Clinical Neurology and Neurosurgery 252 (2025) 108850

Contents lists available at ScienceDirect

Clinical Neurology and Neurosurgery

journal homepage: www.elsevier.com/locate/clineuro

Twist-drill craniostomy with pressure-controlled fibrinolytic irrigation therapy reduces recurrence of chronic subdural hematomas: initial experience in 16 cases

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ARTICLE INFO

Keywords:
Chronic subdural hematoma
Fibrinolytic irrigation
Recurrence
Twist-drill craniostomy
Urokinase

ABSTRACT

Background: Chronic subdural hematoma (cSDH) is prevalent in the elderly, frail, and those on antithrombotic therapy, often resulting in significant morbidity and mortality. Recurrence and reoperation rates are substantial concerns. Emerging evidence suggests that irrigation, drainage, and possibly fibrinolytic therapy, may improve reoperation rates.

Objective: To explore safety and efficacy of twist-drill craniostomy (TDC) with pressure-controlled fibrinolytic irrigation therapy (TDC-FIT) in reducing recurrence rates of cSDH compared to conventional TDC with subdural passive drainage.

Methods: A retrospective study included 314 patients treated with TDC and 16 patients treated with TDC-FIT between January 2021, and March 2024. The primary endpoint was the reoperation rate due to symptomatic recurrence or persistence of cSDH at 6 months. Secondary endpoints included hematoma resolution, perioperative complications, and the impact of antithrombotic therapy and preoperative membrane formation.

Results: Reoperation was required in 107 (34.1 %) TDC patients and in one (6.3 %) TDC-FIT patient ($P = .026$). Hematoma membranes (OR 2.6, 95 % CI 1.6–4.3, $P < .001$) and dual antithrombotic therapy (OR 10.3, 95 % CI 1.1–93.3, $P = .041$) were significantly associated with reoperation in the TDC cohort. TDC-FIT showed superior hematoma resolution with a similar complication profile and functional outcome. TDC-FIT patients had a significantly lower reoperation rate despite a higher presence of hematoma membranes (75 % vs. 34.7 %, $P = .002$).

Conclusion: Preliminary data on TDC-FIT suggests improved reoperation rate and membranous hematoma resolution with comparable safety profiles to conventional TDC. Further prospective studies are needed to validate these findings in larger cohorts.

1. Introduction

Chronic subdural hematoma (cSDH) is a highly prevalent condition, particularly affecting the elderly and individuals with antithrombotic therapy [1–3]. It carries significant morbidity and mortality, with up to 20 % of patients experiencing poor neurological outcomes. Moreover, it can act as a sentinel event, with excess mortality rates reaching 32 % [4–6].

Surgical intervention is typically indicated for symptomatic cases; however, there is no consensus regarding the optimal surgical approach [7,8]. Common surgical techniques include twist-drill craniostomy (TDC) and single or double burr-hole craniostomy (BHC), with drainage placement. In select cases, an open craniotomy may be necessary, although it is associated with higher complication rates, partly due to the need for general anesthesia [2,9,10].

TDC offers the advantage of a minimally invasive procedure that can be performed bedside without the need for general anesthesia, rendering this approach particularly useful in elderly and multimorbid patients [10,11]. Recurrence and the need for reoperation (between 10 % and 20 %) are significant concerns in the management of cSDH and might

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https://doi.org/10.1016/j.clineuro.2025.108850
Received 6 February 2025; Received in revised form 11 March 2025; Accepted 11 March 2025
Available online 15 March 2025

even be worse with TDC compared to BHC or craniotomy [2,8,12]. Hematoma membrane and consolidations are important risk factors for recurrence and reoperation [13–15]. There is no universally accepted approach for evacuating cSDH and preventing recurrence, with surgical practices varying between institutions.

Accordingly, therapeutic improvements are warranted. Endovascular occlusion of the middle meningeal artery (MMA) has shown potential for reducing recurrence rates in three recent randomized clinical trials [16–18]. Meticulous intraoperative saline with body temperature irrigation during BHC, followed by drainage has been showed to reduce recurrence in two randomized controlled trials (RCT) [19,20]. While drain placement has been shown to reduce recurrence rates, the choice between subdural and subgaleal drainage differs across clinical settings [21–24].

Several retrospective studies have demonstrated potential benefits of hematoma resolution using fibrinolytic therapy [25–28]. Considering this, we introduced a twist drill craniostomy with pressure-controlled fibrinolytic irrigation therapy (TDC-FIT) into the management of cSDH patients in our department. Herein, continuous pressure-controlled infusion of the fibrinolytic drug urokinase is used to dissolve consolidated hematomas and membranes and the irrigation serve to reduce hematoma recurrence.

We report our initial experience with TDC-FIT – performed in sixteen patients – and compare hematoma resolution, reoperation rates, and perioperative complications to those observed in our previous cohort of patients treated with TDC without fibrinolytic irrigation between 2021 and 2023.

2. Materials and methods

This retrospective study included all patients aged 18 years or older who underwent a conventional TDC with passive subdural drainage or TDC-FIT for a cSDH between January 2021, and March 2024. TDC-FIT was introduced in our department in June 2023, and since then, both techniques have been performed in parallel. Conventional TDC with passive drainage was not phased out after June 2023 but remains in use, with TDC-FIT increasingly adopted in selected cases where a high recurrence risk or inadequate hematoma evacuation is anticipated. At our institution, surgical intervention for cSDH was indicated for patients with a hematoma thickness of at least 10 mm and/or symptomatic hematoma. Patient selection for TDC-FIT followed the same criteria as our standard treatment protocol, with the only difference being the use of pressure-controlled irrigation therapy.

The primary endpoint of our study was the reoperation rate due to symptomatic recurrence or persistence of cSDH within 6 months following the TDC and TDC-FIT procedure. The effects of patient characteristics, hematoma features and antithrombotic therapy on the reoperation rate were assessed as secondary endpoints. A comparison between TDC and TDC-FIT regarding preoperative characteristics, outcome, and complications was performed.

2.1. Patient data collection

Patient data were collected retrospectively from electronic medical records, surgical notes, and radiological imaging, including pre- and postoperative computed tomography (CT) scans or magnetic resonance imaging. Variables examined included age, sex, use of antithrombotic treatment (phenprocoumon, direct oral anti-coagulants (DOACs), and anti-platelet agents, as well as the use of dual antithrombotic medication), hematoma laterality, presence of hematoma membranes, and surgical approach: (1) TDC with passive subdural drainage or (2) TDC-FIT. Surgical complications, including bleeding, infection, accidental subdural catheter dislocation, misplacement of the subdural catheter into the parenchyma, and mortality were documented. Functional outcome was assessed using the modified Rankin Scale (mRS) at last follow-up. Furthermore, miscellaneous postoperative treatments relevant for the cSDH, e.g. embolization of the MMA and management of spinal cerebrospinal fluid (CSF) fistula or leakage were noted. No missing data was reported.

2.2. Statistical analysis

Statistical analyses were conducted using Microsoft Excel version 16.88 (24081116) for Mac (Microsoft Corporation, Redmond, WA, USA), Wizard Pro Version 1.9.42 (267) (Evan Miller, Chicago, IL, USA), and GraphPad® Prism 10 for macOS, Version 10.2.3 (347). Fisher's exact test and Chi-Square test of independence examined associations between categorical variables, while Mann-Whitney U test analyzed associations between non-parametric continuous variables. Significance levels were set at $P < .05$. Multivariate logistic regression analysis was performed on independent variables with $P \leq .20$ in univariate tests. Based on the coefficients of the multivariate model for hematoma recurrence established in conventional TDC cohort, the predicted risk for reoperation due to hematoma recurrence was calculated for 16 patients who were selected for TDC-FIT. The outcome was presented as odds ratio (OR) and 95 % confidence interval (CI).

2.3. Ethical considerations

The study adhered to ethical guidelines and was conducted in accordance with the Declaration of Helsinki. Institutional Review Board approval was obtained before the initiation of the study (number 24–1201-S1-retro). Patient confidentiality and data anonymization were ensured throughout the research process. To ensure the complete inclusion of all treated patients in this retrospective study, written consent was waived by our Institutional Review Board.

2.4. Surgical and postoperative management procedure for TDC-FIT

The surgical procedure for TDC-FIT adheres closely to our established standard TDC with placement of a subdural drainage (VentriClear® Ventricular Catheter, Neuromedex GmbH, Germany) [11,29,30]. Any antithrombotic therapy was immediately discontinued and, if possible, antagonized. The intervention was then performed as soon as possible after antagonization and normalization of platelet count and coagulation values, typically within hours of diagnosis.

The extent of the hematoma was evaluated using 3-dimensional CT data sets to guide surgical planning and decision-making. Following identification of the entry point, patients were positioned in the lateral decubitus position. Any hair obstructing the area was removed and the site was disinfected and draped. Under local anesthesia, administered subcutaneously as 5 mL of 2 % scandicaine (Aspen Germany GmbH), a bedside TDC was performed using a sterile 3.5 mm drill. This procedure was typically conducted at either the frontal or parietal eminence, providing safe access to the subdural space. A dual-lumen 9 Fr catheter or two 7 Fr catheters for pressure-controlled irrigation were inserted into the subdural space. Two systems for pressure-controlled irrigation were used interchangeably without any preference: (1) the IRRAflow® IRRAS-single catheter system® (IRRAS AB, Sweden) and (2) LiquoGuard® 7 CSF Management System (Möller Medical GmbH, Germany). Once the catheter was in place and fixated with 2–0 nylon suture, the pressure-controlled fibrinolytic therapy was commenced using an electrolyte solution (Jonosteril®, Fresenius-Kabi GmbH, Bad Homburg, Germany) with 200 000 IU/L urokinase (Syner-KINASE, Syne-Medica BV, Houten, Netherlands). Irrigation was performed at a target rate of 100 mL/h. The target rate of 100 mL/h was based on experience with similar protocols for acute SDH [31,32], and our institutional experience in cisternal pressure-controlled irrigation for subarachnoid hemorrhage [33-35]. Continuous intracranial pressure monitoring was achieved through the pressure-controlled catheter. To accurately measure intracranial pressure at the foramen of Monro, mobilization was limited to a seated position under supervision. Nursing staff regularly monitored the system at 60-minute intervals to assess the volume and characteristics of the drainage fluid. Upon clearance of the hematoma, usually after 3–5 days, the catheter was transitioned to passive drainage and typically removed the following day after outflow suspension. The procedure follows the same protocol as our previously published TDC-FIT approach for select patients with acute subdural hematoma [31,32]. Consecutive CT scans were performed according to our institutional standard for cSDH management, including a postoperative scan prior to subdural catheter removal and another at routine follow-up, typically 3–6 weeks later. Additional follow-up imaging was performed if residual hematoma was present. All patients in the TDC-FIT cohort had a complete resolution of the membrane in their postoperative CT scan before conversion to passive drainage. Routine hematoma volume measurements were not conducted. The radiological course from two patients is demonstrated in Fig. 1A-D and Fig. 2A-D.

3. Results

3.1. Preoperative characteristics in the TDC cohort

This study retrospectively analyzed 314 patients who underwent surgical management of cSDH with TDC. The median age was 80 years (range 24–96) and 98 (31.2 %) were female patients. Bilateral hematomas were present in 88 (28 %) cases and membranes within hematomas were identified in 109 (34.7 %) patients. 38 (12.1 %) patients received a bilateral TDC. 154 (49 %) patients had no antithrombotic medication, while 20 (6.4 %) patients were treated with phenprocoumon, 55 (17.5 %) with DOACs, 79 (25.2 %) with antiplatelets, and 6 (1.9 %) with dual antithrombotic therapy. Based on the reoperation rate for each subgroup, multivariate analysis identified the presence of hematoma membranes (OR = 2.6, 95 % CI 1.6–4.3, $P < .001$) and the use of dual antithrombotic medication (OR = 10.3, 95 % CI 1.1–93.3, $P = .041$) as significant risk factors for reoperation. Detailed results are presented in Table 1.

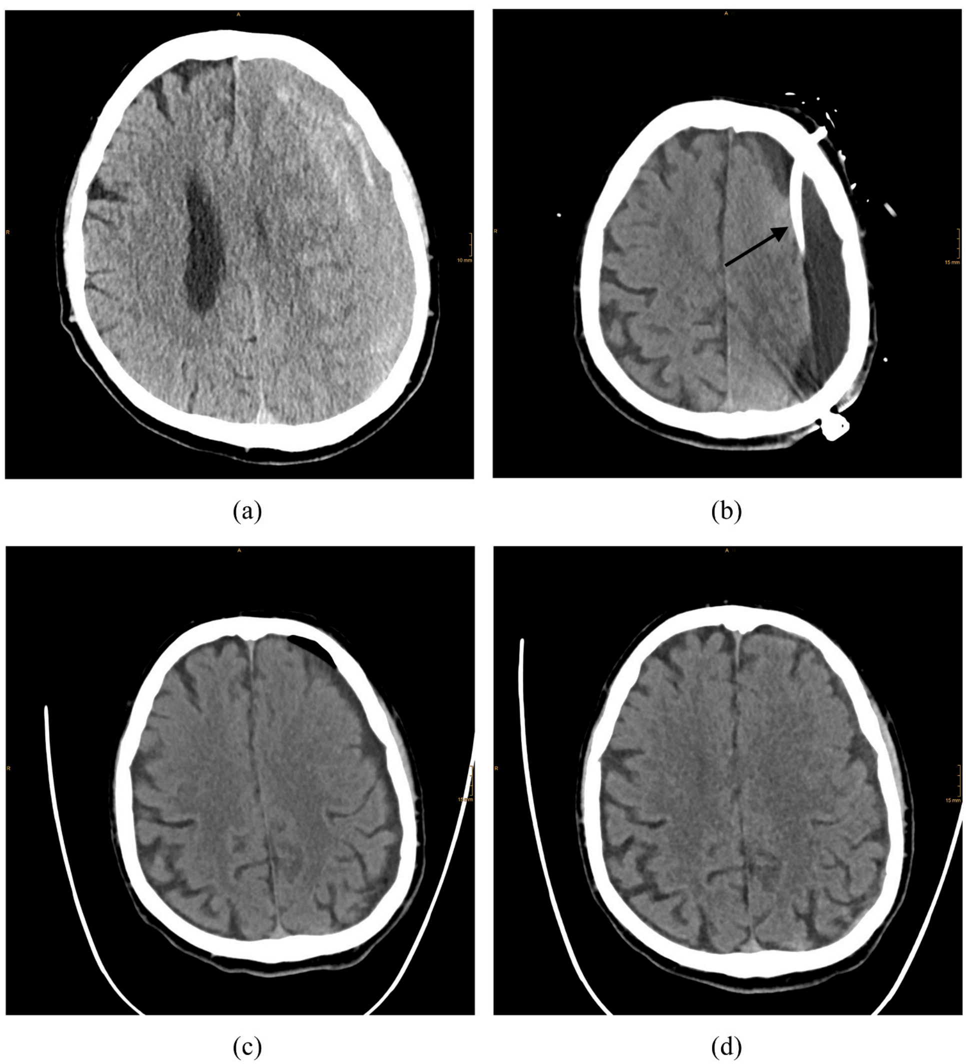

Fig. 1. A-D Radiological course of a 68-year-old male patient treated with TDC-FIT. A. A 68-year-old male with a left-sided membranous cSDH presented to the emergency department with right-sided hemiparesis. **B.** TDC-FIT was performed with a 9 Fr dual-lumen catheter (arrow). At the first radiological follow-up on day 3, the hematoma membranes had completely transformed into a homogenic hypodense subdural fluid collection. Subsequently, the system was changed into a passive drainage. After outflow suspension the drainage was removed. **C.** A CT scan before discharge on day 4 showed a regress of the hematoma and the patient was discharged without neurological deficits. **D.** Three weeks later, the collection was almost completely resolved. The hemiparesis was no longer present, the patient experienced no complications, and the functional outcome was categorized as mRS 0.

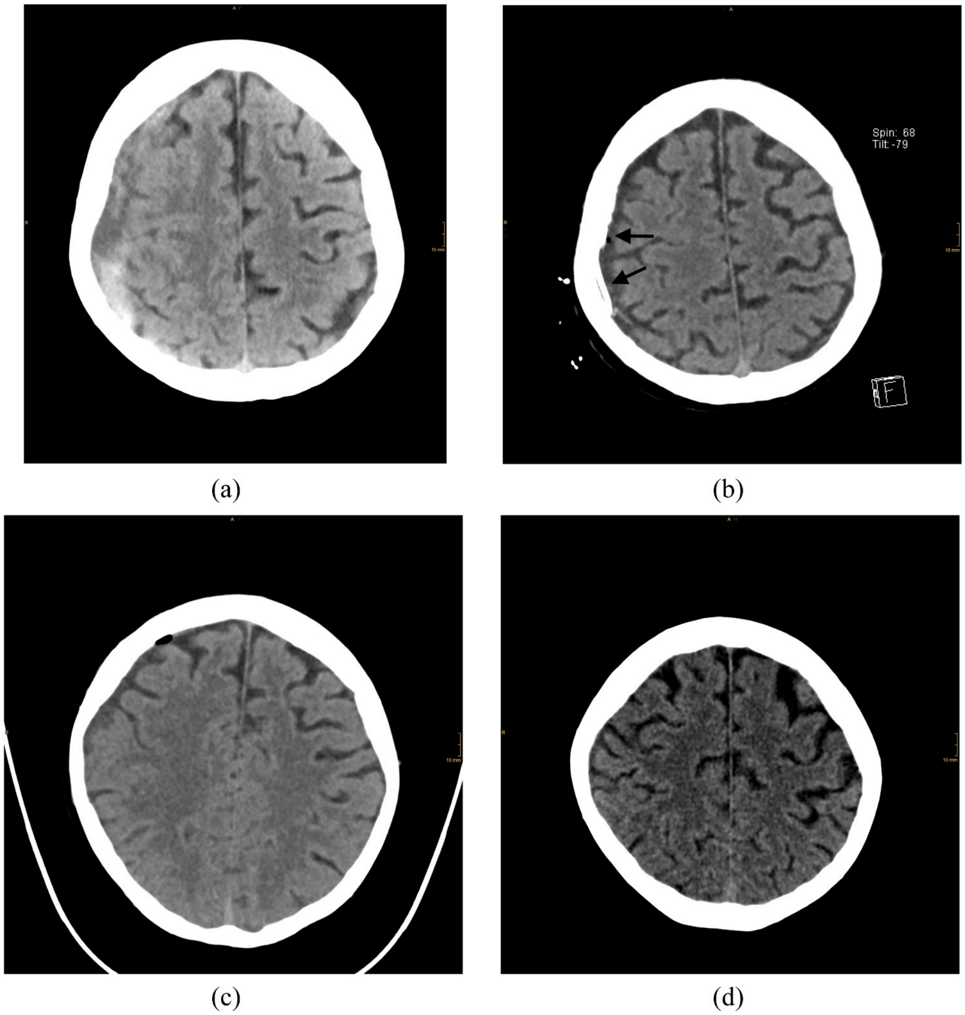

Fig. 2. A-D Radiological course of a 72-year-old female patient treated with TDC-FIT. A. A 72-year-old female on anticoagulants with a right-sided mixed cSDH with membranes presented to the emergency department with progressive headache. **B.** A TDC-FIT was performed with two 7 Fr catheters (arrows). At the first radiological follow-up on day 5, the hematoma membranes had completely resolved. Subsequently, the system was changed into a passive drainage. After outflow suspension the drainage was removed. **C.** A Follow-up on day 10 showed an almost complete hematoma resolution. **D.** Three months later, the hematoma was fully resolved. Headache was not present, and the patient experienced no complications. The functional outcome was categorized as mRS 0.

3.2. Reoperation rate and outcome in the TDC cohort

Within six months of the index surgery, 107 (34.1 %) patients required at least one reoperation. Among them, 75 (23.9 %) had one reoperation, 23 (7.3 %) had two, 7 (2.2 %) had three, and 2 (0.6 %) had four reoperations. Additionally, nine patients were later treated for a CSF fistula or leakage, 15 patients underwent embolization of the MMA, and one patient was treated for both. Postoperative complications after the index surgery occurred in 17 (5.4 %) patients, including acute postoperative bleeding (5 patients), postoperative meningitis or empyema (2 patients), accidental dislocation of the subdural catheter (6 patients), and catheter misplacement (4 patients). 11 (3.5 %) deaths related to perioperative treatment were recorded in our TDC cohort. Detailed results are presented in Table 2.

3.3. Preoperative characteristics and outcome in 16 patients treated with TDC-FIT

Table 3 presents the detailed characteristics of additional sixteen patients who underwent TDC-FIT. The median age of the cohort was 75.5 (range 45–87), with four patients (25 %) being female. Of the sixteen patients in the TDC-FIT cohort, three underwent TDC-FIT as the primary treatment, while eight received TDC-FIT during their first reoperation, four during their second reoperation, and one patient during their third reoperation. Twelve patients (75 %) presented with hematoma membranes. Seven patients (43.8 %) received antithrombotic medication, including three patients on antiplatelets, three patients on anticoagulants, and one patient on dual antithrombotic therapy. One patient (6.3 %) required reoperation after a TDC-FIT due to a recurrent hematoma, managed with one TDC, while another patient (6.3 %) was treated for a postoperative meningitis without permanent sequela. No other complications were observed in this patient cohort and no deaths related to the perioperative treatment was recorded. Additionally, in the TDC-FIT cohort one patient was later treated for a CSF spinal leak and one patient underwent an embolization of the MMA. In the latter case, the decision to perform MMA embolization was not due to hematoma recurrence but rather to proactively minimize the risk of recurrence in a patient with high cardiovascular risk who required antithrombotic therapy.

Based on the conventional TDC cohort, considering the presence of membranes and dual antithrombotic therapy, we statistically estimated a predicted reoperation risk of 45.8 % in our TDC-FIT cohort.

3.4. Comparison between the TDC and TDC-FIT cohorts

A comparative analysis was conducted between the TDC and TDC-

Table 1
Patient and surgical characteristics of conventional TDC.

	No. (%)	Reoperation rate (%)	*P* value Uni-variate	 Multi-variate	OR (CI)
Patients included	314				
Age, median (range), y	80 (24–96)				
Female	98 (31.2)	32.7	.80		
Male	216 (68.8)	34.8			
Unilateral hematoma	226 (72)	33.7	.72		
Bilateral hematoma	88 (28)	36.8			
Membranes	109 (34.7)	49.5	< .001	< .001	2.6 (1.6–4.3)
No membranes	205 (65.3)	26.5			
Unilateral TDC	282 (89.8)	35	.70		
Bilateral TDC	38 (12.1)	31.8			
Antithrombotic therapy	160 (51)	36.9	.29		
No antithrombotic therapy	154 (49)	31.2		Ref.	
Phenprocoumon	20 (6.4)	15		.17	0.4 (0.1–1.5)
DOAC	55 (17.5)	41.8		.25	1.5 (0.8–2.9)
Antiplatelets	79 (25.2)	35.4	.018	.50	1.2 (0.7–2.2)
Dual antithrombotic therapy	6 (1.9)	83.2		.041	10.3 (1.1–93.3)

Abbreviations: CI, confidence interval; DOAC, direct oral anti-coagulants; OR, odds ratio; TDC, twist-drill craniostomy

Table 2
Outcome characteristics of conventional TDC at 6 months after index surgery.

	No. (%)
Patients with reoperations	107 (34.1)
One reoperation	75 (23.9)
Two reoperations	23 (7.3)
Three reoperations	7 (2.2)
Four reoperations	2 (0.6)
Adjunctive postoperative treatment	
CSF fistulas or leakage	9 (2.9)
MMA embolization	15 (4.8)
Both	1 (0.3)
Surgery-related complications	
Complication rate	17 (5.4)
Acute hematoma	5 (1.6)
Empyema/meningitis	2 (0.6)
Catheter dislocation	6 (1.9)
Catheter misplacement	4 (1.3)
Deaths	11 (3.5)

Abbreviations: CSF, cerebrospinal fluid; MMA, middle meningeal artery

FIT cohorts. Both cohorts were similar, but distinctions were evident in the prevalence of hematoma membranes (OR 5.5, 95 % CI 1.7–16, $P = .002$) and reoperation rate (OR 0.2, 95 % CI 0.0–1.0, $P = .026$). There were no deaths in the TDC-FIT cohort compared to 11 (3.5 %) deaths in the TDC cohort. Results are summarized in Table 4.

4. Discussion

We recently introduced TDC-FIT into the management of cSDH patients at high risk for hematoma recurrence (recurrent and membranous cSDH). Our initial experience with this novel technique is encouraging as we observed significantly better outcomes in terms of reoperation rates (6.3 % vs. 34.1 %), despite higher prevalence of hematoma membranes (75 % vs. 34.7 %), while our preliminary data suggests comparable complication rate and functional outcome.

Our retrospective analysis from the conventional TDC cohort of 314 patients confirm that membrane formation in cSDH is the most important risk factor for recurrence, which is also supported in the literature [13–15]. Patients with membranes had a 49.5 % recurrence rate compared to 26.5 % in patients without membranes. Our findings are in line with other studies that suggest a superiority of active removal of cSDH over passive drainage. A recent RCT showed significantly lower recurrence rates if intraoperative irrigation was performed during BHC [20], and another RCT demonstrated that 37°C saline irrigation resulted in less recurrence compared to room temperature (22°C) saline irrigation [19]. Fibrinolytic therapy has been previously used to promote hematoma dissolution. Several retrospective studies have explored the efficacy of intermittent bolus fibrinolytic therapy in patients with cSDH [28]. Neils et al. reported impressive findings, demonstrating a reduction in recurrence rate to 0 % compared to 11.8 % for BHC and 30 % for TDC at one month follow-up with the administration of tissue plasminogen activator [25]. Lu et al. introduced a novel TDC-device, termed micro-steel-needle-tube-bit, for puncture and drainage, coupled with the application of urokinase. Their study showed a recurrence rate of only 0.5 % (1 of 202 patients) after 28 days [26]. Ou et al. demonstrated a significant reduction in hematoma volume and a recurrence rate of only 1.9 % at six months following urokinase administration [27]. The methods reported differed from ours as intermittent bolus injection of urokinase solution was used. So far, all authors noticed minimal complications with fibrinolytic therapy of cSDH. Limitations of the mentioned studies include short follow-up times (1 month) [25,27]. In our TDC-FIT cohort, one patient incurred a culture-positive subdural infection presumably not associated to the subdural irrigation therapy (detected immediately after TDC-FIT which was performed second to a conventional TDC with ineffective hematoma clearance).

We hypothesize that continuous irrigation therapy may be specifically appropriate and more effective for cSDH treatment compared to fibrinolytic bolus injection because it offers the potential to mitigate the presence of inflammatory molecules from the subdural space and also allows for continuous irrigation. Pathophysiological findings support the notion that the pathogenesis of cSDH involves a complex interplay of inflammatory mechanisms. While inflammation is integral to tissue repair, its persistence in cSDH may drive the formation of new membranes, foster fluid accumulation, promote neovascularization, and promote the separation of dural border cells as part of a reparative response. Inflammatory mechanisms may lead to an imbalance between collagen synthesis and degradation and, thus, perpetuate the accumulation of a collagen matrix and subsequent membrane formation [36].

Drawing inspiration from therapeutic approaches in aneurysmal subarachnoid hemorrhage, where fibrinolytic irrigation has been explored as an experimental approach to reduce DCI and systemic inflammatory response syndrome [33,34,37,38], continuous irrigation and removal of inflammatory molecules may similarly hold potential in mitigating sustained inflammation and reducing recurrence in cSDH.

The impact of antithrombotic therapy on recurrence rates remains a subject of debate [39,40]. In our retrospective cohort involving patients receiving TDC, only the use of dual antithrombotic medication was associated with a 10.3-fold higher risk of reoperation. However, due to the limited number of cases (6 patients), further interpretation should be made with caution. Nonetheless, there is potential value in future studies to stratify the type of antithrombotic therapy to better understand their respective impacts on the risk of reoperation and recurrent hematoma.

In summary, TDC-FIT represents a novel approach in managing patients with cSDH, showing promising outcomes in terms of reducing

Table 3
Detailed characteristics of 16 patients treated with TDC-FIT.

Pat #	Agey	Sex	Index Surgery	2nd surgery	3rd surgery	4th surgery	Irrigation type	Side	Anti-thrombotic therapy	Membrane	Reop	Predicted risk
1	71	m	TDC	TDC-FIT	-	-	IRRAflow	left	-	yes	0	45.8 %
2	85	m	TDC-FIT	TDC	-	-	IRRAflow	left	-	no	1	24.6 %
3	75	m	TDC	TDC-FIT	-	-	IRRAflow	left	AP	yes	0	50.8 %
4	45	f	TDC	TDC	TDC-FIT	-	LiquoGuard	left	-	yes	0	45.8 %
5	54	m	TDC	TDC	TDC-FIT	-	IRRAflow	right	-	yes	0	45.8 %
6	82	m	TDC	TDC-FIT	-	-	IRRAflow	left	AP+AC	yes	0	89.7 %
7	77	f	TDC	TDC-FIT	-	-	IRRAflow	left	AC	yes	0	55.5 %
8	64	m	TDC	TDC-FIT	-	-	IRRAflow	right	-	yes	0	45.8 %
9	85	m	TDC	TDC-FIT	-	-	LiquoGuard	right	AP	no	0	28.5 %
10	81	m	TDC	TDC	TDC-FIT	-	IRRAflow	left	-	yes	0	45.8 %
11	80	m	TDC	TDC-FIT	-	-	LiquoGuard	left	-	yes	0	45.8 %
12	68	m	TDC-FIT	-	-	-	LiquoGuard	left	-	yes	0	45.8 %
13	72	f	TDC-FIT	-	-	-	LiquoGuard	right	AC	yes	0	55.5 %
14	87	m	TDC	TDC	TDC-FIT	-	IRRAflow	bilateral	AC	no	0	32.5 %
15	71	m	TDC	TDC	TDC	TDC-FIT	LiquoGuard	left	-	no	0	24.6 %
16	76	f	TDC	TDC-FIT	-	-	IRRAflow	right	AP	yes	0	50.8 %
Predicted risk of reoperation in the TDC-FIT cohort: 45.8 %												

Abbreviations: AC, anti-coagulant therapy; AP, anti-platelet therapy; *Predicted risk* intend risk for reoperation due to hematoma recurrence based on the coefficients of the multivariate model established in the conventional TDC cohort; *Reop* intend reoperation after TDC-FIT at 6 months; TDC, twist-drill craniostomy; TDC-FIT, twist-drill craniostomy with pressure-controlled fibrinolytic irrigation therapy

Table 4
Comparative analysis between the TDC and TDC-FIT cohorts.

	TDC (n = 314)	TDC-FIT (n = 16)	OR (95 % CI)	*P* value
Age, Median (range), y	80 (24–96)	75.5 (45–87)		.09
	No. (%)	No. (%)		
Female	98 (31.2)	4 (25)	1.4 (0.4–3.9)	.78
Antithrombotic therapy	160 (51)	7 (43.8)	0.8 (0.3–1.9)	.62
Dual antithrombotic therapy	6 (1.9)	1 (6.3)	4.3 (0.3–30)	.26
Hematoma membrane	109 (34.7)	12 (75)	5.5 (1.7–16)	.002
Reoperations	107 (34.1)	1 (6.3)	0.2 (0.0–1.0)	.026
Complications	17 (5.4)	1 (6.3)	1.6 (0.3–9.4)	.60
MMA embolization and/or CSF fistula treatment	25 (8.0)	2 (12.5)	1.7 (0.6–1.7)	.63
mRS 0–3	267 (85)	14 (87.5)	0.8 (0.2–3.2)	> .99
Deaths	11 (3.5)	0		

Abbreviations: CI, confidence interval; CSF, cerebrospinal fluid; MMA, meningeal medial artery; OR, odds ratio; TDC, twist-drill craniostomy; TDC-FIT, twist-drill craniostomy with pressure-controlled fibrinolytic irrigation therapy

reoperation rates and hematoma recurrence, while maintaining similar risks to those of a standard bedside TDC with passive drainage.

4.1. Limitations

We acknowledge that our statistical analysis compares two unbalanced data sets, based on our initial experience with a TDC-FIT cohort of 16 patients. Although our study shows significant reduction of reoperation rates in patients with cSDH after TDC-FIT compared to a historical control of conventional TDC with subdural passive drainage, a retrospective analysis of only sixteen patients limits the generalizability. Therefore, the results should be interpreted as exploratory and not causal. Thus, future research should aim to compare the long-term outcomes and complications of TDC-FIT in a larger patient cohort. Nonetheless, our initial findings are promising.

Another limitation is the availability of specialized equipment and associated logistical challenges, which may increase costs and potentially lengthen hospital stays. Further studies should assess the cost-effectiveness of TDC-FIT, particularly whether reduced reoperations could offset these costs.

Additionally, no further analysis was conducted on our patients treated with MMA embolization and CSF fistula, which might have influenced the recurrence rate [8,16,18,41]. However, the comparison between groups showed no cohort difference in the use of adjunctive therapy.

5. Conclusion

Preliminary data on TDC-FIT suggests comparable safety profile to conventional TDC and was associated with lower recurrence rates in patients at high-risk for cSDH recurrence. While these findings are promising, larger prospective studies need to confirm this observation.

Disclosures

The authors have no personal, financial, or institutional relationship in any of the material or devices that could be construed as potential conflicts of interest

Author contribution

Roland Roelz conceptualized and designed the study. Data collection, data curation and project administration were conducted by Marco Bissolo and Roberto Doria-Medina. Roberto Doria-Medina, Marco Bissolo and Roland Roelz performed the data analysis and interpretation. The manuscript was equally drafted by Roberto Doria-Medina and Marco Bissolo, with critical input and revisions provided by Ralf Watzlawick, Mukesch Johannes Shah, Eva Rohr, Klaus-Jürgen Buttler, and Jürgen Beck. All authors reviewed and approved the final manuscript.

Funding

The article processing charge was funded by the Medical Center – University of Freiburg from the internal funding program of the Department of Neurosurgery. We acknowledge support by the Open Access Publication Fund of the University of Freiburg.

CRediT authorship contribution statement

Roelz Roland: Writing – review & editing, Visualization, Validation, Supervision, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Beck Jürgen:** Writing – review & editing. **Buttler Klaus-Jürgen:** Writing – review & editing. **Rohr Eva:** Writing – review & editing. **Shah Mukesch Johannes:** Writing – review & editing. **Watzlawick Ralf:** Writing – review & editing. **Bissolo Marco:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation. **Doria-Medina Roberto:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation.

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