thinner resumption, which may have influenced these findings. This aspect may be relevant, as Zanaty et al. reported that recurrence risk varied according to the timing of antithrombotic resumption, with higher recurrence observed when oral anticoagulation was restarted within the first 48 hours, whereas resumption after 2 days and before 21 days appeared to provide a more favorable balance between recurrence and thromboembolic risk. In that study, anticoagulant and antiplatelet agents were associated with recurrence in univariable analyses, but they were not retained as independent predictors in the multivariable model. (23)

Treatment modalities

This aspect plays a relevant role in recurrence and reintervention risk. In our cohort, the combined strategy of surgical evacuation and middle meningeal artery embolization was associated with a lower likelihood of recurrence compared with single-modality approaches, remaining significant in the multivariable analysis. This finding supports the concept that addressing both the mechanical component of the hematoma through surgical evacuation and the underlying vascularized membranes through embolization may provide a more comprehensive therapeutic effect. In contrast, embolization as a standalone treatment showed a trend toward lower recurrence in the univariable analysis but did not reach statistical significance in our cohort. Nevertheless, growing evidence suggests that embolization alone may represent a reasonable therapeutic option in selected patients, particularly when surgical

treatment is contraindicated. Recent consensus recommendations from the Society of Vascular and Interventional Neurology state that MMA embolization may be considered as a standalone therapy in patients with chronic subdural hematoma in whom surgery is not feasible. (10)

These results are consistent with the growing body of evidence suggesting that middle meningeal artery embolization can reduce treatment failure and recurrence when incorporated into the management of chronic subdural hematoma (10, 11, 17). Recent randomized trials evaluating adjunctive embolization have demonstrated improved treatment durability compared with conventional management alone, supporting the role of endovascular therapy as part of the treatment algorithm. Additionally, recent meta-analyses including randomized evidence have reinforced the benefit of embolization strategies in reducing recurrence and reintervention risk, particularly when used as an adjunct to surgical evacuation(24) these findings emphasize the importance of a multidisciplinary treatment strategy.

Radiological subtypes

Hematoma internal architecture was significantly associated with both recurrence and the need for reintervention, suggesting that radiological subtype may play an important role in predicting treatment durability. Laminar and sedimented hematomas showed the highest recurrence rates, whereas more organized subtypes such as trabecular or bridging hematomas were associated with lower recurrence. This is consistent with prior studies evaluating the role of internal hematoma architecture in predicting recurrence. Hamou et al. demonstrated that hematoma subtype classification based on CT internal architecture is significantly associated with recurrence risk. (8). This relationship has been hypothesized to reflect the natural history of the disease as hematomas with less internal organization may reflect earlier stages of the disease process characterized by active inflammation and fragile neovascularization. These findings suggest that hematoma subtype classification could potentially contribute to treatment decision-making as this assessment may help identify patients at higher risk of recurrence who could benefit from closer follow-up or adjunctive therapies.

Endovascular treatment cohort analysis

The timing of embolization in the combined treatment group varied in our cohort. In this group, most patients underwent MMA embolization after surgical evacuation. Although we did not observe differences according to the timing of MMAE in relation to surgery, this issue has been previously explored by Hamza Salim et al. in a larger combined-treatment cohort, where preoperative MMA embolization was associated with lower odds of reintervention (OR 0.35, $p = 0.003$). (25) However, a RCT evaluating only postoperative MMA embolization reported no symptomatic recurrence in the embolization group. (26) Therefore, the optimal timing of MMA embolization remains uncertain. Nevertheless, performing embolization before surgical drainage may be advantageous, as it could allow more complete occlusion of distal meningeal branches and membrane neovascularization involved in the pathophysiology of non-acute subdural hematoma before surgical alteration of the vascular anatomy.

The type of embolic material did not appear to influence recurrence in our cohort, although an association with reintervention was observed. In our series, several liquid embolic agents were used—including Onyx, Phil, Squid, and cyanoacrylate—along with microparticles and coils, currently previously mentioned RCTs were performed predominantly with liquid embolics, therefore, when embolic materials were grouped by category, most procedures were performed using liquid embolic agents, followed by microparticles and coils (Supplemental Table 1), without significant differences between groups. In the univariable analysis, both cyanoacrylate and microparticles showed a significant protective association, although no embolic material remained independently associated with outcomes in the multivariable model. Interestingly, microparticles also showed a protective association in the univariable analysis. This finding should be interpreted cautiously,, as randomized evidence evaluating microparticles as the primary embolic agent remains limited, and previous studies have reported comparable safety and efficacy between liquid embolic agents and (27–29). The EMPROTECT randomized clinical trial did not demonstrate a statistically significant reduction in recurrence with particle embolization. In this trial, embolization was performed using 300–500 μm microparticles, which may have limited distal penetration into the pathological neovascular membrane and failed to adequately occlude dural anastomotic channels, potentially resulting in incomplete embolization compared with liquid agents. (30) Furthermore, the influence of particle size and morphology, including spherical versus non-spherical configurations, on therapeutic outcomes warrants further investigation. In our study, the number of patients treated with microparticles was limited, and, as an additional limitation, detailed information regarding the particle size used was not available. Moreover, other factors such as the diameter of the middle meningeal artery or the presence of potentially dangerous MMA anastomoses may influence the selection of embolic material, suggesting that treatment choice may depend more on vascular anatomy and procedural characteristics than on the intrinsic properties of a specific agent (See Fig. 1) (31)

(C, D) Selective catheterization of the left MMA parietal branch showing an anastomosis with the petrosquamosal branch (white arrow), treated with proximal coil embolization (Target 360 Ultra 2x6mm). (E, F) Catheterization of the frontal branch (white arrowhead) followed by embolization with liquid embolic agent (Onyx). (G, H) One-month Follow-up NCCT showing reduction in hematoma size, with no rebleeding.

This is consistent with contemporary endovascular practice, where treatment efficacy appears to rely more on adequate distal penetration and complete occlusion of meningeal branches than on the specific embolic agent selected, and with recent evidence demonstrating no significant differences in clinical outcomes between coil-only and liquid or particle embolization strategies (32).

Finally, catheter positioning within the middle meningeal artery did not significantly influence recurrence in our cohort. However, prior technical analyses suggest that embolization of both the anterior and posterior MMA branches may be associated with higher rates of hematoma resolution, emphasizing the importance of adequate distal penetration and vascular coverage of the hematoma membranes (33).

Surgical treatment cohort analysis

Regarding surgical factors, the type of surgical procedure did not show a significant association with recurrence or reintervention in our cohort. Craniotomy, single burr hole, and double burr hole trephination showed comparable outcomes, although in the univariable analysis a trend toward a protective effect was observed for single burr hole drainage. (Supplemental Table 2) This finding is consistent with previous studies reporting no significant differences in recurrence between single and double burr hole techniques for chronic subdural hematoma evacuation (34).

Hematoma thickness remained independently associated with recurrence in the multivariable analysis. Larger hematoma thickness has been previously described as a predictor of recurrence, likely reflecting a larger subdural cavity and impaired postoperative brain re-expansion (35). Postoperative pneumocephalus showed a strong association with both recurrence and reintervention in our cohort, supporting the hypothesis that poor brain re-expansion and persistence of the subdural space favor hematoma reproduction. In line with this concept, postoperative drainage has been consistently associated with lower recurrence rates. In a large multicenter cohort, recurrence rates were significantly higher in patients without drainage compared with those with drain placement (16.1% vs. 5.4%, $p < 0.01$), supporting the role of postoperative drainage in reducing recurrence risk (36)

CONCLUSIONS

In our study, clinical factors showed the strongest association with recurrence and reintervention. Among treatment-related variables, combined management demonstrated an independent protective effect. Most technical factors related to endovascular treatment did not show significant differences, which is consistent with the majority of published studies and may also be partially explained by limited statistical power in some subgroup analyses. Additionally, postoperative pneumocephalus and the duration of subdural drainage were associated with a relevant impact on clinical outcomes.

LIMITATIONS

This study has several limitations. First, its retrospective design may introduce selection bias and limit the generalizability of the findings. Second, although the cohort reflects real-world clinical practice, the number of events in some subgroups was relatively small, which may have limited the ability to detect differences across certain procedural variables. In addition, treatment strategies including embolic material selection, catheter positioning, and timing of embolization were not standardized and were influenced by operator preference and anatomical considerations, which may have introduced procedural variability. Therefore, these results should be interpreted with caution, and further prospective studies are needed to better clarify the impact of specific technical factors on outcomes.

Declarations

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This study was conducted in accordance with established ethical principles for human research and in compliance with the Declaration of Helsinki and its subsequent revisions. The protocol was approved by the Institutional Review Board of the participating centers. Due to the retrospective nature of the study and the use of anonymized data, the requirement for written informed consent was waived.

CONSENT FOR PUBLICATION

Not applicable.

CLINICAL TRIAL NUMBER

Not applicable.

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHOR CONTRIBUTIONS STATEMENT

C.A.L.N. contributed to the conception and design of the study, data analysis, interpretation of the results, and drafting of the manuscript. D.M. contributed to study design, supervision, and critical revision of the manuscript for important intellectual content. J.R.M., O.E.G.L., B.L., V.M.Q., J.A.M., L.O., A.M.R., C.R., L.C.P., C.A.B., M.F., Y.E.M., M.A.M., S.S.M., A.V., A.F.O., C.F.P., and O.V. contributed to data acquisition, interpretation of data, and critical revision of the manuscript.

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Author Contribution

C.A.L.N. contributed to the conception and design of the study, data analysis, interpretation of the results, and drafting of the manuscript. D.M. contributed to study design, supervision, and critical revision of the manuscript for important intellectual content.J.R.M., O.E.G.L., B.L., V.M.Q., J.A.M., L.O., A.M.R., C.R., L.C.P., C.A.B., M.F., Y.E.M., M.A.M., S.S.M., A.V., A.F.O., C.F.P., and O.V. contributed to data acquisition, interpretation of data, and critical revision of the manuscript.

AVAILABILITY OF DATA AND MATERIALS

The datasets generated and/or analyzed during the current study are not publicly available due to institutional policies but are available from the corresponding author on reasonable request.

References

1. Moore AR, Wieczorek PM, Carvalho JCA (2020) Association between Post-Dural Puncture Headache after Neuraxial Anesthesia in Childbirth and Intracranial Subdural Hematoma. JAMA Neurol 77(1):65–72. 10.1001/jamaneurol.2019.2995PubMed PMID: 31524925
2. Kane SF, Butler E, Sindelar BD (2023) Nontraumatic Subarachnoid Hemorrhage and Ruptured Intracranial Aneurysm: Recognition and Evaluation. Am Fam Physician 108(4):386–395 PubMed PMID: 37843947
3. Omura Y, Ishiguro T (2023) Middle meningeal artery embolization for chronic subdural hematoma: a systematic review. Front Neurol 14(October). 10.3389/fneur.2023.1259647
4. Huang KT, Bi WL, Abd-El-Barr M, Yan SC, Tafel IJ, Dunn IF et al (2016) The Neurocritical and Neurosurgical Care of Subdural Hematomas. Neurocrit Care 24(2):294–307. 10.1007/s12028-015-0194-xPubMed PMID: 26399248
5. Mehta V, Harward SC, Sankey EW, Nayar G, Codd PJ (2018) Evidence based diagnosis and management of chronic subdural hematoma: A review of the literature. J Clin Neurosci 50:7–15. 10.1016/j.jocn.2018.01.050PubMed PMID: 29428263
6. Robinson D, Kreitzer N, Ngwenya LB, Adeoye O, Woo D, Hartings J et al (2021) Diffusion-Weighted Imaging Reveals Distinct Patterns of Cytotoxic Edema in Patients with Subdural Hematomas. J Neurotrauma 38(19):2677–2685. 10.1089/neu.2021.0125PubMed PMID: 34107754
7. Lim M, Kheok SW, Lim KC, Venkatanarasimha N, Small JE, Chen RC (2019) Subdural haematoma mimics. Clin Radiol 74(9):663–675. 10.1016/j.crad.2019.04.013 PubMed PMID: 31109715
8. Hamou H, Alzaiyani M, Pjontek R, Kremer B, Albanna W, Ridwan H et al (2022) Risk factors of recurrence in chronic subdural hematoma and a proposed extended classification of internal architecture as a predictor of recurrence. Neurosurg Rev 45(4):2777–2786. 10.1007/s10143-022-01790-8PubMed PMID: 35461433
9. Edlmann E, Giorgi-Coll S, Whitfield PC, Carpenter KLH, Hutchinson PJ (2017) Pathophysiology of chronic subdural haematoma: Inflammation, angiogenesis and implications for pharmacotherapy. J Neuroinflammation 14(1):1–13. 10.1186/s12974-017-0881-y PubMed PMID: 28558815
10. Davies JM, Knopman J, Mokin M, Hassan AE, Harbaugh RE, Khalessi A et al (2024) Adjunctive Middle Meningeal Artery Embolization for Subdural Hematoma. N Engl J Med 391(20):1890–1900. 10.1056/nejmoa2313472PubMed PMID: 39565988
11. Fiorella D, Monteith SJ, Hanel R, Atchie B, Boo S, McTaggart RA et al (2025) Embolization of the Middle Meningeal Artery for Chronic Subdural Hematoma. N Engl J Med 392(9):855–864. 10.1056/nejmoa2409845PubMed PMID: 39565980

12. Miah IP, Holl DC, Blaauw J, Lingsma HF, den Hertog HM, Jacobs B et al (2023) Dexamethasone versus Surgery for Chronic Subdural Hematoma. N Engl J Med 388(24):2230–2240. 10.1056/nejmoa2216767PubMed PMID: 37314705
13. Maher Hulou M, McLouth CJ, Hayden CS, Sheldrake AK, Parekh M, Dillen WL et al (2020) Predictors of re-operation in the setting of non-acute subdural hematomas: A 12-year single center retrospective study. J Clin Neurosci 81:334–339. 10.1016/j.jocn.2020.09.052 PubMed PMID: 33222941
14. Lizana J 1, Aliaga N 2 (2021) Chronic subdural hematoma: A common pathology with complex management. Surg Neurol Int 12(510):36–37. 10.25259/SNI_676_2021
15. Schmidt L, Gørtz S, Wohlfahrt J, Melbye M, Munch TN (2015) Recurrence of subdural haematoma in a population-based cohort - Risks and predictive factors. PLoS ONE 10(10):1–13. 10.1371/journal.pone.0140450PubMed PMID: 26465602
16. Foppen M, Bandral HV, Slot KAM, Vandertop WP, Verbaan D (2023) Success of conservative therapy for chronic subdural hematoma patients: a systematic review. Front Neurol 14(September). 10.3389/fneur.2023.1249332
17. Liu J, Ni W, Zuo Q, Yang H, Peng Y, Lin Z et al (2024) Middle Meningeal Artery Embolization for Nonacute Subdural Hematoma. N Engl J Med 391(20):1901–1912. 10.1056/nejmoa2401201PubMed PMID: 39565989
18. Grønhøj MH, Jensen TSR, Johannsson B, Fugleholm K, Rom-Poulsen F (2023) Early spontaneous cessation of subdural drainage after burr hole evacuation of chronic subdural hematoma and risk of recurrence. PLoS ONE 18(5 May):1–12. 10.1371/journal.pone.0285750PubMed PMID: 37195980
19. Fratini A, Noya C, Santi S, Cannizzaro P, Pampana E, Fabiano S et al (2025) Perioperative Predictors of Recurrency in Chronic Subdural Hematoma: A Retrospective Analysis of 150 Consecutive Cases. World Neurosurg 204:124529. 10.1016/j.wneu.2025.124529PubMed PMID: 41072912
20. Bartek J, Sjåvik K, Dhawan S, Sagberg LM, Kristiansson H, Ståhl F et al (2019) Clinical course in chronic subdural hematoma patients aged 18–49 compared to patients 50 years and above: A multicenter study and meta-analysis. Front Neurol 10(APR):1–9. 10.3389/fneur.2019.00311
21. Salmanian S, Rodemerk J, Al-Rubaiey S, Ahmadzai M, Timner E, Schock L et al (2025) Age-Related Comparative Study of In-Hospital Mortality, Functional Outcome, and Recurrence in a Large Cohort of Patients Surgically Treated for Chronic Subdural Hematoma. J Clin Med 14(21):1–22. 10.3390/jcm14217856
22. Jung YG, Jung NY, Kim E (2015) Independent predictors for recurrence of chronic subdural hematoma. J Korean Neurosurg Soc 57(4):266–270. 10.3340/jkns.2015.57.4.266
23. Zanaty M, Park BJ, Seaman SC, Cliffton WE, Woodiwiss T, Piscopo A et al (2020) Predicting Chronic Subdural Hematoma Recurrence and Stroke Outcomes While Withholding Antiplatelet and Anticoagulant Agents. Front Neurol 10(January):1–8. 10.3389/fneur.2019.01401
24. de Almeida Monteiro G, Mutarelli A, Gonçalves OR, Marinheiro G, Santana L, Fukunaga CK et al (2025) Middle meningeal artery embolization for chronic subdural hematoma: a meta-analysis of

randomized controlled trials with trial sequential analysis. Neurosurg Rev 48(1):1–13. 10.1007/s10143-025-03464-7PubMed PMID: 40210750

25. Salim HA, Shehadeh W, Hajjeh O, Dmytriw AA, Chen H, Essibayi MA et al (2025) Preoperative middle meningeal artery embolization is associated with reduced reoperation rates in chronic subdural hematoma. Interventional Neuroradiol. doi:10.1177/15910199251372487 PubMed PMID: 40891770.
26. Lam A, Selvarajah D, Htike SS, Chan S, Lalloo S, Lock G et al (2022) The efficacy of postoperative middle meningeal artery embolization on chronic subdural hematoma – A multicentered randomized controlled trial. Surg Neurol Int 14(168):36–37. 10.25259/SNI_208_2023
27. Scoville JP, Joyce E, Tonetti A, Bounajem D, Thomas MT, Ogilvy A (2023) Radiographic and clinical outcomes with particle or liquid embolic agents for middle meningeal artery embolization of nonacute subdural hematomas. Interventional Neuroradiol 29(6):683–690 doi:10.1177/15910199221104631 PubMed PMID: 35673710
28. Chen Cjen, Mackenzie L, Jabbour P (2023) Onyx Versus Particles for Middle Meningeal Artery. 92. ;92(5)
29. Krothapalli N, Patel S, Fayad M, Elmashad A, Killory B, Bruno C et al (2023) Outcomes of Particle versus Liquid Embolic Materials Used in Middle Meningeal Artery Embolization for the Treatment of Chronic Subdural Hematoma. World Neurosurg 173:e27–36. 10.1016/j.wneu.2023.01.077PubMed PMID: 36706981
30. Shotar E, Mathon B, Salle H, Rouchaud A, Mounayer C, Bricout N et al (2025) Meningeal Embolization for Preventing Chronic Subdural Hematoma Recurrence After Surgery: The EMPROTECT Randomized Clinical Trial. JAMA 334(2):127–135. 10.1001/jama.2025.7583PubMed PMID: 40471557
31. Salem MM, Kuybu O, Hoang AN, Baig AA, Khorasanizadeh M, Baker C et al (2023) Middle Meningeal Artery Embolization for Chronic Subdural Hematoma: Predictors of Clinical and Radiographic Failure from 636 Embolizations. Radiology 307(4). 10.1148/radiol.222045PubMed PMID: 37070990
32. Fecker A, McIntyre MK, Chen H, Abaricia JO, Priest R, Nesbit G et al (2025) Coil only middle meningeal artery embolization versus particles or liquid embolic agents for chronic subdural hematoma. J Neurointerv Surg 1–6. 10.1136/jnis-2025-023848
33. Catapano JS, Ducruet AF, Nguyen CL, Baranoski JF, Cole TS, Majmundar N et al (2021) Middle meningeal artery embolization for chronic subdural hematoma: An institutional technical analysis. J Neurointerv Surg 13(7):657–660. 10.1136/neurintsurg-2020-016552PubMed PMID: 33077579
34. Sale D (2021) Single versus Double Burr Hole for Drainage of Chronic Subdural Hematoma: Randomized Controlled Study. World Neurosurg 146:e565–e567. 10.1016/j.wneu.2020.10.140PubMed PMID: 33130139
35. Vyas SN, Sharma A (2025) Factors Predicting Recurrence and Resolution of Chronic SDH after Surgery. Asian J Neurosurg 20(01):112–118. 10.1055/s-0044-1796663

36. Cofano F, Pesce A, Vercelli G, Mammi M, Massara A, Minardi M et al (2020) Risk of Recurrence of Chronic Subdural Hematomas After Surgery: A Multicenter Observational Cohort Study. Front Neurol 11(November):1–10. 10.3389/fneur.2020.560269

Figures

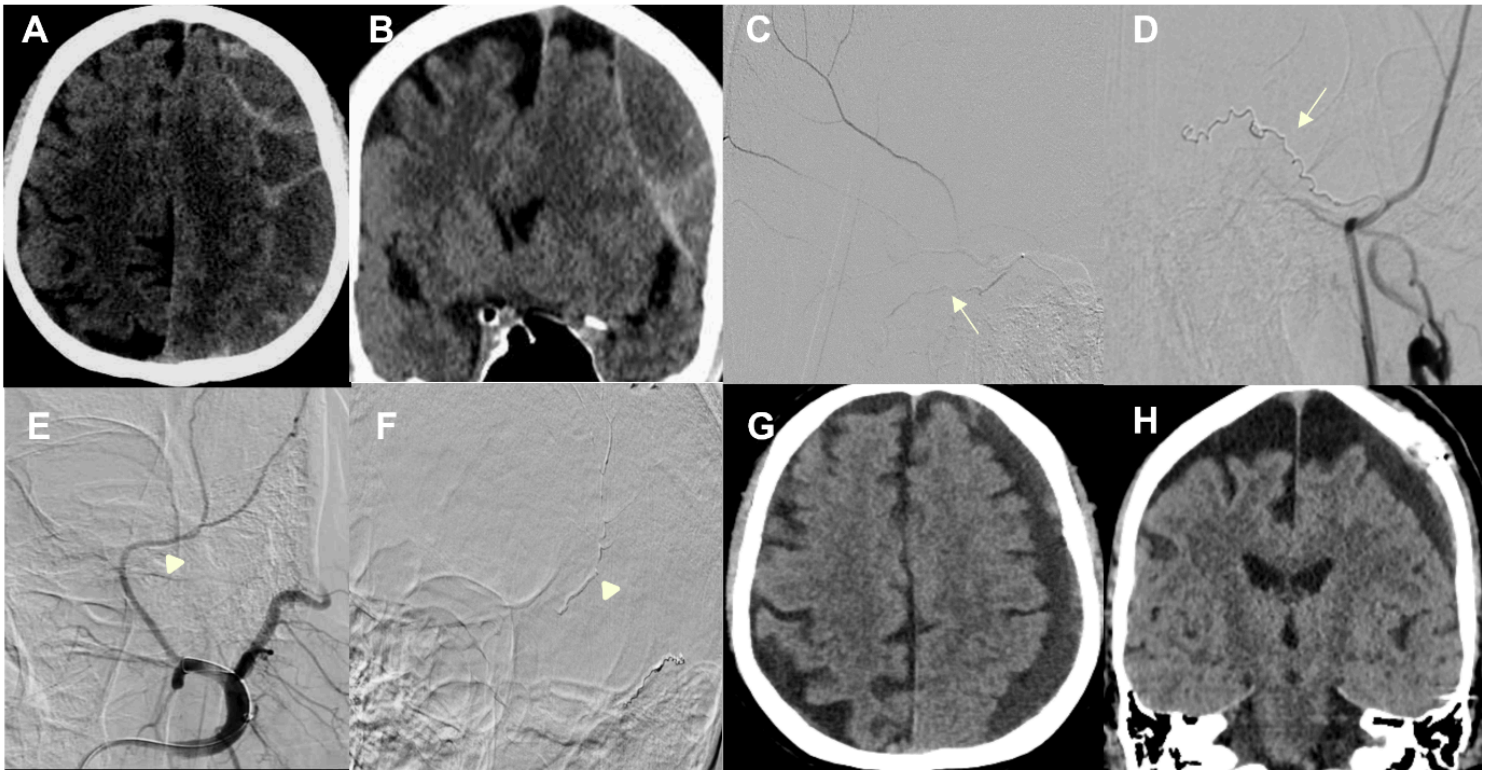


Figure 1

An 80-year-old male with progressive cognitive decline, bradypsychia, and right hemiparesis. The patient underwent emergent surgical drainage followed by left middle meningeal artery (MMA) embolization, achieving complete occlusion and favorable neurological outcome without complications. (A, B) Axial and coronal NCCT demonstrating cSDH with rebleeding, mass effect, and subfalcine herniation. (C, D) Selective catheterization of the left MMA parietal branch showing an anastomosis with the petrosquamosal branch (white arrow), treated with proximal coil embolization (Target 360 Ultra 2x6mm). (E, F) Catheterization of the frontal branch (white arrowhead) followed by embolization with liquid embolic agent (Onyx). (G, H) One-month Follow-up NCCT showing reduction in hematoma size, with no rebleeding.

Supplementary Files

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- SupplementalTable1.docx

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