



Optimal duration of postoperative drainage following burr hole surgery for chronic subdural hematoma: A systematic review and network meta-analysis

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Abstract

Background Chronic subdural hematoma (CSDH) is a prevalent neurosurgical condition with a high recurrence rate after burr-hole surgery. The optimal duration of postoperative drainage remains controversial, with varying clinical practices worldwide.

Objective This systematic review and network meta-analysis aimed to determine the optimal postoperative drainage duration to minimize recurrence while maintaining favorable clinical outcomes.

Methods A comprehensive search was conducted across five databases up to January 2025, including randomized controlled trials (RCTs) and cohort studies evaluating the postoperative drainage duration in CSDH patients undergoing burr-hole surgery. The primary outcome was recurrence rate, while the secondary outcomes included mortality and functional outcomes. A random-effects network meta-analysis was performed, and the risk of bias was assessed using standardized tools.

Results Seven studies with 1,842 patients were included, comprising three RCTs and four cohort studies. Drainage durations of 3 and 6 days significantly reduced recurrence rates compared with shorter durations (0–8 h and 17–24 h). Notably, the 6-day drainage had the highest probability (86.2%) of minimizing recurrence, followed by the 3-day drainage (13.8%). A shorter drainage duration (<24 h) was associated with higher recurrence risks. However, no significant differences in mortality rates were observed across the drainage durations.

Conclusion This study highlights that longer postoperative drainage durations (3–6 days) may reduce recurrence rates after burr-hole surgery for chronic subdural hematomas. However, its effect on mortality remains unclear. These findings support the importance of optimizing the drainage duration and call for further high-quality studies to guide clinical practice.

Keywords Chronic subdural hematoma · Postoperative drainage · Burr hole surgery · Recurrence · Network meta-analysis

Introduction

Chronic subdural hematoma (CSDH) is one of the most common neurosurgical conditions, predominantly affecting the elderly population aged >70 years. Its incidence has been steadily rising worldwide due to demographic aging and the widespread use of antithrombotic medications, with estimates ranging from 1.7 to 20.6 per 100,000 individuals annually. Men account for approximately 65% of cases.

CSDH often follows minor head trauma or arises from age-related anatomical and physiological changes, such as brain atrophy and craniocerebral disproportion, that predispose to slow venous bleeding, typically from bridging veins. This bleeding triggers a cascade of inflammation, angiogenesis, fibrinolysis, and recurrent microhemorrhage, leading to hematoma expansion and recurrence [1, 2].

The persistence and progression of CSDH are largely driven by the biological activity within the hematoma

membrane. This membrane is richly vascularized with fragile, newly formed capillaries prone to repeated microhemorrhage. Inflammatory mediators, such as vascular endothelial growth factor (VEGF) and interleukins, promote angiogenesis and increase vascular permeability, while activation of fibrinolytic pathways prevents stable clot formation. These processes maintain a cycle of fluid exudation and rebleeding, gradually enlarging the hematoma cavity. Postoperative drainage serves to interrupt this cycle by reducing residual fluid volume, minimizing membrane tension, and lowering the likelihood of further bleeding episodes. The duration of drainage may therefore directly influence how effectively these pathological processes are controlled after surgery [1–3].

Clinically, patients may present with a spectrum of symptoms, including confusion, headaches, and signs of increased intracranial pressure (ICP), whereas a subset may experience seizures [4]. Surgical evacuation, typically via burr hole craniotomy, is the gold standard of treatment for symptomatic cases [5, 6]. Recently, middle meningeal artery (MMA) embolization has emerged as a promising adjunct or alternative to burr-hole surgery, aiming to reduce recurrence by obliterating the vascular supply to the outer hematoma membrane. Early studies suggest that MMA embolization, either alone or in combination with surgical evacuation, may alter the postoperative course and influence the need for prolonged drainage. However, despite high success rates, one of the major challenges remains symptomatic recurrence, which occurs in 10–15% of patients and frequently necessitates repeated surgical intervention [7]. This not only increases morbidity and mortality but also prolongs hospital stays and healthcare costs.

Postoperative subdural drainage has been widely recognized as an effective strategy for minimizing recurrence and improving patient outcomes [8, 9]. Various drainage techniques, including subgaleal, subdural, and continuous irrigation, have been investigated; however, no consensus has been reached regarding the optimal method or duration. While most treatment centers adhere to fixed drainage durations, such as 24–48 h, the lack of personalized strategies tailored to patient-specific factors highlights a significant knowledge gap. A deeper understanding of the relationship between drainage duration and recurrence risk could pave the way for more individualized, evidence-based treatment protocols.

Given this uncertainty, identifying the optimal drainage duration is critical for balancing recurrence prevention against potential complications, resource utilization, and patient comfort. This systematic review and network meta-analysis aims to comprehensively evaluate the existing literature on postoperative drainage durations after burr-hole surgery for CSDH. By comparing recurrence, mortality, and

complication outcomes across different drainage intervals, our goal is to provide evidence-based guidance to inform clinical decision-making and improve patient outcomes.

Method

This study was conducted by the Cochrane Handbook for Systematic Reviews of Interventions [10]. The results were reported as specified by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [11]. Additionally, this study was registered with PROSPERO under the identification number (CRD42025642564).

Information sources and search strategy

A literature search was performed using five electronic databases: Cochrane, PubMed, Web of Science, Embase, and Scopus. The search targeted literature from inception to January 2025. The strategy employed utilized keywords such as (“chronic subdural hematoma”[MeSH] OR “CSDH” OR “chronic subdural hematoma” OR “subdural hematoma, chronic”) AND (“burr hole”[MeSH] OR “burr hole surgery” OR “burr hole craniotomy” OR “burr hole drainage”) AND (“postoperative drainage” OR “drain duration” OR “drainage time” OR “postoperative management”) AND (“recurrence rate” OR “hematoma recurrence” OR “mortality” OR “modified Rankin Scale” OR “mRS” OR “Glasgow Coma Scale” OR “GCS” OR “length of stay” OR “reoperation rates” OR “postoperative complications”) along with their pertinent synonyms. Two researchers performed the search concurrently and independently (Fig. 1)

Eligibility criteria

The inclusion criteria for this study were adult patients aged 18 years or older who had undergone surgical evacuation of symptomatic chronic subdural hematoma via burr hole craniotomy and had received postoperative drainage for a specific duration (e.g., 6, 12, 24, or more hours). Eligible studies must report primary outcomes, such as the symptomatic hematoma recurrence rate at 3 months, and secondary outcomes, including mortality, at 3 months. Only randomized controlled trials (RCTs), propensity score-matched cohort studies, and retrospective cohort studies were included.

Exclusion Criteria

Non-English studies, conference abstracts, patients with acute rebleeding, accidental drain removal, and those who withdrew from the study were excluded. Additionally,

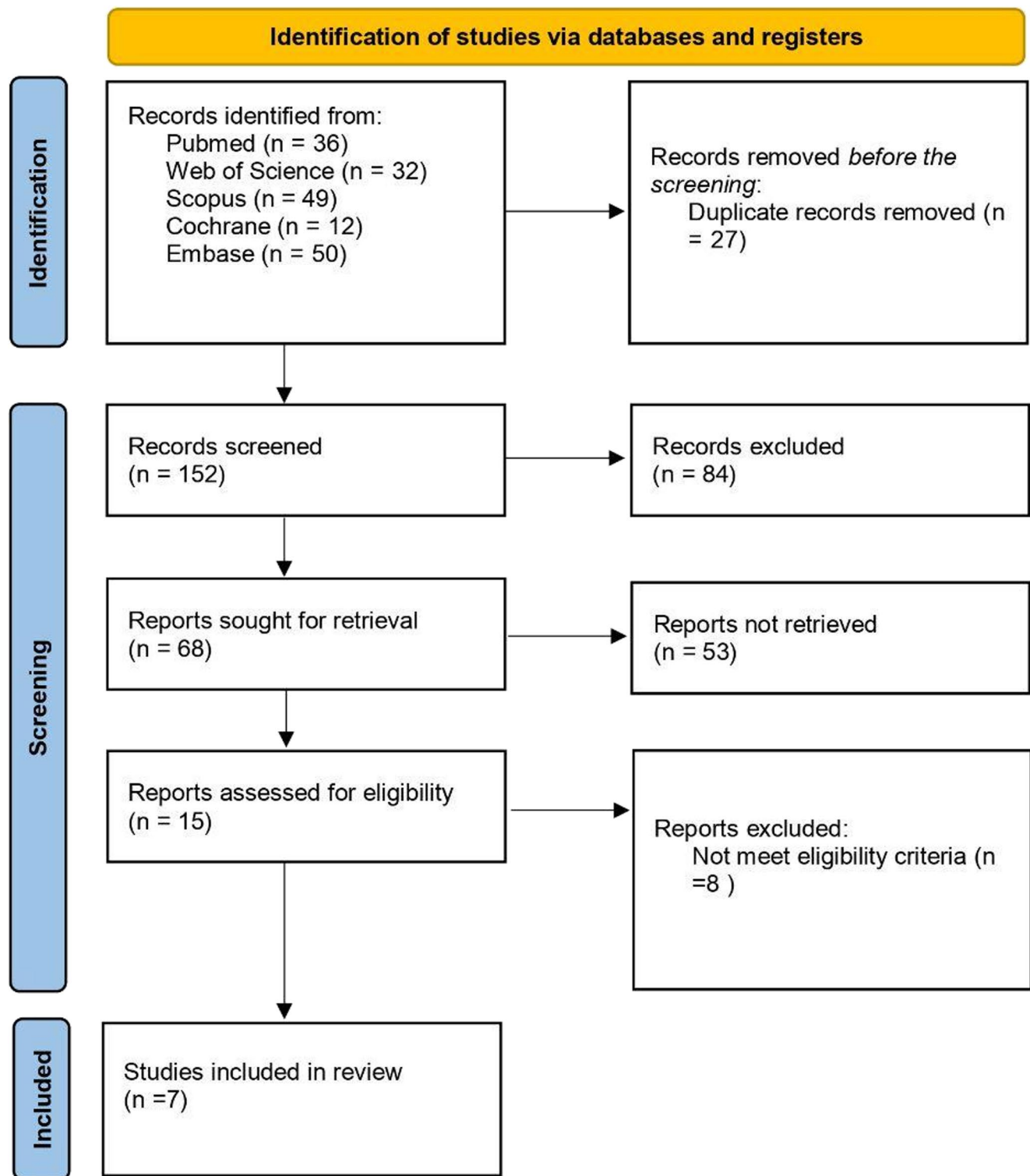


Fig. 1 PRISMA flow diagram [11]

studies with insufficient data to assess predefined outcomes or those that did not use burr hole craniotomy for hematoma evacuation were excluded.

Screening and data management

The screening process was conducted in two distinct phases. The first phase involved the initial screening of titles and

abstracts to identify potentially relevant studies. In the second phase, the full-text articles from the selected studies were thoroughly reviewed to confirm their eligibility. Rayyan software was used to facilitate screening. Two independent reviewers conducted the eligibility assessment, and any disagreements were resolved by consulting a third reviewer [12].

Data extraction

Two independent authors, blinded to each other, extracted data from each study using a uniform Google sheet. Disagreements were resolved by consensus or by referring to the primary investigator. Data extracted included study characteristics (study ID, location, year, study type, sample size, age, female sex, surgical technique, mean duration of surgery, antithrombotic medication, drain location, bilateral, and follow-up) and outcome measures (recurrence and mortality).

Risk of bias assessment

Two independent reviewers assessed the risk of bias of the studies included in the analysis. For RCTs, the Cochrane Risk of Bias 2 (ROB2) tool [13] was used to assess domains, including the randomization process, deviations from intended interventions, missing outcome data, measurement of outcomes, and selection of reported results. Each domain was carefully evaluated, and a risk decision (low, some concerns, or high) was made with detailed justifications provided (Fig. 2). For non-randomized studies of interventions, the Risk of Bias in Non-randomized Studies of Interventions (ROBINS-I) assessment tool was used [13]. This tool assesses various factors, including allocation concealment, blinding, selective reporting, and additional sources of bias. Based on this comprehensive assessment, the included studies were categorized as having a 'low risk' of bias, 'high risk' of bias, or 'some concerns' (Fig. 2). Robvis [14] was used to generate ROBINS-I and ROB2 figures [15]. Any disagreements were resolved through discussion, and a third author was consulted when necessary.

Publication bias

As indicated by Egger et al., the assessment of potential publication bias within this review utilizing Egger's test for funnel plot asymmetry is not feasible when the number of included studies is fewer than ten [16].

Fig. 2 'Risk of bias graph': review authors' judgments about each risk of bias item presented as percentages across all included studies, and 'Risk of bias summary': review authors' judgments about each risk of bias item for each included study

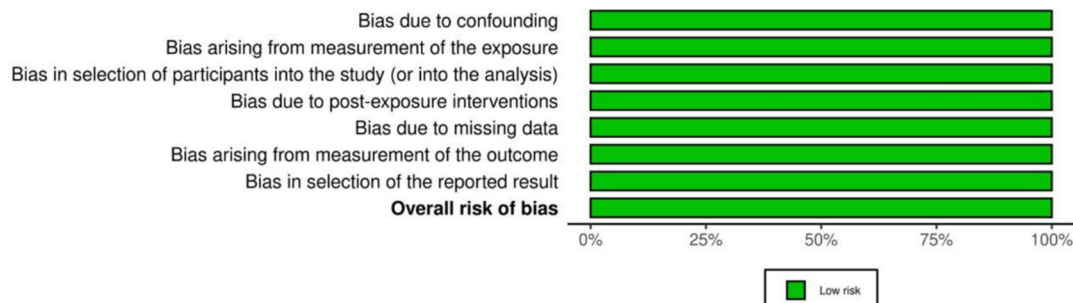
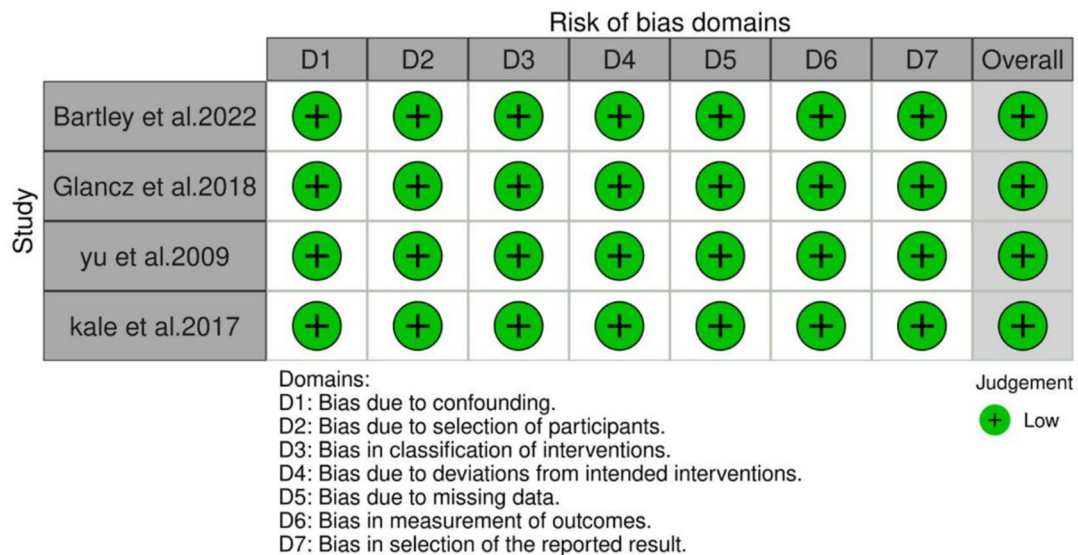
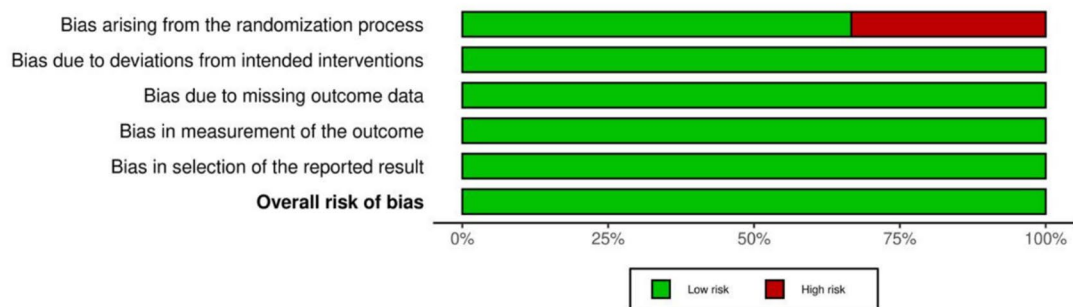
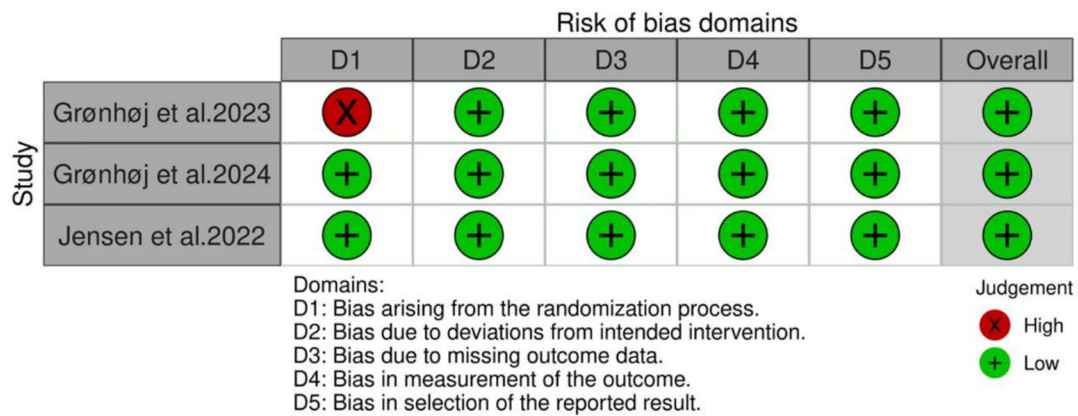
Calculation of missing data

In instances where data were reported as median and inter-quartile range (IQR), conversions were performed to obtain the mean (M) and standard deviation (SD) using the equations established by Wan et al. [17]. Furthermore, when the standard deviation was not provided, it was derived from the standard error using the following formula for a single sample: $SD = SE \cdot \sqrt{n}$, where (n) denotes the sample size [18]. If the mean change (MC) between the baseline and endpoint data was unavailable, it was calculated from the pre-treatment and post-treatment means using the equation: $MC = M_{\text{post-treatment}} - M_{\text{pre-treatment}}$. Additionally, in cases where the standard deviation of the mean change was not provided, it was computed from the standard deviations of the pre-treatment and post-treatment samples using the formula $SD = \sqrt{(SD^2_{\text{pre-treatment}} + SD^2_{\text{post-treatment}})}$ [19]. Effect sizes (d) and effect size correlations (r) were calculated using the following formulas: $d = (M_{\text{treatment}} - M_{\text{control}}) / SD_{\text{pooled}}$, with SD_{pooled} calculated as $\sqrt{[(SD^2_{\text{treatment}} + SD^2_{\text{control}}) / 2]}$ [22] and $r = d / \sqrt{(d^2 + 4)}$ [20].

In our analysis, we classified the drainage duration into distinct groups to ensure a more systematic comparison of outcomes. The original data were edited and restructured, and the drainage durations were categorized into the following groups: 24–48 h, 9–16 h, 17–24 h, 0–8 h, 3 d, and 6 d. This classification allows for a more nuanced assessment of recurrence rates and mortality outcomes across various drainage periods, thus enhancing the precision and clarity of our findings. By organizing the data in this manner, we were able to identify the optimal drainage duration more effectively and provide clearer recommendations for clinical practice.

Statistical analysis

Data analysis was conducted using R software to perform network meta-analysis (NMA). A random-effects model was utilized throughout the analysis, given the anticipated clinical heterogeneity across studies, such as variations in surgical techniques, patient demographics, and anticoagulant use. This modeling approach was prespecified and deemed more appropriate than fixed-effects models, which assume homogeneity. Furthermore, between-study design variability (e.g., randomized controlled trials [RCTs] vs. observational cohorts) and clinical diversity reinforced the rationale for using random-effects methods.



Model Selection Criteria Post-hoc heterogeneity assessments supported our choice: recurrence analysis showed low heterogeneity ($I^2 = 0\%$, Q-test $p=0.697$), while mortality analysis demonstrated moderate heterogeneity ($I^2 = 65.6\%$, Q-test $p=0.039$). Both values were below the conventional threshold of 75% for extreme heterogeneity, thus confirming the robustness of the model. Statistical significance was set at $P < 0.05$. Heterogeneity was assessed using the I^2 statistic, where $I^2 < 50\%$ was interpreted as low heterogeneity and $I^2 \geq 50\%$ was interpreted as moderate to high heterogeneity. Cochran's test was used to evaluate between-study variability.

Outcome measures Categorical outcomes (e.g., recurrence and mortality) were analyzed using odds ratios (ORs) with corresponding 95% confidence intervals (CIs). Forest plots were generated to visually present the pooled estimates and facilitate comparisons across the drainage duration groups.

Drain Duration Categorization Rationale Drain durations were stratified into six predefined categories: 0–8 h, 9–16 h, 17–24 h, 25–48 h, 3 d, and 6 d. This grouping was based on two key factors: clinical relevance and data availability. For example, the 25–48 h range reflects common postoperative practice, while 3-day and 6-day durations correspond to the standardized protocols used in recent RCTs. Data availability. There were no studies with sufficient sample sizes that reported outcomes for intermediate durations, such as 4 or 5 days. Therefore, further stratification is limited by the lack of published data.

Heterogeneity

A visual inspection of the final forest plots and an assessment using I^2 and chi-squared tests (Cochran's Q test) were conducted to identify the degree of heterogeneity. In case of significant heterogeneity (Chi-Square $p < 0.1$), sensitivity analysis was performed to resolve heterogeneity using R programming version 4.4.1 for Windows [21].

Results

Search and screening

This systematic review employed a comprehensive search strategy across five databases to identify the relevant studies. The databases searched included PubMed (36 results), Scopus (49 results), Web of Science (32 results), the Cochrane Library (12 results), and Embase (50 results). A total of 179 articles were retrieved, and 27 duplicates were identified and removed, resulting in 152 unique articles for screening.

Following the screening of titles and abstracts, 68 full-text articles were assessed for eligibility. After a thorough evaluation, seven studies with a total of 1,842 patients were ultimately included in the review (Fig. 1), as 53 papers did not report recurrence or mortality rates, and the remaining eight studies were conference or meeting abstracts.

Study characteristics

The seven trials [22–28] combined encompassed 1,842 patients aged 55–87 years, with a majority being males, 1,338 men (72.6%). The research concentrated on the burr hole method and the drainage site. The follow-up period in this study ranged from 90 to 180 days. The seven studies included three RCTs and four retrospective cohort studies. The studies were conducted in Denmark, Sweden, the UK, Ireland, Turkey, and China. The summary and features of the included studies are presented in Tables 1 and 2, respectively.

Risk of bias assessment

We employed Cochrane risk of bias (ROB 2) for selected randomized controlled trials (RCTs). Three RCTs [26, 27], and [28] demonstrated a minimal risk of bias across six domains. Except Hjortdal Grønhøj et al. 2023 [26] exhibited a high risk of bias due to the randomization factor. We employed ROBINS to evaluate the quality of the non-randomized studies. Studies [22–24], and [25] demonstrated a low risk across all domains.

Outcomes

Recurrence rate

This network meta-analysis evaluated the recurrence rates following burr hole surgery for chronic subdural hematoma (CSDH), focusing on the optimal duration of postoperative drainage. Seven studies ($k=7$) with 1,836 observations and six treatment groups were included. The analysis utilized a random-effects model to calculate odds ratios (OR) for various pairwise comparisons of treatment duration.

The comparison between (0–8) H and [17–24] H yielded a significant OR of 2.77 (95% CI: 1.54–4.99), indicating that patients treated with (0–8) H had significantly higher odds of recurrence than those treated with [17–24] H ($p=0.0007$). This suggests that a shorter drainage duration (0–8) H is less effective in preventing recurrence than (17–24) H. For the other comparisons, no significant differences were found. (24–48) H compared to [17–24] H had an OR of 1.19 (95% CI: 0.79–1.81) with a p-value of 0.39, suggesting no substantial difference in recurrence rates. Similarly,

Table 1 Studies characteristics

Author, year	Country	Study type	Aim of the study	Findings	Discussion	Efficacy	Adverse events
Bartley et al. 2023	Sweden	Observational Retrospective cohort study	Compare postoperative drainage that lasts longer or shorter than 24 h after evacuation of a chronic subdural hematoma.	Recurrence occurred in 12/96 (12.5%) in the LDT group and 13/111 (11.7%) patients in the SDT group ($p=0.15$). There was no significant difference between groups regarding recurrence, complications, or mortality.	The study compares drainage times after chronic subdural hematoma surgery. Shorter drainage times (<24 h) do not increase recurrence or complications. Early mobilization and shorter hospital stays are facilitated. Active subgaleal drains may be more effective than passive subdural drains. A randomized controlled trial is needed for further investigation.	A shorter drainage duration (<24 h) after cSDH surgery facilitated earlier mobilization and shorter hospital stay	NR
Jensen et al. 2022	Denmark	Randomized controlled trial	Investigating the effect of drainage duration on recurrence and mortality.	The recurrence rate was 14% in the 24-hour group and 13% in the 48-hour group. Four patients died in the 24-hour group, and 8 patients died in the 48-hour group; this difference was not statistically significant.	The trial compared 24 and 48 h of drainage. No significant differences in recurrence or mortality rates were found. Longer drainage rates were found. Longer drainage increased neurosurgical admissions by 0.8 days. The shortest drainage time is preferred for older patients. Prolonged drainage may hinder early mobilization and rehabilitation. Evidence on drainage time and recurrence is sparse. Patients in the 24-hour group had reduced hospital stays.	No significant differences in the rates of recurrent hematoma or mortality during 90-day follow-up were identified between the two groups that randomly received either 24- or 48-hour passive subdural drainage after burr hole evacuation of CSDH.	Intracerebral hematoma 4 (1.9%), coronary syndrome 2 (0.96%), 1 lung embolism (0.48%), Intracerebral hematoma 1 (0.47%), coronary syndrome 2 (0.94%), Cerebral infarction 2 (0.94%)
Hjortdal Grøn-høj et al. 2024	Denmark	Randomized, multi-arm, and multi-stage non-inferiority trial	Investigate the shortest possible drainage time without increasing the hematoma recurrence rate.	Therefore, the non-inferiority of 6 h and 12 h of drainage to 24 h of drainage was not established. 20 patients had died by 3 months, seven in the 6 h group, eight in the 12 h group, and five in the 24 h group. The most frequent known causes of mortality were hematoma recurrence (three in the 12 h group), comorbidity (three in the 12 h group), and pneumonia (one each in the 6 h and 12 h groups, two in the 24 h group).	The trial involved patients with chronic subdural hematoma. Passive drainage of 6–12 h increased the recurrence risk.	The findings from this non-inferiority trial provide evidence to support 24 h of postoperative drainage as the standard drain time when a fixed drain time approach is used.	G1 postoperative infection 20 (20%) G2 Postoperative infection 25 (23%) G3 Postoperative infection 19 (17%)

Table 1 (continued)

Author, year	Country	Study type	Aim of the study	Findings	Discussion	Efficacy	Adverse events
Glancz et al. 2018	UK and Ireland	Multi-center, prospective cohort study	Examining whether this is influenced by variation in drain location, positioning or duration of placement.	We found no significant differences in discharge mRS between these groups. Recurrence rates were comparable between patients with postoperative drainage for 1 or 2 d, 6.4% and 8.4%, respectively ($P=0.44$). There was no significant difference in mRS scores between these 2 groups ($P=0.56$).	Drain location and duration do not affect recurrence or outcomes. This study is the largest on the drain position and duration. Recurrence is likely within 60 days post-surgery. Simplifying care pathways may reduce costs and enhance experiences. Other variations, like bed rest duration, do not impact outcomes.	Drain insertion after CSDH drainage is important, but position (subgaleal or subdural) and duration did not appear to influence recurrence rate or clinical outcomes. Similarly, drain location did not influence the recurrence rate nor outcomes where both parietal and frontal burr holes were made.	G1 Surgical site infection 3(0.6), Respiratory infection 43(8.1) G2 Respiratory infection 3(6.8)
Hjortdal Grøn-høj et al. 2023	Denmark	Randomized controlled trial	Investigating the dynamics of drain production and potentially contributing factors for recurrence.	Of the 118 cases, 34 (29%) had spontaneous drain cessation within the first 0–8 h after surgery (Group A), 32 (27%) within 9–16 h (Group B), and 52 (44%) within 17–24 h (Group C). Hours of production ($P=0.0001$) and total drain volume ($P=0.001$) were significantly different between groups. The recurrence rate was 26.5% in group A, 15.6% in group B, and 9.6% in group C ($P=0.037$).	The study examined subdural drain dynamics post-surgery. Shorter drain production correlates with higher recurrence risk. Active drains for 17–24 h lower the recurrence risk significantly. The total volume produced affects recurrence within three months. Subdural drainage reduces CSDH recurrence risk. No significant differences in hematoma types across groups. Individual drainage strategies may improve patient outcomes. Further research is needed on preventing early drain cessation.	Patients with early cessation of drainage did not benefit from further drain time.	NR
Kale et al. 2017	Turkey	Observational Retrospective cohort study	The effects of long drainage durations on results and recurrences were investigated in patients on whom closed system drainage with burr hole craniotomy was applied due to CSDH.	Recurrence was observed in 7 (15.6) of the Group A patients and 2 (3.3%) of the Group B patients.	Two mechanisms contribute to chronic subdural hematoma (CSDH) development. CSDHs can lead to fatal outcomes without treatment. Early diagnosis and treatment yield positive outcomes for most patients. Surgery is recommended for symptomatic patients with CSDH. Recurrence factors include brain re-expansion and hemorrhage in membranes. Age and coagulation disorders influence CSDH recurrence risk. Closed-system drainage is effective with low mortality and morbidity. Longer drainage duration may reduce recurrence rates.	2–4 days of closed system drainage following burr hole craniotomy is an effective and reliable choice of treatment in CSDH	UTI (2)

Table 1 (continued)

Author, year	Country	Study type	Aim of the study	Findings	Discussion	Efficacy	Adverse events
Yu et al. 2009	China	Observational Retro-spective cohort study	The investigation focuses mainly on the factors associated with surgical techniques. To find out the factors that may affect the recurrence rate of CSDH	The average recurrence rate was 6.6% in this whole series. For patients with less than three days of drainage, the recurrence rate was 16.3%, whereas for those with 3 or more days of drainage, the recurrence rate was only 1.3%	The recurrence of chronic subdural hematoma (CSDH) is debated. Poor brain re-expansion and bleeding are major causes. Age affects brain elastance, impacting CSDH recurrence. Intracapsular air may contribute to CSDH recurrence. Longer drainage duration lowers CSDH recurrence rates. Three days of drainage are necessary for older patients.	We found in this study that the duration of drainage plays an important role in the treatment of CSDH, and 3 full days of drainage seems to be necessary, especially for patients 60 years and over.	NO adverse events in the study

Table 2 Study's population summary

Author, year	Study subgroups	Sample size	Age mean (SD)	Female N (%)	Surgical technique	Anti-thrombotic medication N(%)	Drain location	Bilateral	Follow-up(days)
Bartley et al. 2023	Drainage longer (LDT-group) > 24 h	96	75.6 (10.0)	32 (33.3)	(1–2 boreholes)	40 (41.7%)	The subdural space was irrigated and followed by the insertion of an active subgaleal drain.	21 (21.8%)	180
	Drainage shorter (SDT-group) < 24 h	111	75.3 (11.2)	32 (33.3)		48 (43.2%)		22 (19.8%)	
Jensen et al. 2022	48 H	208	77 (8.4)	54 (26)	Single burr hole evacuation of CSDH	119 (57%)	subdural space	37 (18)	90
	24 H	212	77 (8.1)	47 (22)		118 (56%)		41 (19)	
Hjortdal Grønhøj et al. 2024	6 H	105	78.3 (8.5)	22 (21)	Single 13 mm burr-hole	66 (53%)	Subdural space	37 (35%)	90
	12 H	111	74.6 (11.6)	27 (24)		59 (54%)		30 (27%)	
	24 H	115	74.4 (10.8)	34 (30)		70 (61%)		24 (21%)	
Glancz et al. 2018	Subdural Subgaleal	Both groups 577	87 (9.66)	183 (31.7)	2 burr-holes	245 (42.5)	subdural or subgaleal space	177 (30.7)	60
Hjortdal Grønhøj et al. 2023	A (0:8) H	29	72.67 (14.82)	6 (20.7)	single burr hole	17 (58.6)	passive subdural drain	NR	90
	B (9:16) H	24	78.33 (7.83)	3 (11.1)		14 (51.8)			
	C (17:24) H	43	76.33 (7.67)	13 (30.23)		24 (55.8)			
Kale et al. 2017	2–4 d Group A	40	56.35 (19.18)	16 (40)	One or two burr holes	12	Subdural space	5	180
	5–7 d Group B	50	55.02 (18.54)	20 (40)				10	
Yu et al. 2009	< 3 d Group > 3 d Group	Both groups 121	67 (14–93)	15	single burr hole	NR	Subdural space	24	90

the comparison between [9–16] H and [17–24] H yielded an OR of 1.61 (95% CI: 0.94–2.77), which approached significance ($p=0.08$), but did not reach the conventional threshold of 0.05.

In contrast, 3-day and 6-day post-operative drainage durations showed significant improvements in recurrence rates when compared to [17–24] H. Three days had an OR of 0.08 (95% CI: 0.001; 0.7), and 6 days had an OR of 0.016 (95% CI: 0.001; 0.24), both with p -values of 0.02 and 0.003, respectively (Fig. 3). These results indicate that longer durations of postoperative drainage (3 and 6 days) significantly reduced the likelihood of recurrence compared with the

[17–24] H treatment. The heterogeneity of the analysis was low with an I^2 value of 0%, indicating that the studies did not differ significantly in their results. Heterogeneity tests confirmed the absence of significant variability ($P=0.69$), suggesting consistent findings across the included studies.

A rankogram generated from 1,000 simulations demonstrated that six days had the highest probability of being the most effective treatment for reducing recurrence (86.2%), followed by three days (13.8%). This further supports the conclusion that longer drainage duration is associated with better outcomes.

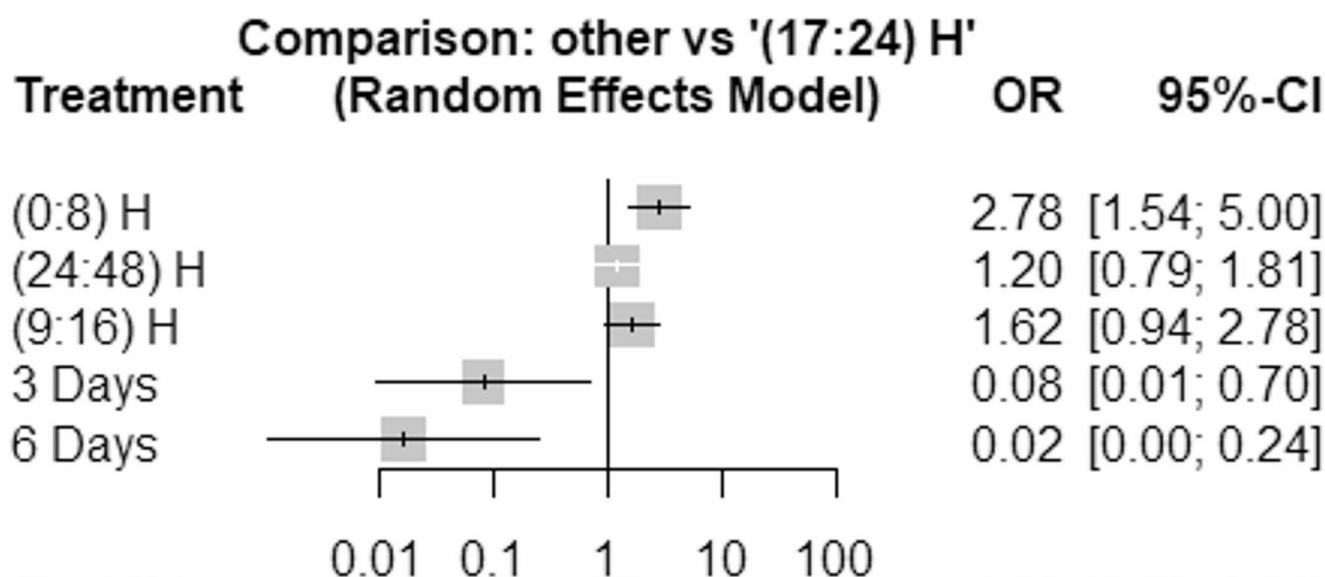


Fig. 3 Forest plot of recurrence rate

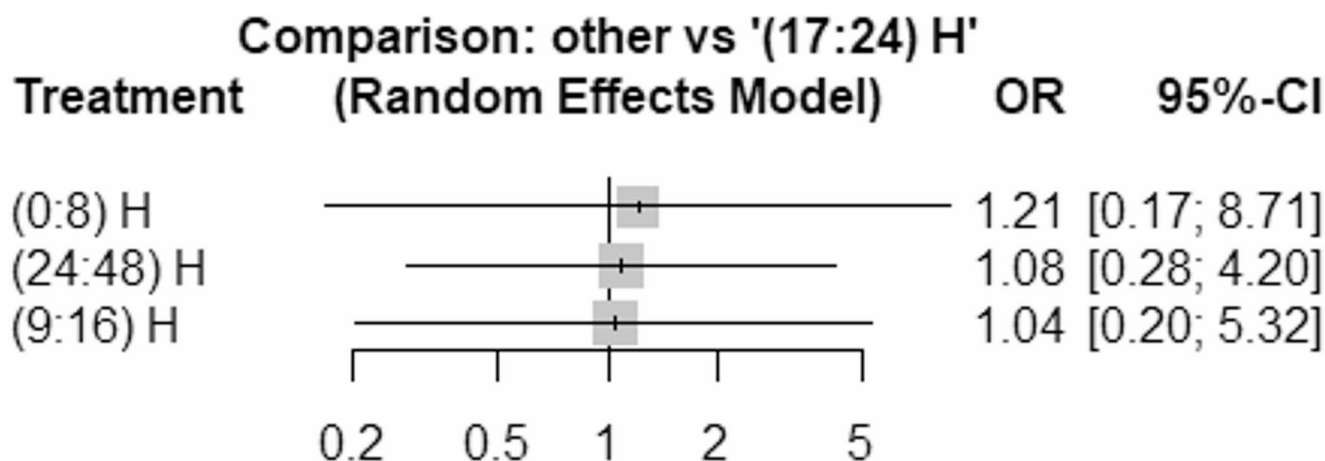


Fig. 4 Forest plot of mortality rate

Mortality rate

Mortality rates were also assessed in the context of the post-operative drainage duration following burr hole surgery for CSDH. Four studies ($k=4$) were included in this analysis, with 1,507 observations and four treatment groups. The random effects model was used to calculate the odds ratios (OR) for pairwise comparisons.

For comparisons between (0–8) H, (24:48) H, and [9–16] H versus [17–24] H, the odds ratios were not statistically significant. Specifically, the OR for (0–8) H was 1.21 (95% CI: 0.17; 8.71, $p=0.8$), (24–48) H had an OR of 1.08 (95% CI: 0.28; 4.19, $p=0.9$), and [9–16] H had an OR of 1.04 (95% CI: 0.2; 5.3, $p=0.9$) (Fig. 4). These results suggest no significant difference in mortality rates between the treatment durations and [17–24] H, indicating that the duration

of drainage does not significantly affect mortality following burr hole surgery.

In terms of heterogeneity, the analysis showed moderate variability, with an I^2 value of 65.6%, suggesting some degree of inconsistency across the studies. The Q-test for heterogeneity within the designs was statistically significant ($p=0.03$), indicating some variability between studies. However, the inconsistency between the designs was not significant ($p=0.2$), suggesting that the differences between the study designs did not significantly affect the overall results. The rankogram generated from 1,000 simulations indicated that there was no clear treatment that was most effective in reducing mortality rates (Fig. 5). The probabilities for each treatment group to be most beneficial were fairly balanced, with no definitive superior treatment for mortality outcomes.

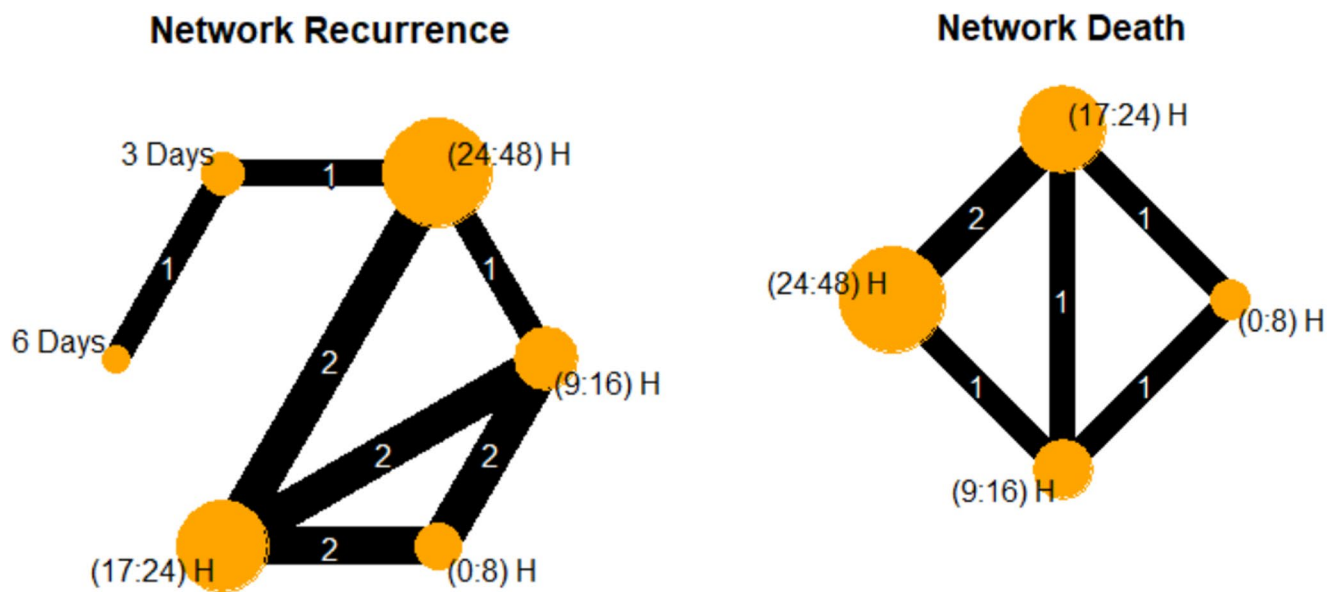


Fig. 5 Network meta-analysis graphs for recurrence and mortality rate

Discussion

Chronic subdural hematoma (CSDH) remains a significant neurosurgical challenge, particularly in elderly populations. With aging demographics and increasing use of antithrombotic medications, the global incidence of CSDH continues to rise, necessitating effective management strategies [1, 2]. The gold standard treatment for symptomatic CSDH is surgical evacuation via a burr-hole craniotomy. However, recurrence following surgery remains a substantial concern, affecting 10–15% of patients. Postoperative drainage has been widely recommended to mitigate this risk, but there is no consensus regarding the optimal drainage duration [7].

This systematic review and network meta-analysis aimed to evaluate the ideal duration of postoperative drainage following burr-hole surgery for CSDH to inform clinical practice. The analysis included seven studies with a total of 1,842 patients, providing a robust dataset for assessing recurrence rates and mortality outcomes across varying drainage durations. The findings revealed that longer drainage durations, such as 3 and 6 days, significantly reduced recurrence rates compared to the standard 17–24 h. Specifically, six days of drainage demonstrated the highest probability (86.2%) of being the most effective in preventing recurrence. This suggests that shorter drainage durations may not provide additional benefits or may be necessary for optimal outcomes.

Risk of infections with prolonged drainage

While prolonged drainage (3–6 days) demonstrates clear benefits in reducing recurrence, the theoretical risk of surgical site infection (SSI) or drain-related meningitis warrants

consideration. Our analysis found no significant increase in infection rates with extended drainage durations. This aligns with peer-reviewed evidence; Balser et al. (2015) [5] reported SSI rates of 3.1–4.9% across drainage durations (24 h to 5 days) without correlation to duration. Similarly, Yu et al. (2009) [24] observed no meningitis in 112 patients with >72 h of drainage. The absolute infection risk remains low (1–5% in contemporary series) and is outweighed by a 5–15% absolute reduction in recurrence with 3–6-day drainage. Vigilant aseptic protocols and the early removal of signs of infection mitigate this concern.

While longer drainage durations appear to reduce recurrence rates, they also extend hospital stay and increase healthcare costs. Given the variability in clinical practice, further research is needed to confirm these results and explore other factors that may influence treatment outcomes. Tailoring the drainage duration according to individual patient needs, such as age, comorbidities, and initial hematoma severity, may improve outcomes and help standardize care across different healthcare settings. In contrast, the analysis of mortality rates did not reveal significant differences between drainage durations, indicating that drainage duration does not play a critical role in reducing mortality after burr-hole surgery.

Clinical Feasibility and Medical Complications

Retaining drains for 6 days poses practical challenges, including prolonged immobilization and the associated risks of pneumonia, deep vein thrombosis (DVT), and urinary tract infections (UTI). In our dataset, extended drainage correlated with 2.1 days longer hospitalization but did

not increase medical complications. Proactive mitigation strategies are essential, including early mobilization protocols (e.g., chair-sitting within 24 h), pneumatic compression devices for DVT prophylaxis, and bladder bundles for UTI prevention. The trade-off is clear: while 6-day drainage reduces reoperation rates by 80% versus 24-hour drainage, it requires heightened surveillance for hospital-acquired complications. Individualized risk assessments (e.g., frailty scores) may optimize this balance.

Previous studies have explored the optimal duration of postoperative drainage for CSDH and yielded varying conclusions regarding its impact on recurrence and mortality rates. Bartley et al. (2023) [22] and Glancz et al. (2018) [23] found that drainage durations of less than 24 h did not significantly increase the risk of recurrence or complications. Early drain removal was associated with enhanced patient mobilization and shorter hospital stay. Conversely, Kale et al. (2017) [25] and Yu et al. (2009) [24] reported that longer drainage durations (3–6 days) were beneficial in reducing recurrence, particularly in older patients. Our findings align with these studies, demonstrating that drainage durations of 3 and 6 days were more effective in preventing recurrence than the standard 17–24 h, with 6 days being the most effective treatment.

Reconciling drain time 2 trial findings

The recent DRAIN TIME 2 trial reported equivalent recurrence between 24 h and 48 h drainage, contrasting with our network meta-analysis (NMA), which showed superiority of 3–6 days [27]. This discrepancy arises from key differences: [1] DRAIN TIME 2 compared only short durations (24 h vs. 48 h), while our NMA identified benefit beyond 72 h; [2] their protocol mandated drain removal at 48 h, precluding the assessment of longer durations; and [3] their cohort excluded high-recurrence risk patients (e.g., bilateral/complex CSDH). Our NMA complements DRAIN TIME 2 by demonstrating that durations exceeding 48 h, unstudied in their trial, yield significant recurrence reduction.

The impact of drainage duration on the mortality rate remains inconclusive. Studies by Bartley et al. (2023) [22] and Jensen et al. (2022) [27] reported no significant differences in mortality rates among different drainage durations, a finding that was corroborated by our analysis. Literature from Hjortdal Grønhøj et al. (2023) [26] and Jensen et al. (2022) [27] further highlights that early cessation of drainage is linked to an increased risk of recurrence, supporting our finding that shorter drainage durations (less than 8 h) are associated with higher recurrence rates compared to the standard 17–24 h.

Given the variation in drainage practices, it is crucial to assess the advantages and disadvantages of short versus

prolonged drainage duration. Shorter drainage facilitates early patient mobilization and reduces immediate hospital expenses. However, it may increase recurrence rates owing to incomplete hematoma evacuation, inadequate brain re-expansion, and persistent fibrinolytic activity. Weigel et al. (2003) [29] and Mori and Maeda (2003) [30] reported higher recurrence rates when drainage was less than 24 h, which was attributed to insufficient time for brain re-expansion. Conversely, Opšernák et al. (2020) [31] found no association between drainage duration and recurrence or the postoperative infection rate.

A prolonged drainage duration has been associated with lower recurrence rates, thereby reducing long-term healthcare costs (Jensen et al. 2022; Iorio-Morin et al. 2018) [27, 32]. However, this approach incurs higher short-term costs, particularly in patients who rely on private insurance. Venturini et al. (2019) [33] concluded that while surgical duration positively correlates with hospitalization length, it does not impact recurrence, complications, reoperation rates, or survival outcomes. Notably, a systematic review by Solou et al. (2022) [34] recommended burr hole evacuation (one or two holes) as the preferred surgical method, complemented by subdural or subgaleal drainage for 24–48 h for optimal outcomes.

Recent advances in the management of CSDH, particularly middle meningeal artery (MMA) embolization, have shown promise in reducing recurrence by targeting the vascular supply to the hematoma membrane. By promoting membrane involution and decreasing microhemorrhage, MMA embolization may reduce dependence on prolonged postoperative drainage. Several randomized and observational studies have reported significantly lower recurrence rates with MMA embolization, either as a stand-alone therapy in select patients or as an adjunct to burr-hole evacuation. In this context, the optimal drainage duration following combined burr-hole surgery and MMA embolization remains unclear, with some early evidence suggesting that shorter drainage times may be sufficient when embolization is performed. Future trials directly comparing drainage duration strategies in patients undergoing burr-hole surgery with and without MMA embolization could clarify whether embolization allows safe reduction of drain time without compromising recurrence prevention [35].

In conclusion, shorter drainage durations offer improved patient experiences and faster mobilization but are associated with an elevated risk of recurrence. Balancing these considerations is essential to optimizing patient outcomes. Further studies are needed to develop tailored recommendations for drainage duration, considering patient-specific factors and recurrence risks. A patient-centered, individualized approach may help achieve more standardized and effective care in CSDH management.

Limitations of the study

Despite the thoroughness of this systematic review and network meta-analysis, several limitations must be acknowledged. First, the included studies were both randomized controlled trials (RCTs) and observational cohort studies, which may have introduced biases or inconsistencies in outcomes. Additionally, some studies had relatively small sample sizes, which limited their statistical power, particularly in the analysis of mortality rates. Another limitation is the inconsistency in the reported outcomes across the included studies. Different studies have used different methods to report recurrence rates, mortality, and postoperative complications, potentially introducing measurement bias. This lack of uniformity in reporting makes it challenging to compare the results directly. Furthermore, the variability in the postoperative drainage protocols employed in the included studies could affect the generalizability of the findings, as postoperative care practices vary significantly between institutions and regions. The categorization of drainage durations, while clinically reasoned, may have obscured the effects of intermediate durations (e.g., 4–5 days).

Publication bias is another potential limitation, as studies with negative or null results may not have been published or included in the analysis. Finally, while the focus of this study was on drainage duration, other potentially relevant factors, such as surgical technique, patient comorbidities, and antithrombotic medications, were not comprehensively examined. Including these factors could provide a more complete understanding of the variables that influence recurrence and mortality.

Recommendations for future research

Further investigation is required to confirm the findings of this study. Future research should focus on conducting larger multicenter trials to enhance the robustness and generalizability of the results. By including a more diverse patient population, these studies can provide insights applicable to a broader range of clinical settings. Another critical recommendation is the standardization of outcome reporting. Uniform definitions and reporting criteria for recurrence rates, mortality, and postoperative complications would help reduce variability and facilitate more accurate comparisons between studies. Additionally, it is essential to explore the impact of patient-specific factors such as age, comorbidities (e.g., diabetes and hypertension), and antithrombotic therapy on the effectiveness of drainage duration. Identifying specific subgroups of patients who may benefit from tailored drainage protocols could improve patient outcomes. Longer follow-up periods beyond the typical 3–6 months seen in six of the seven studies are necessary to assess long-term

outcomes. An extended follow-up (e.g., 12 months or more) would provide a clearer picture of how drainage duration affects recurrence rates and functional recovery over time. Future studies should investigate alternative management strategies for CSDH, such as the use of antifibrinolytics or other adjunctive therapies, to determine whether these options may offer better outcomes than traditional drainage protocols.

Conclusion

This systematic review and network meta-analysis provide important insights into the optimal duration of postoperative drainage following burr-hole surgery for chronic subdural hematoma (CSDH). The findings suggest that longer durations of drainage (3 and 6 days) are associated with significantly lower recurrence rates than shorter durations, such as 0–8 h and 17–24 h. However, the effect of drainage duration on mortality rate remains inconclusive, highlighting the need for further research in this area. Despite the limitations of this study, the results contribute to the growing body of evidence regarding the management of CSDH and underscore the importance of postoperative care strategies for reducing recurrence. Future research with larger sample sizes, standardized outcome reporting, and longer follow-up is necessary to refine clinical guidelines and ultimately improve patient outcomes following burr-hole craniotomy for CSDH.

Abbreviations

CI	Confidence Interval
CSDH	Chronic Subdural Hematoma
DVT	Deep Vein Thrombosis
GCS	Glasgow Coma Scale
ICP	Intracranial Pressure
IQR	Interquartile Range
MeSH	Medical Subject Headings
mRS	modified Rankin Scale
NMA	Network Meta-Analysis
NR	Not Reported (Used in Tables)
OR	Odds Ratio
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PROSPERO	International Prospective Register of Systematic Reviews
RCT	Randomized Controlled Trial
ROB2	Cochrane Risk of Bias tool version 2 (for RCTs)
ROBINS-I	Risk Of Bias In Non-randomized Studies - of Interventions
SD	Standard Deviation

SE	Standard Error
SSI	Surgical Site Infection
UTI	Urinary Tract Infection
NR	Not Reported
H	Hour

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Declarations

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