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Surgical evacuation for chronic subdural hematoma: Predictors of reoperation and functional outcomes

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ABSTRACT

Background: Although chronic subdural hematoma (CSDH) incidence has increased, there is limited evidence to guide patient management after surgical evacuation.
Objective: To identify predictors of reoperation and functional outcome after CSDH surgical evacuation.
Methods: We identified all patients with CSDH between 2010 and 2018. Clinical and radiographic variables were collected from the medical records. Outcomes included reoperation within 90 days and poor (3–6) modified Rankin Scale score at 3 months.
Results: We identified 461 surgically treated CSDH cases (396 patients). The mean age was 70.1 years, 29.7 % were females, 298 (64.6 %) underwent burr hole evacuation, 152 (33.0 %) craniotomy, and 11 (2.4 %) craniectomy. Reoperation rate within 90 days was 12.6 %, whereas 24.2 % of cases had a poor functional status at 3 months. Only female sex was associated with reoperation within 90 days (OR = 2.09, 95 % CI: 1.17–3.75, $P = 0.013$). AMS on admission (OR = 5.19, 95 % CI: 2.15–12.52, $P < 0.001$) and female sex (OR = 3.90, 95 % CI: 1.57–9.70, $P = 0.003$) were independent predictors of poor functional outcome at 3 months.
Conclusion: Careful management of patients with the above predictive factors may reduce CSDH reoperation and improve long-term functional outcomes. However, larger randomized studies are necessary to assess long-term prognosis after surgical evacuation.

1. Introduction

Chronic subdural hematoma (CSDH) incidence is expected to increase significantly and is so common that it is projected to be the most prevalent cranial condition among adults by 2030.[1] The incidence is increasing because of the ageing population.[2] Patients with CSDH are generally difficult to treat with high rates of readmission,[3] high inpatient costs,[4] and mortality rates ranging from 1.5 % to 32 % depending on the age and comorbidities.[5,6] The reported recurrence rates range from 5 % to 33 %.[3,7–10] Recurrence leads to a significant economic burden to the family and society.[11] Several studies have identified predictors for CSDH recurrence, usually with mixed results.[9,12] Despite the decreasing mortality after subdural hematoma (SDH), it is still unclear if functional recovery has improved.[4] Additionally, there is limited data regarding risk factors for readmission after SDH evacuation, and there is limited understanding of the differences in predictive factors between SDH types.[3] As the healthcare system is moving towards patient-centered

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Abbreviations

AMS	Altered Mental Status
AUROC:	Area Under the ROC CI: Confidence interval
CSDH	Chronic Subdural Hematoma
CT	Computed Tomography
CVD	Cardiovascular disease
GCS	Glasgow Coma Scale/Score
IQR	Interquartile range
MLS	Midline Shift
OR	Odds Ratio
ROC:	Receiver-Operating Characteristics
SDH	Subdural Hematoma
TBI	Traumatic Brain Injury

care, we aimed to identify the predictors of postoperative hematoma clearance, reoperation, and functional outcomes after CSDH evacuation.

2. Methods

2.1. Study population

We performed a retrospective review of patients undergoing operative evacuation of CSDH in our center between 2010 and 2018. The study is in accordance with the Strengthening the Reporting of Observational studies in Epidemiology (STROBE) guidelines. It was approved by the Institutional Review Board (IRB), and patient consent was waived due to the study's retrospective design. We included adult patients undergoing burr hole drainage, craniotomy, and craniectomy, and all CSDH variations were included. Bilateral SDH on a patient was considered as two separate cases.

2.2. Data collection

Baseline and postoperative data for all patients were obtained and included age, sex, race, hypertension, CVD, blood thinners, Glasgow Coma Scale/Score (GCS), smoking, unilateral or bilateral hematoma, presenting symptoms, presenting CT findings (MLS, hematoma thickness, hematoma area, atrophy), mode of treatment, surgical complications, postoperative and follow-up CT findings, follow-up duration, reoperation within 90 days, and mRS at three months. Hematoma area was measured manually as the largest area of the hematoma in the axial plane with freehand region of interest in cm^2. Clearance rate (percent hematoma thickness change[12]) was defined as the SDH thickness difference of the postoperative from the preoperative axial CT scan at the thickest slices, divided by the preoperative thickness.

2.3. Outcome measures

The outcome measures were reoperation within 90 days and modified Rankin Scale (mRS) score at 3 months in cases with available follow-up. The mRS score was dichotomized to 0–2 (good functional outcome) and 3–6 (poor functional outcome) to express the difference between the dependent and independent functional status. Reoperation decision was at the surgeon's discretion due to continued symptoms, acute SDH, residual hematoma, or hematoma recurrence.

2.4. Statistical analyses

Univariable predictors of reoperation within 90 days and poor functional outcome were identified using binary logistic regression models. Those predictors with p values < 0.1 were then entered into multivariable logistic regression models to identify independent predictors of reoperation within 90 days and poor functional outcome. Tolerance and variance inflation factors were used to test the covariates for multicollinearity. The fit of the models was assessed using the Hosmer–Lemeshow goodness-of-fit test. To assess the performance of clearance in predicting no reoperation within 90 days, a nonparametric receiver-operating characteristics (ROC) curve was generated, and Youden's index was used. An area under the ROC (AUROC) curve of 0.5 indicates no discrimination, while an AUROC curve of 1.0 indicates perfect discrimination. Stratified analyses were performed for treatment type and SDH acuity, and the subgroup AUROC curves were compared using Chi-square statistics. All tests were two-tailed, and statistical significance was defined as $p < 0.05$. Missing data were not imputed, but were dropped out for each outcome in the analysis. All analyses were performed using the Stata software (version 17.0, College Station, TX).

3. Results

A total of 461 cases (396 patients) surgically treated for CSDH were identified. The mean age was 70.1 (13.1) years, and 29.7 % were females. In total, 74.0 % of cases had hypertension, 10.1 % used both antiplatelets and anticoagulants before admission, and 15.6 % were smokers (Table 1).

Admission clinical and radiological characteristics are shown in Table 2. The median (Interquartile range, IQR) GCS on admission was 15 (14–15), and the most common symptom was headache (46.0 %), followed by AMS (36.0 %). In total, 31.9 % of hematomas were bilateral. On admission, the mean midline shift was 6.9 (5.0) mm, and 46.7 % had brain atrophy.

Operative and postoperative variables are summarized in Table 3. Of the cases, 298 (64.6 %) underwent burr hole evacuation (41 with one and 257 with two burr holes), while 152 (33.0 %) and 11 (2.4 %) underwent craniotomy and craniectomy, respectively. Postoperative seizures (2.8 %) were the most common surgical complication following the need for retreatment (11.7 %). Overall, complications occurred in 17.4 % of the cases. Immediately postoperatively, 66.8 % of cases had partial evacuation with persistent MLS, and 5.6 % had complete evacuation without MLS. The mean postoperative hematoma clearance rate was 40 % (40 %).

Follow-up and outcome variables are presented in Table 4. The median (IQR) radiographic follow-up was 1.5 (1–3) months, with 41.0 % of cases having complete evacuation without MLS. Fifty-four patients (12.6 %) underwent reoperation within 90 days. The mean clinical follow-up duration was 2 (1–4) months, with 24.2 % of cases having a poor functional status at 3 months and 5.8 % being deceased.

Table 1
Demographics and medical history.

	Total, *n* (%)
Number of patients	396
Number of cases, *n*	461
Patient demographics and medical history	
Age, mean (SD)	70.1 (13.1)
Females, *n* (%)	137/461 (29.7)
Race	
White, *n* (%)	291/461 (63.1)
African Amerian, *n* (%)	111/461 (24.1)
Asian, *n* (%)	26/461 (5.6)
Hispanic, *n* (%)	8/461 (1.7)
Unknown, *n* (%)	25/461 (5.4)
Hypertension, *n* (%)	336/454 (74.0)
Cardiovascular disease, *n* (%)	200/444 (45.0)
Use of antiplatelets only, *n* (%)	156/416 (37.5)
Use of anticoagulants only, *n* (%)	59/416 (14.2)
Use of both antiplatelets and anticoagulants, *n* (%)	42/416 (10.1)
Smoking, *n* (%)	68/435 (15.6)

SD, standard deviation.

Table 2
Admission characteristics.

	Total, *n* (%)
Admission clinical characteristics	
Admission GCS, median (IQR)	15 (14–15)
Symptomatic, *n* (%)	447/461 (97.0)
Headache, *n* (%)	212/461 (46.0)
Altered mental status, *n* (%)	166/461 (36.0)
Weakness, *n* (%)	130/461 (28.2)
Paresthesia, *n* (%)	30/461 (6.5)
Seizure, *n* (%)	22/461 (4.8)
Other, *n* (%)	124/461 (26.9)
Admission radiographic characteristics	
Laterality	
Unilateral, Left, *n* (%)	176/461 (38.2)
Unilateral, Right, *n* (%)	138/461 (29.9)
Bilateral, *n* (%)	147/461 (31.9)
Acuity	
Subacute, *n* (%)	56/461 (12.1)
Chronic, *n* (%)	103/461 (22.3)
Acute on Chronic, *n* (%)	134/461 (29.1)
Acute on Subacute, *n* (%)	23/461 (5.0)
Subacute on Chronic, *n* (%)	145/461 (31.5)
Admission CT findings	
Homogeneous isodense, *n* (%)	28/440 (5.5)
Homogeneous hyperdense, *n* (%)	13/440 (3.0)
Homogeneous hypodense, *n* (%)	39/440 (8.9)
Mixed density, *n* (%)	360/440 (81.8)
Midline shift, mean mm (SD)	6.9 (5.0)
Hematoma thickness, mean mm (SD)	18.4 (7.0)
Hematoma area, mean cm^2 (SD)	16.3 (7.7)
Brain atrophy, *n* (%)	192/411 (46.7)

CT, computed tomography scan; IQR, interquartile range; SD, standard deviation.

Table 3
Perioperative variables.

	Total, *n* (%)
Surgical approach	
Burr Hole(s), *n* (%)	298/461 (64.6)
1, *n* (%)	41/461 (8.9)
2, *n* (%)	257/461 (55.7)
Craniotomy, *n* (%)	152/461 (33.0)
Craniectomy, *n* (%)	11/461 (2.4)
Surgical complications	
Total, *n* (%)	80/461 (17.4)
Bleeding, *n* (%)	2/461 (0.4)
Infection, *n* (%)	8/461 (1.7)
Postop seizures, *n* (%)	13/461 (2.8)
Retreatment*, *n* (%)	54/461 (11.7)
Other, *n* (%)	13/461 (2.8)
Postop CT	
Findings	
Complete evacuation/Persistent MLS, *n* (%)	7/449 (0.9)
Complete evacuation/No MLS, *n* (%)	25/449 (5.6)
Partial evacuation/Persistent MLS, *n* (%)	300/449 (66.8)
Partial evacuation/No MLS, *n* (%)	117/449 (26.1)
Hematoma thickness, mean mm (SD)	12.9 (5.9)
Hematoma area, mean cm^2 (SD)	8.7 (5.9)
Hematoma postop clearance rate, mean (SD)	0.4 (0.4)

CT, computed tomography scan; MLS, midline shift; Postop, postoperative; SD, standard deviation. *Due to bleeding or insufficient hematoma evacuation or recurrence.

3.1. Predictors of reoperation

Reoperation within 90 days was associated only with female sex (OR = 2.09, 95 % CI: 1.17–3.75, $P = 0.013$, Table 5). No other variable with a *p*-value <0.1 was found to be entered into a multivariable logistic regression model.

Postoperative clearance was not associated with reoperation within 90 days ($P = 0.146$). The ROC of postoperative clearance and no reoperation revealed an AUROC of 0.5126 (Supplemental Fig. 1). Stratified analysis for treatment type subgroups and CSDH acuity showed that AUROC curves were not significantly different ($P = 0.819$ and 0.946, respectively; Supplemental Figs. 2 and 3).

Table 4
Follow-up and outcomes.

	Total, *n* (%)
Follow up CT	
Duration, median months (IQR)	1.5 (1–3)
Findings	
Complete evacuation/Persistent MLS, *n* (%)	9/383 (2.3)
Complete evacuation/No MLS, *n* (%)	157/383 (41.0)
Partial evacuation/Persistent MLS, *n* (%)	62/383 (16.2)
Partial evacuation/No MLS, *n* (%)	94/383 (24.5)
Recurrence	56/383 (14.6)
Hematoma thickness, median mm (IQR)	7.0 (0.0–11.6)
Hematoma area, median cm^2 (IQR)	2.9 (0–7.8)
Reoperation within 90 days, *n* (%)*	54/427 (12.6)
Follow up duration, median months (IQR)	2 (1–4)
mRS at 3 months**	
0, *n* (%)	133/359 (37.0)
1, *n* (%)	85/359 (23.7)
2, *n* (%)	54/359 (15.0)
3, *n* (%)	33/359 (9.2)
4, *n* (%)	28/359 (7.8)
5, *n* (%)	5/359 (1.4)
6 (Death), *n* (%)	21/359 (5.8)
3–6, *n* (%)	87/359 (24.2)

CT, computed tomography scan; IQR, interquartile range; mRS, modified Rankin Scale; MLS, midline shift. *Available for 92.6 % of cases.**Available for 77.9 % of cases.

3.2. Predictors of functional outcome

The predictors of poor (3–6) mRS at 90 days via univariable and multivariable logistic regression are presented in Table 6. In univariable analysis, poor outcome was associated with age ($P < 0.001$), both antiplatelet and anticoagulant use ($P = 0.045$), lower GCS ($P = 0.007$), unilateral CSDH ($P = 0.012$), absence of headache ($P < 0.001$), paresthesia ($P = 0.021$), seizures ($P = 0.007$), AMS ($P < 0.001$), preoperative thickness ($P = 0.006$), craniectomy ($P = 0.026$), postoperative thickness ($P = 0.032$), follow-up thickness ($P = 0.003$), and follow-up hematoma area ($P = 0.004$). Multivariable analysis identified two independent predictors of poor functional outcome within 90 days: Female sex (OR = 3.90, 95 % CI: 1.57–9.70, $P = 0.003$) and AMS (OR = 5.19, 95 % CI: 2.15–12.52, $P < 0.001$) on admission.

4. Discussion

CSDH is one of the most prevalent neurosurgical diseases, but its management is still controversial, considering the absence of randomized studies and evidence-based guidelines. We report an analysis of a big cohort of 461 cases with CSDH treated surgically, focusing on predicting CSDH postoperative clearance, reoperation, and functional outcome. We found that reoperation within 90 days is associated with female sex, whereas female sex and AMS on admission independently predict poor functional status at 3 months. This study presents 3-month functional outcomes and reoperation rates among consecutive patients with CSDH. It is one of the few to assess postoperative clearance and its association with outcomes.

We observed an acceptable reoperation rate (12.6 %) compared to a wide range of reported recurrence rates of 5–33 %.[3,7–10] However, the literature is heterogenous, as some studies report recurrence as reaccumulation requiring evacuation. According to Lakomkin et al,[3] the most common cause of readmission after CSDH evacuation was recurrent SDH (46.7 %). They found that hypertension requiring medication and abnormal INR were predictors of readmission after CSDH.[3] Our

Table 5
Univariable and multivariable predictors of reoperation within 90 days.

	No reoperation ($n = 373$)	Reoperation ($n = 54$)	Univariable		Multivariable	
			OR (95%CI)	*p*-value	OR (95%CI)	*p*-value
Age, mean years (SD)	69.5 (13.0)	70.7 (12.7)	1.00 (0.98–1.03)	0.507	–	–
Female, *n* (%)	103/373 (27.6)	24/54 (44.4)	2.09 (1.17–3.75)	**0.013**	2.09 (1.17–3.75)	**0.013**
Race, *n* (%)						
Unknown	18/373 (4.8)	2/54 (3.7)	Ref.	Ref.	–	–
White	242/373 (64.9)	31/54 (57.4)	1.15 (0.25–5.20)	0.853	–	–
African American	86/373 (23.1)	16/54 (29.6)	1.67 (0.35–7.93)	0.516	–	–
Asian	20/373 (5.4)	4/54 (7.4)	1.8 (0.29–11.03)	0.525	–	–
Hispanic	7/355 (1.9)	1/54 (1.9)	1.28 (0.09–16.53)	0.847	–	–
Hypertension, *n* (%)	280/373 (75.1)	39/52 (75.0)	0.99 (0.50–1.94)	0.992	–	–
CVD, *n* (%)	166/364 (45.6)	19/52 (36.5)	0.69 (0.37–1.25)	0.220	–	–
Antiplatelet/Anticoagulant use, *n* (%)						
Antiplatelet only	130/339 (38.3)	16/49 (32.7)	0.78 (0.42–1.46)	0.450	–	–
Anticoagulant only	51/339 (15.0)	3/49 (6.1)	0.37 (0.11–1.23)	0.106	–	–
Both	35/339 (10.3)	4/49 (8.2)	0.77 (0.26–2.26)	0.638	–	–
GCS, median (IQR)	15 (14–15)	15 (14.5–15)	0.95 (0.81–1.11)	0.491	–	–
Smoker, *n* (%)	53/361 (14.7)	6/47 (12.8)	0.85 (0.34–2.10)	0.726	–	–
Bilateral SDH, *n* (%)	122/373 (32.7)	17/54 (31.5)	0.94 (0.51–1.74)	0.857	–	–
Symptom, *n* (%)						
Headache	176/373 (47.2)	28/54 (51.9)	1.20 (0.68–2.13)	0.521	–	–
Weakness	107/373 (28.7)	13/54 (24.1)	0.78 (0.40–1.52)	0.482	–	–
Paresthesia	23/373 (6.2)	1/54 (1.9)	0.28 (0.03–2.17)	0.227	–	–
Seizure	21/373 (5.6)	0/54 (0)	0.221 (0–1.299)	0.109	–	–
AMS	129/373 (34.6)	22/54 (40.7)	1.30 (0.72–2.33)	0.377	–	–
SDH acuity, *n* (%)						
Subacute	45/373 (12.1)	6/54 (11.1)	0.91 (0.36–2.25)	0.840	–	–
Chronic	84/373 (22.5)	12/54 (22.2)	0.98 (0.49–1.95)	0.961	–	–
Acute on Chronic	104/373 (27.9)	19/54 (35.2)	1.40 (0.76–2.56)	0.270	–	–
Acute on Subacute	22/373 (5.9)	1/54 (1.9)	0.30 (0.03–2.27)	0.245	–	–
Subacute on Chronic	118/373 (31.6)	16/54 (29.6)	0.90 (0.48–1.69)	0.767	–	–
MLS, mean mm (SD)	6.9 (5.0)	7.3 (4.7)	1.01 (0.96–1.07)	0.572	–	–
Thickness, mean mm (SD)	18.2 (7.0)	19.1 (7.7)	1.01 (0.97–1.05)	0.362	–	–
Area, mean cm^2 (SD)	16.2 (7.7)	16.0 (7.0)	0.99 (0.95–1.03)	0.867	–	–
Brain atrophy, *n* (%)	151/337 (44.8)	23/47 (48.9)	1.18 (0.64–2.17)	0.595	–	–
Surgical approach, *n* (%)						
1 Burr hole	34/373 (9.1)	3/54 (5.6)	0.58 (0.17–1.97)	0.390	–	–
2 Burr holes	205/373 (55.0)	31/54 (57.4)	1.10 (0.62–1.96)	0.735	–	–
Craniotomy	123/373 (33.0)	20/54 (37.0)	1.19 (0.66–2.16)	0.555	–	–
Craniectomy	11/373 (3.0)	0/54 (0)	0.440 (0–2.761)	0.444	–	–
Postop thickness, mean cm^2 (SD)	12.6 (5.5)	13.7 (7.5)	1.03 (0.98–1.08)	0.227	–	–
Postop area, mean cm^2 (SD)	8.4 (5.5)	9.2 (6.4)	1.02 (0.97–1.07)	0.330	–	–
Postop clearance, mean (SD)	0.4 (0.4)	0.3 (0.6)	0.63 (0.34–1.17)	0.146	–	–

CVD, cardiovascular disease; GCS: Glasgow Coma Scale/Score; IQR, interquartile range; MLS, midline shift; OR, odds ratio; Postop, postoperative; SD, standard deviation; SDH: subdural hematoma.Bold values indicate statistical significance at $p < 0.05$.

findings suggest that only female sex was associated with reoperation within 90 days. There are mixed findings in the literature regarding male sex as a risk factor for the recurrence of CSDH. A systematic review and meta-analysis by Mishra et al[9] found that there was no association between gender and CSDH recurrence. The same study reported that recurrence after CSDH was associated with age, anticoagulation and antiplatelet therapy, diabetes, liver disease, obesity, seizures, bilateral CSDH, brain atrophy, homogeneous, laminar, or separated hematoma, MLS >10 mm, and hematoma thickness >20 mm.[9] However, another systematic review and meta-analysis by Zhu et al[13] found that male sex was a factor that correlates with postoperative recurrence of CSDH. Among the 21 factors that were associated with postoperative recurrence, male sex, bilateral hematoma, and no drainage had convincing evidence.[13] Randomized trials or larger, multicenter studies of SDH evacuation are needed to better evaluate the impact of surgery on CSDH recurrence and reoperation rates.

Postoperative hematoma clearance was not associated with reoperation in our study. According to Katsigiannis et al,[14] the percentage of hematoma drained correlated with recurrence, but did not independently predict outcome after surgery for chronic SDH. Motiei-Langroudi et al[12] found that percent hematoma thickness change on postoperative CT was a predictor of reoperation for patients with CSDH.

We found that female sex and AMS on admission were independent predictors of poor 3-month functional outcome, suggesting that admission symptoms may have long-term consequences on a patient's independence. Admission GCS was also associated with poor functional outcome. Various studies have reported the association between poor neurologic status on admission with worse outcomes in CSDH.[15,16] Weimer et al,[17] in a prospective study, found that poor admission neurological status, along with age, poor premorbid functional status, history of smoking, and fever during hospitalization were independent predictors of poor functional outcome at 3 months among patients admitted with SDH. Leroy et al[18] found that age, residual hematoma thickness, and a low GCS score could independently predict outcome after surgical evacuation for CSDH. They also reported that 28 % of patients had a poor 3-month functional outcome (mRS 3–6), whereas sex was not associated with poor outcome.[18] Katsigiannis et al[14] found that preoperative neurological status, along with age, surgical technique, and recurrence were independent predictors of functional outcome after surgery for CSDH.

We also observed that long-term functional outcomes appear worse for those on antiplatelets and anticoagulants, low GCS, paresthesia, seizures, and absence of headache on admission, unilateral CSDH, increased preoperative, postoperative, and follow-up thickness, increased follow-up hematoma area, and craniectomy. Kwon et al[19] found that age, hematoma thickness, MLS, blood thinners, positive Babinski response, disorientation, and motor deficits were associated with poor mRS at 6 months after unilateral burr-hole evacuation for

Table 6
Univariable and multivariable predictors of poor functional outcome at 90 days.

	Good outcome ($n = 272$)	Poor outcome ($n = 87$)	Univariable		Multivariable	
			OR (95%CI)	*p*-value	OR (95%CI)	*p*-value
Age, mean years (SD)	67.7 (12.4)	74.2 (12.5)	1.04 (1.02–1.07)	**<0.001**	1.03 (0.99–1.07)	0.071
Female, *n* (%)	74/272 (27.2)	33/87 (37.9)	1.63 (0.98–2.71)	0.058	3.90 (1.57–9.70)	**0.003**
Race, *n* (%)						
Unknown	13/272 (4.7)	3/87 (3.4)	Ref.	Ref.	–	–
White	180/272 (66.1)	51/87 (58.6)	1.22 (0.33–4.47)	0.756	–	–
African American	59/272 (21.6)	23/87 (26.4)	1.68 (0.44–6.48)	0.445	–	–
Asian	14/272 (5.1)	9/87 (10.3)	2.78 (0.61–12.59)	0.183	–	–
Hispanic	6/272 (2.2)	1/87 (1.1)	0.72 (0.06–8.46)	0.796	–	–
Hypertension, *n* (%)	202/271 (74.5)	65/84 (77.3)	1.16 (0.65–2.08)	0.598	–	–
CVD, *n* (%)	116/268 (43.2)	43/81 (53.1)	1.48 (0.90–2.44)	0.122	–	–
Antiplatelet/Anticoagulant use, *n* (%)						
Antiplatelet only	93/248 (37.5)	30/75 (40)	1.01 (0.60–1.68)	0.960	–	–
Anticoagulant only	37/248 (14.9)	10/75 (13.3)	0.82 (0.39–1.73)	0.612	–	–
Both	23/248 (9.2)	14/75 (18.6)	2.07 (1.01–4.23)	**0.045**	2.37 (0.65–8.55)	0.186
GCS, median (IQR)	15 (15–15)	15 (14–15)	0.84 (0.74–0.95)	**0.007**	0.83 (0.67–1.03)	0.097
Smoker, *n* (%)	32/267 (11.9)	11/79 (13.9)	1.18 (0.56–2.48)	0.647	–	–
Bilateral SDH, *n* (%)	89/272 (32.7)	16/87 (18.3)	0.46 (0.25–0.84)	**0.012**	0.69 (0.27–1.77)	0.451
Symptom, *n* (%)						
Headache	148/272 (54.4)	25/87 (28.7)	0.33 (0.20–0.56)	**<0.001**	0.67 (0.28–1.63)	0.384
Weakness	78/272 (28.6)	23/87 (26.4)	0.89 (0.51–1.54)	0.686	–	–
Paresthesia	12/272 (4.4)	10/87 (11.4)	2.81 (1.17–6.76)	**0.021**	2.34 (0.32–16.73)	0.395
Seizure	6/272 (2.2)	8/87 (9.2)	4.48 (1.51–13.32)	**0.007**	3.22 (0.12–81.17)	0.476
AMS	83/272 (30.5)	46/87 (52.8)	2.55 (1.55–4.18)	**<0.001**	5.19 (2.15–12.52)	**<0.001**
SDH acuity, *n* (%)						
Subacute	36/272 (13.2)	8/87 (9.2)	0.66 (0.29–1.48)	0.320	–	–
Chronic	69/272 (25.3)	17/87 (19.5)	0.71 (0.39–1.29)	0.269	–	–
Acute on Chronic	75/272 (25.5)	28/87 (32.1)	1.24 (0.73–2.10)	0.408	–	–
Acute on Subacute	17/272 (6.2)	3/87 (3.4)	0.53 (0.15–1.87)	0.328	–	–
Subacute on Chronic	75/272 (27.5)	31/87 (35.6)	1.45 (0.87–2.42)	0.153	–	–
MLS, mean mm (SD)	6.9 (4.9)	7.7 (5.3)	1.03 (0.98–1.08)	0.191	–	–
Thickness, mean mm (SD)	17.8 (6.9)	20.2 (7.4)	1.04 (1.01–1.08)	**0.006**	0.98 (0.91–1.05)	0.610
Area, mean cm^2 (SD)	15.9 (7.5)	17.5 (7.8)	1.02 (0.99–1.06)	0.097	1.04 (0.97–1.13)	0.227
Brain atrophy, *n* (%)	112/253 (44.2)	40/70 (57.1)	1.67 (0.98–2.86)	0.058	0.73 (0.30–1.74)	0.482
Surgical approach, *n* (%)						
1 Burr hole	25/272 (9.1)	7/87 (8)	0.86 (0.36–2.07)	0.744	–	–
2 Burr holes	157/272 (57.7)	42/878 (48.2)	0.68 (0.42–1.10)	0.124	–	–
Craniotomy	85/272 (31.2)	32/87 (36.7)	1.28 (0.77–2.12)	0.339	–	–
Craniectomy	5/272 (1.8)	6/87 (6.9)	3.95 (1.17–13.29)	**0.026**	1.31 (0.17–9.97)	0.788
Postop thickness, mean cm^2 (SD)	12.5 (5.6)	14.1 (7.2)	1.04 (1.00–1.08)	**0.032**	1.00 (0.89–1.13)	0.880
Postop area, mean cm^2 (SD)	8.2 (5.2)	9.6 (7.3)	1.03 (0.99–1.07)	0.073	0.95 (0.84–1.07)	0.477
Follow-up thickness, mean (SD)	6.6 (6.2)	9.5 (8.1)	1.06 (1.02–1.10)	**0.003**	1.03 (0.92–1.16)	0.507
Follow-up area, mean cm^2 (SD)	4.1 (4.8)	6.4 (7.3)	1.06 (1.02–1.11)	**0.004**	1.02 (0.90–1.17)	0.682
Postop clearance, mean (SD)	0.4 (0.3)	0.3 (0.5)	0.90 (0.50–1.61)	0.729	–	–
Reoperation within 90 days, *n* (%)	32/272 (11.7)	14/76 (18.4)	1.69 (0.85–3.36)	0.133	–	–

CVD, cardiovascular disease; GCS: Glasgow Coma Scale/Score; IQR, interquartile range; MLS, midline shift; OR, odds ratio; Postop, postoperative; SD, standard deviation; SDH: subdural hematoma.Bold values indicate statistical significance at $p < 0.05$.

CSDH. Sex was not associated with poor functional outcome.[19] Ro et al[20] reported functional outcome 3 months after burr-hole craniostomy for CSDH. They found that patients with severe preoperative neurologic deficits and older patients had poor mRS, patients with iso-density had better mRS, whereas the mRS of male patients was non-significantly better.

5. Limitations

This is a single-center, retrospective study. Therefore, the findings may not be generalizable to other institutions with varying patient populations. Including all variations of CSDH introduces heterogeneity and confounding to the data, which we addressed by including chronicity, CT findings, and surgical approach to the analyses, and by stratifying AUCs. Thus, our study population is likely to show worse outcomes when compared to cohorts of only CSDH. The thickest slice was used for postoperative hematoma clearance, instead of hematoma volumes, which may be different pre and postoperatively and not uniform throughout the hematoma. No data on head trauma were collected. Long-term follow-up SDH measurements vary based on when CT was performed, whereas some patients were lost to follow-up. Finally, the study's observational nature may involve selection bias regarding which patients were offered surgical evacuation; different surgeons have different thresholds for operation and reoperation.

6. Conclusion

We report an analysis of outcomes after surgical evacuation of CSDH. Reoperation within 90 days is associated with female sex, whereas AMS on admission and female sex independently predict 3-month poor functional status. Careful management of patients with those factors may reduce CSDH reoperation and improve long-term functional outcomes. Also, understanding risk factors leading to reoperation may help in determining indications for new treatment options such as endovascular embolization for SDH. However, larger randomized studies of SDH evacuation in patients are necessary to assess long-term prognosis after surgical evacuation.

Data sharing statement

The relevant anonymized patient-level data are available on reasonable request from the authors.

CRediT authorship contribution statement

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.wnsx.2023.100246.

References

1. 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. https://doi.org/10.3171/2014.9.JNS141550.
2. Borger V, Vatter H, Oszvald Á, Marquardt G, Seifert V, Güresir E. Chronic subdural haematoma in elderly patients: a retrospective analysis of 322 patients between the ages of 65-94 years. *Acta Neurochir*. 2012;154(9):1549–1554. https://doi.org/10.1007/s00701-012-1434-x.
3. Lakomkin N, Graffeo CS, Hadjipanayis CG. Specific causes and predictors of readmissions following acute and chronic subdural hematoma evacuation. *J Clin Neurosci Off J Neurosurg Soc Australas*. 2020;75:35–39. https://doi.org/10.1016/j.jocn.2020.03.042.
4. Frontera JA, de los Reyes K, Gordon E, et al. Trend in outcome and financial impact of subdural hemorrhage. *Neurocritical Care*. 2011;14(2):260–266. https://doi.org/10.1007/s12028-010-9418-2.
5. Miranda LB, Braxton E, Hobbs J, Quigley MR. Chronic subdural hematoma in the elderly: not a benign disease. *J Neurosurg*. 2011;114(1):72–76. https://doi.org/10.3171/2010.8.JNS10298.
6. Gazzeri R, Laszlo A, Faiola A, et al. Clinical investigation of chronic subdural hematoma: relationship between surgical approach, drainage location, use of antithrombotic drugs and postoperative recurrence. *Clin Neurol Neurosurg*. 2020;191, 105705. https://doi.org/10.1016/j.clineuro.2020.105705.
7. Weigel R, Schmiedek P, Krauss JK. Outcome of contemporary surgery for chronic subdural haematoma: evidence based review. *J Neurol Neurosurg Psychiatry*. 2003;74(7):937–943. https://doi.org/10.1136/jnnp.74.7.937.
8. Sharma R, Rocha E, Pasi M, Lee H, Patel A, Singhal AB. Subdural hematoma: predictors of outcome and a score to guide surgical decision-making. *J Stroke Cerebrovasc Dis Off J Natl Stroke Assoc*. 2020;29(11), 105180. https://doi.org/10.1016/j.jstrokecerebrovasdis.2020.105180.
9. Mishra R, Deora H, Florez-Perdomo WA, et al. Clinical and radiological characteristics for recurrence of chronic subdural hematoma: a systematic review and meta-analysis. *Neurol Int*. 2022;14(3):683–695. https://doi.org/10.3390/neurolint14030057.
10. Kolias AG, Chari A, Santarius T, Hutchinson PJ. Chronic subdural haematoma: modern management and emerging therapies. *Nat Rev Neurol*. 2014;10(10):570–578. https://doi.org/10.1038/nrneurol.2014.163.
11. Munoz-Bendix C, Pannewitz R, Remmel D, et al. Outcome following surgical treatment of chronic subdural hematoma in the oldest-old population. *Neurosurg Rev*. 2017;40(3):461–468. https://doi.org/10.1007/s10143-016-0803-y.
12. Motiei-Langroudi R, Stippler M, Shi S, et al. Factors predicting reoperation of chronic subdural hematoma following primary surgical evacuation. *J Neurosurg*. 2018;129(5):1143–1150. https://doi.org/10.3171/2017.6.JNS17130.
13. Zhu F, Wang H, Li W, et al. Factors correlated with the postoperative recurrence of chronic subdural hematoma: an umbrella study of systematic reviews and meta-analyses. *EClinicalMedicine*. 2022;43, 101234. https://doi.org/10.1016/j.eclinm.2021.101234.
14. Katsigiannis S, Hamisch C, Krischek B, et al. Independent predictors for functional outcome after drainage of chronic subdural hematoma identified using a logistic regression model. *J Neurosurg Sci*. 2020;64(2):133–140. https://doi.org/10.23736/S0390-5616.17.04056-5.
15. Rovlias A, Theodoropoulos S, Papoutsakis D. Chronic subdural hematoma: surgical management and outcome in 986 cases: a classification and regression tree approach. *Surg Neurol Int*. 2015;6:127. https://doi.org/10.4103/2152-7806.161788.
16. El-Kadi H, Miele VJ, Kaufman HH. Prognosis of chronic subdural hematomas. *Neurosurg Clin*. 2000;11(3):553–567.
17. Weimer JM, Gordon E, Frontera JA. Predictors of functional outcome after subdural hematoma: a prospective study. *Neurocritical Care*. 2017;26(1):70–79. https://doi.org/10.1007/s12028-016-0279-1.
18. Leroy H-A, Aboukaïs R, Reyns N, et al. Predictors of functional outcomes and recurrence of chronic subdural hematomas. *J Clin Neurosci Off J Neurosurg Soc Australas*. 2015;22(12):1895–1900. https://doi.org/10.1016/j.jocn.2015.03.064.
19. Kwon C-S, Al-Awar O, Richards O, Izu A, Lengvenis G. Predicting prognosis of patients with chronic subdural hematoma: a new scoring system. *World Neurosurg*. 2018;109:e707–e714. https://doi.org/10.1016/j.wneu.2017.10.058.
20. Ro HW, Park SK, Jang DK, Yoon WS, Jang KS, Han YM. Preoperative predictive factors for surgical and functional outcomes in chronic subdural hematoma. *Acta Neurochir*. 2016;158(1):135–139. https://doi.org/10.1007/s00701-015-2625-z.