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Endovascular treatment of cerebral venous sinus thrombosis: A systematic review and meta-analysis of efficacy based on technique

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Abstract

Background: Cerebral venous sinus thrombosis (CVST) is rare but potentially life-threatening. Although systemic anticoagulation is the primary treatment, endovascular thrombectomy (EVT) or thrombolysis may be considered for refractory cases. Considering advanced techniques and device technology, we undertook an updated systematic review and meta-analysis to evaluate clinical and radiographic outcomes for treating CVST.

Methods: We searched PubMed and EMBASE for studies describing CVST patients treated with EVT. Presenting symptoms, procedural details, and clinical and radiographic outcomes were analyzed. Random-effects models were generated to calculate pooled proportions of clinical and radiographic outcome variables.

Results: We analyzed 26 studies comprising 273 patients (mean age 37 years, 57.7% female). Preprocedural intracranial hemorrhage was present in 167/243 (67.1%) patients. Endovascular thrombectomy techniques included aspiration thrombectomy alone (29.3%), aspiration plus stent retriever (19%), stent retriever alone (12.5%), balloon/catheter maceration (6.6%), and AngioJet rheolytic system (32.6%). Random-effects model indicated that 37% of patients had complete recanalization and 57% had partial recanalization. The model indicated that 79% of patients had a good clinical outcome (modified Rankin Scale score 0–2) at last follow-up. There were no statistically significant differences between modern systems (stent retriever and/or aspiration) and older systems (rheolytic thrombectomy and catheter maceration). Aspiration alone yielded a significantly higher frequency of good clinical outcomes compared with the combined technique (83.8% vs. 61.5%, $p = 0.004$).

Conclusion: Endovascular thrombectomy for CVST refractory to systemic anticoagulation achieved high recanalization rates, favorable outcomes, and low procedural complication rates. Modern and older techniques exhibited similar safety and efficacy. These findings support EVT as an effective treatment option.

Keywords

Cerebral venous system thrombosis, aspiration thrombectomy, stent retriever thrombectomy, rheolytic thrombectomy, outcome

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Introduction

Cerebral venous sinus thrombosis (CVST) is a rare but often devastating condition.[1] A thrombus in the cerebral sinus or vein can lead to retrograde venous drainage and elevated venous pressure, which gives rise to venous stasis causing venous infarcts and ischemic and hemorrhagic stroke.[2] The incidence of CVST is estimated to be 1–2 cases per 100,000 individuals, accounting for less than 1% of all strokes.[1,3] Cerebral venous sinus thrombosis predominantly affects adults aged 20–50 years, with fewer than 10% of cases occurring in individuals over the age of 65.[1,3] It is also associated with risk factors such as oral contraceptive use, pregnancy, puerperium, malignancy, infections, dehydration, and recent history of trauma.[4]

The clinical presentation of CVST can vary based on the location and progression of the thrombus, but signs and symptoms of increased intracranial pressure are frequently observed.[5] Patients often present with new-onset

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headaches, seizures, papilledema, focal neurological deficits, impaired consciousness, or even coma.[3,5] Approximately half of patients with CVST have intracranial hemorrhage (ICH) at presentation.[6] Despite medical intervention, up to 20% of patients experience death or significant disability.[6,7]

The primary goal of treatment is to achieve recanalization of the thrombosed vessel, which has been associated with better clinical outcomes.[8] The first line of treatment for CVST is systemic anticoagulation (AC).[9] For cases refractory to AC, endovascular therapy, including local thrombolysis and/or endovascular mechanical thrombectomy (EVT), may be considered.[10–12] The 2017 Thrombolysis or Anticoagulation for Cerebral Venous Thrombosis (TO-ACT) randomized controlled trial showed no significant difference in functional outcomes between patients treated with systemic AC alone and those treated with endovascular therapy in addition to systemic AC.[13] However, this study grouped two fundamentally different endovascular techniques—local thrombolysis using a microcathether to deliver a thrombolytic agent directly to the site of the clot and mechanical thrombectomy, which involves the use of catheters, stents, or balloons to extract or aspirate the thrombus—making it difficult to distinguish their individual effects. Moreover, there is considerable variability in the EVT techniques employed for CVST treatment. These include older methods such as rheolytic device (RD) thrombectomy and direct catheter maceration or fragmentation (CMF), as well as more modern approaches such as aspiration thrombectomy, stent retriever thrombectomy, or a combination of both.

Given the lack of clear consensus on the most effective technique and the significant variability in the devices and approaches used, a systematic review and meta-analysis were performed to compare the efficacy of various EVT techniques used to treat CVST refractory to AC or patients at risk of severe disease.

Methods

The present study followed the Cochrane Handbook for Systematic Reviews of Interventions[14] to develop our study protocol and search strategy. Data are reported in accordance with the Preferred Reporting for Systematic Reviews and Meta-Analyses guidelines.[15] The study protocol was not published or registered in any databases.

Search strategy

Potentially eligible studies were identified in December 2023 through a search of PubMed and EMBASE databases for literature published from January 2005 to November 2023. The PubMed database was searched using the MeSH primary term “sinus thrombosis, intracranial,” with secondary terms including “cerebral OR venous OR thrombectomy OR mechanical.” The EMBASE database was searched using the terms “cerebral venous sinus thrombosis” AND “thrombectomy.” Additionally, meta-analysis and review articles were also cross-referenced to ensure all potentially eligible studies were screened.

Study selection

Titles and abstracts of studies identified through our search criteria were first screened to assess their eligibility, followed by a full-text review using the predetermined inclusion and exclusion criteria. We included prospective and retrospective cohort studies, as well as case series that reported on patients with CVST who were treated with EVT. Only studies that report clinical and radiographic outcomes, and clearly specify the technique used for each patient were included. Case series with fewer than three patients were excluded to improve the generalizability of the findings and limit potential selection bias. Additionally, we excluded systematic reviews, meta-analyses, and conference abstracts. We also excluded studies of patients treated with endovascular intra-sinus thrombolysis without thrombectomy, studies of procedures performed using Burr hole access, and articles not published in English. Study eligibility for inclusion was assessed independently by two authors. Disagreements between reviewers were resolved by consensus among the two independent reviewers or the third independent reviewer.

Data extraction

Patient-level data were extracted from study tables or supplementary figures. We collected data points on age, sex, potential risk factors for thrombus formation, ICH at presentation, and clinical deterioration to coma before thrombectomy. Data on the sinus involved and the use of systematic AC were also gathered. Procedural variables, including the EVT device and technique (i.e., RD thrombectomy, direct CMF, aspiration thrombectomy, stent-retriever thrombectomy, or aspiration combined with stentretriever thrombectomy), as well as associated venoplasty and the concurrent administration of intrasinus thrombolysis were recorded.

Outcome variables included the degree of sinus or vein recanalization (complete, partial, or absent) post-procedure, the presence of post-procedural expansion or new ICH, clinical outcome (measured by modified Rankin Scale [mRS] score) at the last follow-up, and mortality. Complete recanalization was defined as uninterrupted blood flow with only small residual thrombi present. Partial recanalization was characterized as extensive thrombi with minor interruptions of continuous blood flow. Absent recanalization was defined as no recanalization and complete disruption of blood flow. A good clinical outcome was defined as an mRS score of 0–2. When available, mRS scores were extracted directly from the studies. For the six patients without reported mRS scores, the clinical outcome was inferred from the clinical descriptions as good (“having no neurological deficits” at the last known clinical encounter) or bad (“expired”).

The primary outcomes of our study were degree of recanalization of the thrombosed sinus following EVT and clinical outcome at last known follow-up. We compared these outcome variables between older and modern thrombectomy techniques: we classified RD thrombectomy and direct catheter CMF as older techniques and aspiration and stent retriever thrombectomy as modern. Secondarily, we compared the recanalization rates and clinical outcomes within each subgroup (older and modern). Specifically, we compared outcomes between RD thrombectomy and direct CMF, as well as between aspiration alone and combined aspiration with stent retriever thrombectomy.

Risk of bias analysis

The Risk of Bias In Non-Randomized Studies – of Interventions (ROBINS-I) tool was employed to assess the potential risk of bias across the following eight domains: confounding, selection of participants into study, classification of intervention, missing data, measurements of outcomes, and selection of reported result. Each domain was assessed and rated as "low risk" or "high risk" based on information available in the studies.

Statistical analysis

Descriptive statistics were reported as the mean ± standard deviation for continuous variables and as frequency (n) with percentage (%) for categorical variables. For the meta-analysis, study outcomes were pooled as proportions of the events of interest relative to the total cases enrolled, with both fixed-effects and random-effects models generated. Heterogeneity was assessed using the I^2 statistic using the following thresholds: 0–40% for low heterogeneity, 41–60% for moderate heterogeneity, and >60% for substantial heterogeneity. Publication bias was evaluated using funnel plots to assess asymmetry, supplemented by Egger's test. Group comparisons for categorical variables were performed using the Chi-square (χ^2) test or Fisher's exact test, as appropriate based on the expected frequencies in the contingency table. A p-value of <0.05 was considered statistically significant for all analyses. Statistical analyses were conducted using R (version 4.4.2) and IBM SPSS Statistics (version 25).

Results

Literature search

A total of 347 studies were identified through our initial query on PubMed (214) and EMBASE (133). After removing 86 duplicate studies, 261 abstracts and titles were screened. Of these, 174 were excluded for being unrelated to CVST or for being narrative or systematic reviews, meta-analyses, or case reports/series with fewer than three patients. A full-text review was conducted for the remaining 87 studies, 61 of which were excluded for unspecified thrombectomy technique, lack of recanalization and outcome data, Burr hole access thrombectomy, or being conference abstracts only. Ultimately, 26 studies were included in the final analysis. The inclusion process is summarized in Figure 1. The ROBINS-I evaluation of potential risk of publication bias for the included studies is presented in Supplementary Table 1.

Included studies characteristics

This meta-analysis reviewed 26 retrospective case series and reviews published between 2007 and 2023, including a total of 273 patients.[11,12,16–39] Among these, six studies used RD thrombectomy, accounting for 89 patients, three studies employed CMF techniques ($n = 18$), 17 studies exclusively used aspiration catheters ($n = 80$), 11 studies combined aspiration catheters with stent retrievers ($n = 52$), and four studies reported using stent retrievers alone ($n = 34$). Table 1 presents the demographics and patient characteristics for each study, and Table 2 provides a summary of intraoperative variables, outcome measures, and complication rates for each study.

Overall patient characteristics

The mean age of the cases was 37.0 ± 16.6 years, with female patients comprising 57.7% of the sample (Table 3). Preprocedural ICH was reported in 167/243 (67.1%) patients, and preprocedural coma was described in 52/246 (21.1%). AC before the procedure was administered in 99.3% of cases (271/273). The reported indications for EVT in the included studies were clinical deterioration despite AC (213, 78%), severe neurological deficit or comatose at presentation (33, 12.1%), and radiographically worsening ICH (27, 9.9%). Risk factors were reported for all but 16 patients. Among risk factors for CVST, 12.1% of patients reported oral contraceptive use ($n = 31$), 3.9% reported dehydration ($n = 10$), and 10.9% experienced the event during the peripartum period ($n = 28$). Additionally, 9.7% had a genetic predisposition ($n = 25$), 8.2% reported autoimmune conditions predisposing them to thrombosis ($n = 21$), and 5.4% had a history of malignancy ($n = 14$). Table 3 summarizes the overall frequency of patient characteristic variables across all studies.

Intervention characteristics

The superior sagittal sinus was involved in 78.6% of cases ($n = 213$), the sigmoid sinus in 44.7% ($n = 122$), the transverse sinus in 74.7% ($n = 204$), and the straight sinus in 20.5% ($n = 56$) (Table 3). The most commonly used devices in the included studies were the AngioJet rheolytic thrombectomy system (Boston Scientific, Marlborough, Massachusetts, USA), the Penumbra aspiration system (Penumbra Inc., Alameda, California, USA), the Sofia Plus aspiration catheter (MicroVention, Inc., Aliso Viejo, California, USA), the Trevo stent retriever (Stryker, Kalamazoo, Michigan, USA), and the Solitaire stent retriever (Covidien, Irvine, California, USA).

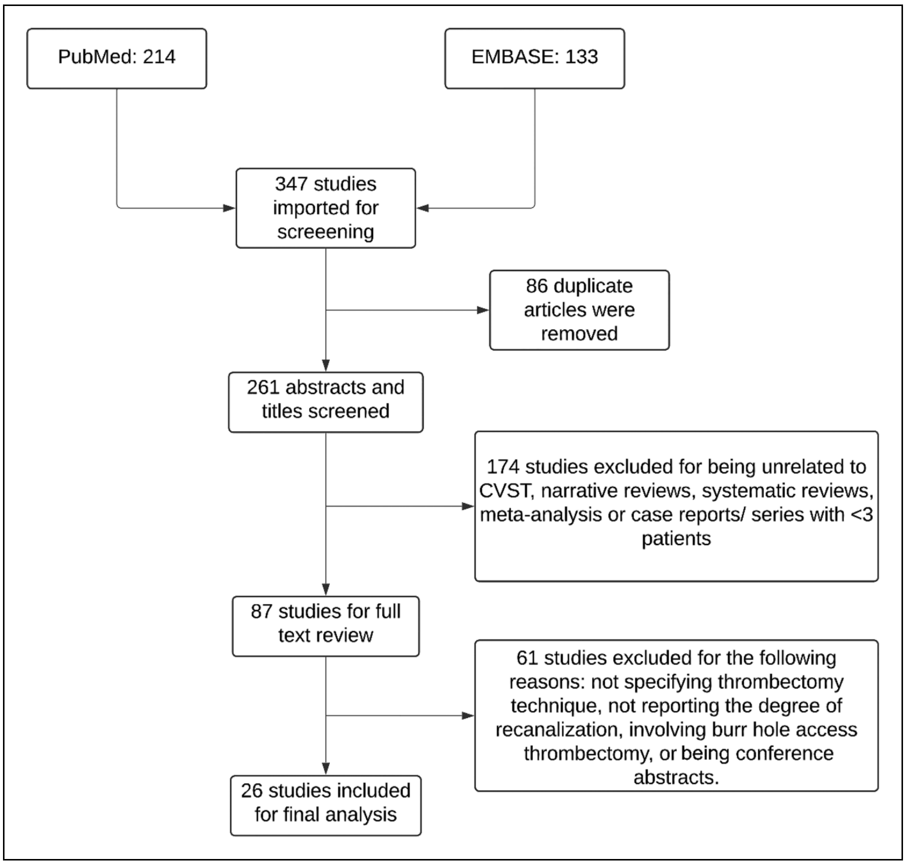

Figure 1. PRISMA inclusion and exclusion flow diagram. CVST: cerebral venous sinus thrombosis.

Additionally, intrasinus thrombolysis was performed concomitantly in 52.7% of cases ($n = 144$), and 10.3% underwent additional venoplasty.

Primary clinical outcomes

Among all patients included in the studies, 208 achieved good clinical outcomes. Using a random-effects model, the pooled proportion of good clinical outcomes was estimated at 79% (95% confidence interval [CI]: 69%–86%, Figure 2(a)). Heterogeneity was low, with an I^2 value of 11.5% ($p = 0.296$). However, Egger's test indicated significant publication bias ($p < 0.0001$), and the funnel plot analysis was asymmetric, further confirming the presence of this bias (Figure 3).

The pooled mortality rate at the last follow-up was estimated at 12% using the random-effects model (95% CI: 9%–17%, Figure 2(b)), corresponding to 34 deaths among all cases. Heterogeneity across studies was minimal ($I^2 = 0.0\%$, $p = 0.999$). Despite this, the funnel plot was asymmetric, and Egger's test revealed statistically significant publication bias ($p < 0.0001$).

Complete recanalization was achieved in 131 cases, accounting for 37% of the pooled proportions based on the random-effects model (95% CI: 21%–55%, Figure 4(a)). Heterogeneity analysis revealed a moderate level of heterogeneity across studies ($I^2 = 48.3\%$, $p = 0.003$), while Egger's test indicated no significant risk of publication bias ($p = 0.137$). Partial recanalization was observed in 127 cases, with a pooled proportion of 57% according to the random-effects model (95% CI: 39%–74%) (Figure 4(b)). Heterogeneity was moderate ($I^2 = 46.7\%$, $p = 0.005$), and Egger's test showed no significant publication bias for this model ($p = 0.413$).

Repeated thrombectomy was reported in 1.5% of cases ($n = 4$), and 8.4% of cases ($n = 23$) experienced expanding or new ICH post-procedure (Table 3). Additionally, two cases involved cortical vein rupture, and one case was reported to have sinus perforation.

Comparing clinical outcomes

A comparative analysis was performed between subjects who underwent treatment with modern techniques and those treated with older techniques, including all 273 patients. The results revealed no statistically significant differences between the two groups in terms of good clinical outcomes (mRS 0–2, $p = 0.111$), rates of complete and partial recanalization ($p = 0.230$), mortality rates ($p = 0.168$), or complication rates (Table 4). In a subanalysis comparing clinical outcomes among only patients for whom 90-day follow-up was available, patients treated with antiquated technique had higher rates of good clinical outcome (86.8% vs. 65.3%) (Supplementary Table 2).

Table 1. Baseline characteristics of subjects in included studies.

Study (year)	Type of study	Patients	Female	Age (y) (mean ± SD)	Location of thrombus	PrP ICH	PrP coma	Systemic AC	Risk factors
Kirsch et al. (2007)[24]	RR	4	3 (75.0)	40.7 ± 18.0	3 SSS 3 TS 3 SigS 1 StS	3 (75.0)	1 (25.0)	4 (100.0)	2 OCP 1 AI 1 Other
Stam et al. (2008)[11]	RR	15	12 (80.0)	30.3 ± 12.1	12 SSS 13 TS 7 StS	15 (100.0)	2 (13.3)	15 (100.0)	5 OCP 1 PP 2 AI 2 M 5 Other
Modi et al. (2009)[31]	CS	4	4 (100.0)	51.0 ± 25.4	4 SSS 3 TS	4 (100.0)	1 (25.0)	4 (100.0)	1 D 2 AI 1 Other
Choulakian & Alexander (2010)[18]	CS	4	N/A	N/A	4 SSS 2 TS 1 SigS	2 (50.0)	0 (0.0)	3 (75.0)	1 OCP 3 Other
Dashti et al. (2013)[21]	RR	13	7 (53.8)	46.4 ± 12.0	9 SSS 4 TS 3 SigS	N/A	3 (23.1)	13 (100.0)	1 D 1 PP 3 AI 8 Other
Jankowitz et al. (2013)[22]	RR	6	5 (83.3)	43.8 ± 25.3	3 SSS 3 TS 1 SigS 2 StS	4 (66.7)	1 (16.7)	6 (100.0)	1 D 1 M 4 Other
Mortimer et al. (2013)[33]	CS	9	N/A	7.3 ± 6.6	6 SSS 8 TS 3 SigS	9 (100.0)	1 (11.3)	9 (100.0)	1 AI 8 Other
Li et al. (2013)[26]	RR	52	22 (42.3)	33.7 ± 13.6	47 SSS 49 TS 28 SigS 8 StS	35 (67.3)	3 (5.8)	52 (100.0)	2 OCP 10 PP 10 G 3 M 27 Other
Mokin et al. (2015)[32]	RR	11	6 (54.5)	39.2 ± 16.5	7 SSS 8 TS 6 SigS	N/A	N/A	11 (100.0)	1 OCP 2 D 2 PP 1 G 1 M 4 Other
Lee et al. (2016)[25]	CS	10	6 (60.0)	53.0 ± 15.0	6 SSS 9 TS 5 SigS 3 StS	8 (80.0)	4 (40.0)	10 (100.0)	2 OCP 1 D 2 G 3 AI 2 Other
Chen et al. (2017)[16]	RR	14	9 (64.3)	32.8 ± 12.3	12 SSS 8 TS 6 SigS 2 StS	10 (71.4)	11 (78.6)	14 (100.0)	1 OCP 7 PP 6 Other
Mammen et al. (2017)[28]	RR	8	8 (100.0)	27.7 ± 8.4	5 SSS 6 TS 3 SigS 6 StS	0 (0.0)	0 (0.0)	8 (100.0)	8 Other
Tsang et al. (2018)[38]	CS	6	3 (50.0)	50.7 ± 15.9	5 SSS 4 TS 3 SigS 2 StS	N/A	0 (0.0)	6 (100.0)	1 OCP 2 AI 1 M 2 Other
Zhang et al. (2018)[39]	RR	9	4 (44.4)	39.2 ± 12.7	7 SSS 5 TS 3 StS	9 (100.0)	2 (22.2)	9 (100.0)	1 D 3 PP 1 AI 4 Other
Omoto et al. (2019)[34]	CS	3	1 (33.3)	21.3 ± 4.0	3 SSS 2 TS 2 SigS	2 (66.7)	2 (66.7)	2 (66.7)	1 M 2 Other
Styczen et al. (2019)[37]	CS	13	10 (76.9)	36.4 ± 13.4	9 SSS 10 TS 7 SigS 5 StS	7 (53.8)	6 (46.2)	13 (100.0)	5 OCP 3 G 2 M 3 Other
Lu et al. (2019)[27]	RR	5	2 (40.0)	38.4 ± 5.0	5 SSS	1 (20.0)	1 (20.0)	5 (100.0)	1 G 4 Other

(continued)

Table 1. Continued.

Study (year)	Type of study	Patients	Female	Age (y) (mean ± SD)	Location of thrombus	PrP ICH	PrP coma	Systemic AC	Risk factors
Andersen et al. (2021)[12]	RR	11	8 (72.7)	32.5 ± 15.5	5 SSS 10 TS 8 SigS 4 StS	6 (54.5)	4 (36.4)	11 (100.0)	4 OCP +2 D 2 G 1 M 2 Other
Dandapat et al. (2020)[20]	RR	16	9 (56.3)	47.2 ± 22.5	13 SSS 12 TS 6 SigS 3 StS	8 (50.0)	N/A	16 (100.0)	N/A
Medhi et al. (2020)[29]	RR	7	2 (28.6)	39.6 ± 13.5	6 SSS 4 TS 3 SigS	5 (71.4)	0 (0.0)	7 (100.0)	7 Other
Peng et al. (2021)[36]	RR	7	3 (42.9)	45.7 ± 18.2	7 SSS 5 TS 4 SigS	4 (57.1)	3 (42.9)	7 (100.0)	1 OCP 1 D 1 PP 1 G 1 AI 2 Other
Chew et al. (2022)[17]	CS	6	3 (50.0)	40.0 ± 8.4	4 SSS 3 TS 3 SigS	5 (83.3)	0 (0.0)	6 (100.0)	1 OCP 5 Other
Cleaver et al. (2022)[19]	CS	3	3 (100.0)	45.0 ± 17.3	2 SSS 1 TS 1 SigS 1 StS	3 (100.0)	0 (0.0)	3 (100.0)	3 Other
Mera Romo et al. (2022)[30]	RR	9	5 (55.6)	37.0 ± 10.5	9 SSS 7 TS 5 SigS	5 (55.6)	0 (0.0)	9 (100.0)	3 OCP 1 G 2 AI 3 Other
Jedi et al. (2022)[23]	RR	20	12 (60.0)	36.3 ± 18.3	14 SSS 20 TS 19 SigS 7 StS	14 (70.0)	3 (15.0)	20 (100.0)	2 OCP 3 PP 2 G 1 AI 2 M 10 Other
Palanisamy et al. (2023)[35]	RR	8	3 (37.5)	33.9 ± 12.8	6 SSS 5 TS 2 SigS 2 StS	4 (50.0)	4 (50.0)	8 (100.0)	2 G 2 AI 4 Other
Total		273	150 (57.7)	37.0 ± 16.6	213 SSS 204 TS 122 SigS 56 StS	163 (67.1)	52 (21.1)	271 (99.3)	31 OCP 10 D 28 PP 25 G 21 AI 14 M 128 Other

Values reported as *n* (%) unless otherwise indicated.
PrP: preprocedural; ICH: intracranial hemorrhage; AC: anticoagulation; SSS: superior sagittal sinus; TS: transverse sinus; SigS: sinus sigmoid; StS: straight sinus; OCP: oral contraceptive; AI: autoimmune; PP: peripartum; M: malignancy; D: dehydration; N/A: not applicable; G: genetic.

Subjects treated with the aspiration-alone technique and those treated with the combined aspiration plus stent retriever technique, including 132 cases, were compared further. The results demonstrated that good clinical outcomes (mRS 0–2) were significantly higher in the aspiration-alone group compared with the combined technique group (83.8% vs. 61.5%, $p = 0.004$). No significant differences were observed between the groups in mortality ($p = 0.261$), recanalization ($n = 0.522$), or complication rates (Table 5).

A final comparison was conducted between subjects treated with RD thrombectomy and those treated with the CMF technique, a total of 107 cases. The results indicated that the RD group had a significantly higher rate of complete recanalization compared with the CMF group

Table 2. Intraoperative variables, outcome variables, and complication rates in included studies.

Study (year)	Patients (*n*)	Device used	Venoplasty	Intrasinus thrombolysis	Good clinical outcome*	Mortality at discharge	Recanalization: Complete	Recanalization: Partial	Complications
Kirsch et al. (2007)[24]	4	RD	0 (0.0)	0 (0.0)	4 (100.0)	1 (25.0)	0 (0.0)	4 (100.0)	N/A
Stam et al. (2008)[11]	15	RD	0 (0.0)	15 (100.0)	15 (100.0)	4 (26.7)	5 (33.3)	9 (60.0)	3 ENIH
Modi et al. (2009)[31]	4	RD	N/A	0 (0.0)	3 (75.0)	1 (25.0)	1 (25.0)	3 (75.0)	1 ENIH
Choulakian & Alexander (2010)[18]	4	Asp only	3 (75.0)	0 (0.0)	3 (75.0)	1 (25.0)	3 (75.0)	1 (25.0)	N/A
Dashti et al. (2013)[21]	13	RD	0 (0.0)	0 (0.0)	7 (53.8)	2 (15.4)	5 (38.5)	7 (53.8)	N/A
Jankowitz et al. (2013)[22]	6	Asp only	0 (0.0)	4 (66.7)	4 (66.7)	1 (16.7)	6 (100.0)	0 (0.0)	1 ENIH
Mortimer et al. (2013)[33]	9	3 Asp only 6 CMF	2 (22.2)	9 (100.0)	8 (88.9)	1 (11.1)	2 (22.2)	7 (77.8)	N/A
Li et al. (2013)[26]	52	RD	N/A	52 (100.0)	44 (84.6)	6 (11.5)	45 (86.5)	3 (5.8)	4 ENIH
Mokin et al. (2015)[32]	11	7 Asp only 3 Asp-StR 1 RD	N/A	5 (45.5)	5 (45.5)	3 (27.3)	3 (27.3)	8 (72.7)	N/A
Lee et al. (2016)[25]	10	CMF	0 (0.0)	3 (30.0)	8 (80.0)	1 (10.0)	0 (0.0)	10 (100.0)	N/A
Chen et al. (2017)[16]	14	StR	0 (0.0)	14 (100.0)	11 (78.6)	0 (0.0)	10 (71.4)	4 (28.6)	2 ENIH
Mammen et al. (2017)[28]	8	Asp only	8 (100.0)	3 (37.5)	7 (87.5)	1 (12.5)	0 (0.0)	5 (62.5)	N/A
Tsang et al. (2018)[38]	6	Asp only	N/A	6 (100.0)	5 (83.3)	0 (0.0)	0 (0.0)	6 (100.0)	N/A
Zhang et al. (2018)[39]	9	2 Asp only 7 Asp-StR	0 (0.0)	9 (100.0)	6 (66.7)	0 (0.0)	6 (66.7)	3 (33.3)	N/A
Omoto et al. (2019)[34]	3	Asp only	3 (100.0)	3 (100.0)	3 (100.0)	0 (0.0)	1 (33.3)	2 (66.7)	N/A
Styczen et al. (2019)[37]	13	4 Asp only 9 Asp-StR	N/A	0 (0.0)	12 (92.3)	1 (7.7)	4 (30.8)	7 (53.8)	3 ENIH 1 RMT 1 SP
Lu et al. (2019)[27]	5	3 Asp only 2 ASP-StR	5 (100.0)	0 (0.0)	4 (80.0)	0 (0.0)	0 (0.0)	5 (100.0)	2 RMT
Andersen et al. (2021)[12]	11	2 CMF 3 Asp only 1 Asp-StR 5 StR	2 (18.2)	9 (81.8)	5 (45.5)	2 (18.2)	6 (54.5)	4 (36.4)	2 ENIH
Dandapat et al. (2020)[20]	16	2 Asp only 14 Asp-StR	0 (0.0)	3 (18.8)	7 (43.8)	1 (6.3)	2 (12.5)	14 (87.5)	N/A
Medhi et al. (2020)[29]	7	Asp only	0 (0.0)	4 (57.1)	6 (85.7)	0 (0.0)	0 (0.0)	7 (100.0)	N/A
Peng et al. (2021)[36]	7	4 Asp-StR 3 StR	4 (57.1)	5 (71.4)	7 (100.0)	0 (0.0)	4 (57.1)	3 (42.9)	N/A
Chew et al. (2022)[17]	6	Asp-StR	0 (0.0)	0 (0.0)	3 (50.0)	2 (33.3)	5 (83.3)	1 (16.7)	N/A
Cleaver et al. (2022)[19]	3	2 Asp only 1 Asp-StR	0 (0.0)	0 (0.0)	3 (100.0)	0 (0.0)	1 (33.3)	2 (66.7)	N/A
Mera Romo et al. (2022)[30]	9	Asp only	0 (0.0)	0 (0.0)	8 (88.9)	1 (11.1)	8 (88.9)	1 (11.1)	4 ENIH
Jedi et al. (2022)[23]	20	5 Asp only 3 Asp-StR 12 StR	N/A	0 (0.0)	13 (65.0)	4 (20.0)	9 (45.0)	8 (40.0)	2 ENIH 1 RMT
Palanisamy et al. (2023)[35]	8	6 Asp only 2 Asp-StR	1 (12.5)	0 (0.0)	7 (87.5)	1 (12.5)	5 (62.5)	3 (37.5)	1 ENIH 2 CVR
Total	273	89 RD 18 CMF 80 Asp only 52 Asp-StR 34 StR	28 (16.8)	144 (52.7)	208 (76.2)	34 (12.5)	131 (48.0)	127 (46.5)	23 ENIH 4 RMT 1 SP 2 CVR

Values reported as *n* (%) unless otherwise indicated.
*Good clinical outcome is defined as a modified Rankin score of 0–2.
RD: rheolytic device; N/A: not applicable; ENIH: expansion or new development of intracranial hematoma; Asp: aspiration catheter; StR: stent retriever; CMF: catheter maceration/fragmentation; CVR: cortical vein rupture; RMT: repeated mechanical thrombectomy; SP: sinus perforation.

(62.9% vs. 11.1%), whereas the CMF group had a significantly higher rate of partial recanalization compared with the RD group ($p < 0.001$). No significant differences were observed between the groups in good clinical outcomes ($p = 0.741$), mortality rates ($p = 0.921$), or complication rates (Table 6).

Discussion

Given the significant variability in the devices and approaches used to treat CVST refractory to AC, we completed a systematic review and meta-analysis of the efficacy of various EVT techniques used. In our review of

26 studies, five different thrombectomy techniques were used in the treatment of 273 patients: rheolytic thrombectomy, CMF, aspiration catheter alone, aspiration combined with stent retriever, and stent retriever alone. Our pooled analysis using a random-effects model revealed that 37% of cases achieved complete recanalization, whereas 57% achieved partial recanalization. Although the rate of complete recanalization is lower than has been reported in other systematic reviews, the overall rate of recanalization remains high when combining complete and partial recanalization.[10,40–42] Previous studies have suggested that there is no significant difference in long-term clinical outcomes between complete and partial recanalization,[26,43] and there is evidence that the degree of recanalization continues to improve over the months after initial EVT treatment while on AC.[40,44]

Our random-effects model estimated that 79% of patients achieved a favorable clinical outcome (mRS 0–2), with an overall mortality rate of 12%. These findings align with previous studies investigating EVT or systemic AC for the treatment of CVST.[45] For example, Ilyas et al.[10] reported that 75% of patients in their cohort treated with EVT achieved good clinical outcomes. Interestingly, patients who received local thrombolytic therapy alone also had a similar rate of good clinical outcomes (79%).[10] The International Study on Cerebral Vein and Dural Sinus Thrombosis (ISCVT) reported that 86% of patients had good clinical outcome (mRS 0–2).[6] This is higher than we observed, likely because the ISCVT included all patients regardless of disease severity and the treatment they received.[6] In our review, we have included only patients treated with EVT, who are more likely to have severe presentation.

Several risk factors for poor outcomes have been identified, such as age over 37 years, impaired mental status, ICH on admission, and thrombosis of multiple sinuses.[6,46] Among the patients included in our review, 67% had preprocedural ICH, and 21% were in coma before treatment. This suggests that the patients included in our review had more severe clinical presentations, which are often associated with worse prognoses. Considering that EVT is typically reserved for more severe cases, achieving similar or even better recanalization rates and favorable clinical outcomes raises the question of whether earlier use of EVT could further improve outcomes for patients with CVST.[47] The TO-ACT trial explicitly included only patients with severe CVST as defined by radiographically confirmed CVST presenting with coma, ICH, or thrombosis of the deep cerebral venous system.[13] This selection of only severe cases may also further limit the trial's ability to demonstrate the effectiveness of EVT. These findings suggest that reserving EVT only for patients with severe symptoms or those who continue to worsen with AC may result in the treatment being offered too late.[21]

Some authors have suggested that EVT may be more feasible technically than arterial thrombectomy, given the larger size of the cerebral dural sinuses and the associated larger venous thrombi.[26,48] Rapid removal of the thrombus and restoration of blood flow can reduce venous congestion and improve cerebral perfusion. Furthermore, a reduction in thrombus burden with EVT may enhance the effectiveness of systemic AC therapy.[21,26]

Table 3. Demographics, preoperative characteristics, intraoperative variables, clinical outcomes, and complication rates across all studies.

Variables	Value
Number of patients	273
Age (years), mean ± SD	37.0 ± 16.6
Female sex	150/260 (57.7)
Preprocedural ICH	163/243 (67.1)
Preprocedural coma	52/246 (21.1)
Preprocedural systemic AC	271/273 (99.3)
Risk factors ($n = 257$)	
OCP use	31 (12.1)
Dehydration	10 (3.9)
Peripartum	28 (10.9)
Genetic	25 (9.7)
Autoimmune	21 (8.2)
Malignancy	14 (5.4)
Other	128 (49.8)
Indication for EVT	
Clinical status deterioration despite AC	213 (78.0)
Severe neurological deficit or comatose at presentation	33 (12.1)
Radiographically worsening ICH	27 (9.9)
Intraoperative variables	
Sinus involved	
Superior sagittal sinus	213 (78.6)
Sigmoid sinus	122 (44.7)
Transverse sinus	204 (74.7)
Straight sinus	56 (20.5)
Device used	
Rheoltyic device	89 (32.6)
Catheter maceration/fragmentation	18 (6.6)
Asp only	80 (29.3)
Asp + StR	52 (19.0)
StR only	34 (12.5)
Venoplasty	28 (10.3)
Intrasinus thrombolysis	144 (52.7)
Clinical outcome	
Good clinical outcome (mRS score 0–2)	208 (76.2)
Mortality	34 (12.5)
Recanalization rate	
Complete	131 (48.0)
Partial	127 (46.5)
Complications	
Repeat EVT	4 (1.5)
Expanding or new ICH	23 (8.4)
Other complications	3 (1.1)

Values reported as *n* (%) unless otherwise indicated.
ICH: intracranial hemorrhage; AC: anticoagulation; OCP: oral contraceptive pill; EVT: endovascular mechanical thrombectomy; Asp: aspiration catheter; StR: stent retriever; mRS: modified Rankin scale.

There is considerable variability among the thrombectomy techniques that are included in our study. Thrombectomy for CVST was initially reported in 1999 with the use of AngioJet device, an RD that relies on

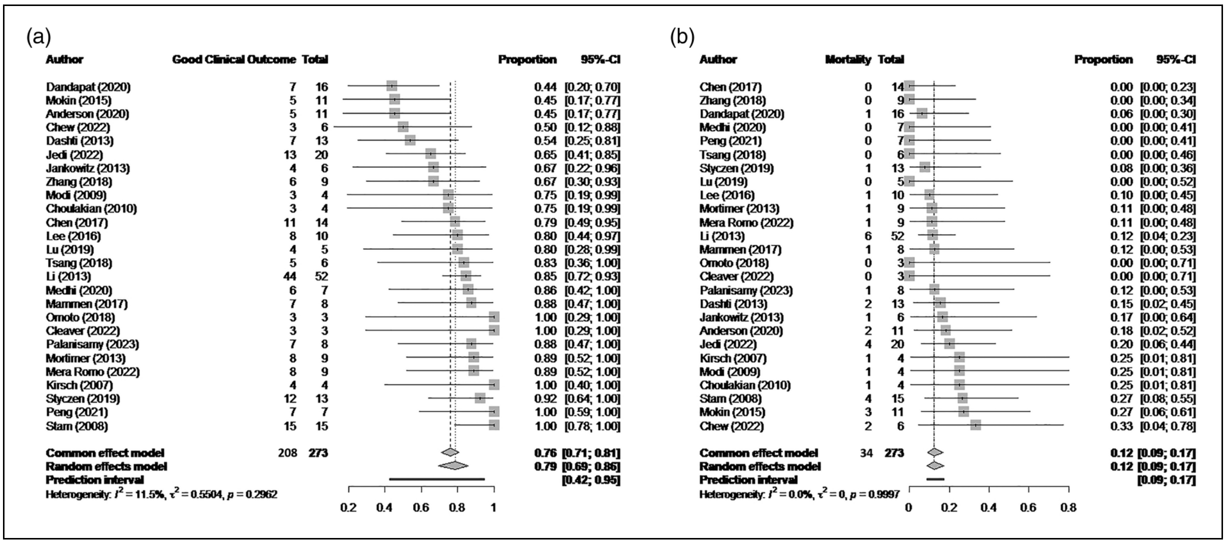

Figure 2. Forest plot analysis of good clinical outcome (a) and mortality (b) proportions across studies. CI: confidence interval.

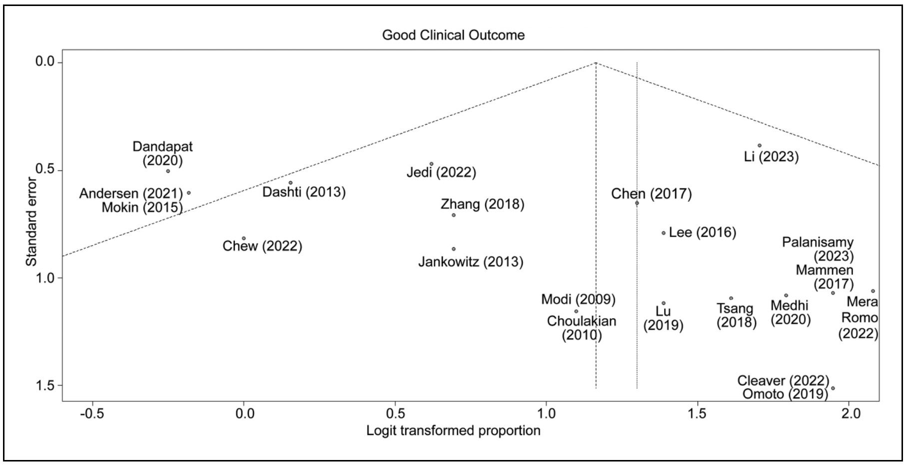

Figure 3. Funnel plot assessing publication bias on good clinical outcome.

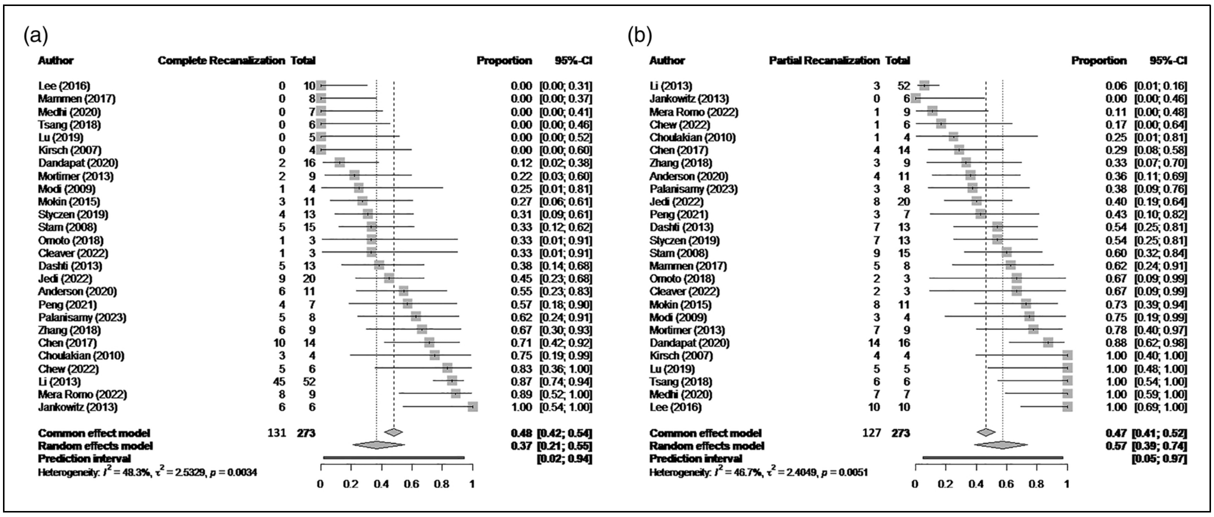

Figure 4. Forest plot analysis of complete recanalization (a) and partial recanalization (b) proportions across studies. CI: confidence interval.

Table 4. Comparison of clinical outcomes and complication rates between antiquated techniques and modern techniques.

Outcome variables	Total (*n* = 273)	Antiquated (*n* = 107)	Modern (*n* = 166)	*p* value
Good clinical outcome (mRS score 0–2), *n* (%)	208 (76.2)	87 (81.3)	121 (72.9)	0.111
Mortality, *n* (%)	34 (12.5)	17 (15.9)	17 (10.2)	0.168
Recanalization rat				
Complete, *n* (%)	131 (48.0)	58 (54.2)	73 (44.0)	0.230
Partial, *n* (%)	127 (46.5)	43 (40.2)	84 (50.6)	
Complications				
Repeat EVT, *n* (%)	4 (1.5)	0 (0.0)	4 (2.5)	0.158
Expanding or new ICH, *n* (%)	23 (8.6)	9 (8.4)	14 (8.7)	0.935
Other complications, *n* (%)	3 (1.1)	0 (0.0)	3 (1.8)	0.282

Chi-square test was used when all expected frequencies exceeded 5; Fisher's exact test was used when expected frequencies were 5 or fewer.
mRS: modified Rankin Scale; EVT: endovascular mechanical thrombectomy; ICH: intracranial hemorrhage.

Table 5. Comparison of clinical outcomes and complication rates between use of aspiration catheter alone and aspiration catheter with stent retriever.

Outcome variables	Total (*n* = 132)	Asp alone (*n* = 80)	Asp + StR (*n* = 52)	*p* value
Good clinical outcome (mRS score 0–2), *n* (%)	99 (75.0)	67 (83.8)	32 (61.5)	**0.004**
Mortality, *n* (%)	13 (9.8)	6 (7.5)	7 (13.5)	0.261
Recanalization rate				
Complete, *n* (%)	52 (39.4)	33 (41.3)	19 (36.5)	0.522
Partial, *n* (%)	75 (56.8)	43 (53.8)	32 (61.5)	
Complications				
Repeat EVT, *n* (%)	4 (3.2)	4 (5.4)	0 (0.0)	0.142
Expanding or new ICH, *n* (%)	9 (7.1)	6 (7.8)	3 (6.0)	0.701
Other complications, *n* (%)	3 (2.3)	2 (2.5)	1 (1.9)	0.828

Bold value indicates statistical significance ($p < 0.05$). Chi-square test was used when all expected frequencies exceeded 5; Fisher's exact test was used when expected frequencies were 5 or fewer.
Asp: aspiration; StR: stent retriever; mRS: modified Rankin Scale; EVT: endovascular mechanical thrombectomy; ICH: intracranial hemorrhage.

the Bernoulli effect created by streaming a high-pressure saline jet through the device.[42,49] Other techniques such as direct catheter maceration are also described more commonly in the early years.[50] In the past decade, modern techniques such as aspiration catheters and stent retrievers have emerged.[51–53] Considering the variability, we classified older techniques such as Angiojet and catheter maceration as older and compared their angiographic and clinical outcomes with those of modern systems. We observed no statistical difference between the two groups. However, in a subanalysis including only patients with an explicitly reported clinical outcome at 90 days, we observed higher rates of good clinical outcome with the antiquated technique. This could be due to the characteristic of the AngioJet, a bulky device that creates Bernoulli effect through high-pressure saline, which may be more effective against the large and often calcified thrombus of the cerebral venous system. It is important to note that only 133 patients were included in this subanalysis, which may significantly reduce generalizability of these findings.

Table 6. Comparison of clinical outcomes and complication rates between use of rheolytic device and catheter maceration/fragmentation technique.

Outcome variables	Total (*n* = 107)	RD (*n* = 89)	CMF (*n* = 18)	*p* value
Good clinical outcome (mRS score 0–2), *n* (%)	87 (81.3)	73 (82.0)	14 (77.8)	0.741
Mortality, *n* (%)	17 (15.9)	14 (15.7)	3 (16.7)	0.921
Recanalization rate				
Complete, *n* (%)	58 (54.2)	56 (62.9)	2 (11.1)	**<0.001**
Partial, *n* (%)	43 (40.2)	27 (30.3)	16 (88.9)	
Complications				
Expanding or new ICH, *n* (%)	9 (8.4)	8 (9.0)	1 (5.6)	0.632
Other complications, *n* (%)	0 (0%)	0 (0%)	0 (0%)	-

Bold value indicates statistical significance ($p < 0.05$). Chi-square test was used when all expected frequencies exceeded 5; Fisher's exact test was used when expected frequencies were 5 or fewer.
RD: rheolytic device; CMF: catheter maceration/fragmentation; mRS: modified Rankin Scale; ICH: intracerebral hemorrhage.

When only modern techniques were analyzed, aspiration alone was compared with aspiration combined with a stent retriever. Although the rates of complete or partial recanalization between these two groups were not different, better clinical outcomes were observed in patients treated with aspiration alone. This may be attributed to higher risk of venous injury when using a bulky stent retriever through a sinus. A higher number of stent retriever passes has been associated with greater risk of ICH and subsequent clinical outcomes.[54] The rate of expanding or new ICH was not different between these two groups. Outcomes for aspiration technique are often influenced by characteristics of the catheter itself.[55–57] Maximizing catheter-to-vessel size ratio has been shown to improve distal flow control and revascularization efficacy in large-vessel occlusion strokes.[56–58] Venous sinuses are larger in diameter and exceed the size of available aspiration catheters, possibly leading to suboptimal aspiration efficiency. Recent advancement in aspiration catheter technology has led to the development of large-bore aspiration catheters with internal diameter up to 0.088 inches. However, data on the effect of large bore aspiration catheter on outcomes in CVST are limited.

Utilizing larger-diameter aspiration catheters or adjunctive techniques that better accommodate the unique anatomy of venous sinuses could further enhance revascularization rates.

A similar analysis of the older techniques revealed a higher rate of complete recanalization with Angiojet, likely because of its ability to more effectively break down large, often calcified thrombi in larger venous sinuses.[21,59] The overall rate of complete recanalization observed with the RD alone (62%) is comparable to that published previously (55%).[42] However, a limitation of this device is its reduced flexibility, making it difficult to navigate through tortuous vessels.[21]

A significant concern with EVT in CVST is the risk of hemorrhagic transformation, which is associated with worse clinical outcomes.[60] In this review, despite a high proportion of patients with poor prognostic indicators, only 8.6% of patients in this cohort had expanding or new ICH. This suggests that EVT can be performed with relatively low complication rates, even in high-risk patients.

Thrombectomy is an invasive procedure and not without risk. Potential complications include vessel perforation, access site hematomas, iatrogenic arteriovenous fistula, and infections.[10,12] The rate of these complications was minimal in the studies included in our review (1.1%). However, given the significant publication bias noted, the reported rate of complications rate may be underestimated.

Limitations

There are several limitations to this study. As a systematic review and meta-analysis of retrospective studies and case series, it is susceptible to publication bias. Published studies may predominantly report positive outcomes with minimal complications because negative results are less frequently shared. In the absence of randomized controlled trials, conducting a meta-analysis based solely on retrospective studies and case series introduces potential heterogeneity and selection bias limiting the generalizability of our findings. To reduce this bias, we included only series with more than three patients; however, publication bias and heterogeneity persisted.

The data reported in the included studies were not standardized. In some cases, specific outcome data had to be inferred based on clinical descriptions of the patients. Furthermore, there was no standard length of follow-up for outcome data collection. Some studies reported outcomes at 30 days, but others did so at longer time points. This variability in follow-up timing could influence the results.

It is important to note that the reported good clinical outcomes and low mortality rates in most studies appear to be skewed toward favorable results. Although this trend might have developed randomly, it may also reflect bias introduced by sample size or study design. As a result, our findings should be interpreted with caution, because they may not be fully generalizable to broader populations. However, it is worth emphasizing that these results align with the trends observed in the existing evidence on this topic to date.

Despite these limitations, we believe our study provides a valuable overview of the existing data on EVT for the treatment of CVST. Given the relative rarity of this condition and the diversity of techniques used in EVT, this meta-analysis aimed to clarify the effectiveness of individual techniques by pooling and comparing data from currently available studies. Future prospective multicenter studies or randomized control trials comparing mechanical thrombectomy to best medical therapy will be valuable, especially as developments in EVT technology continue to evolve.

Conclusion

This systematic review and meta-analysis found that EVT for CVST patients can lead to high rates of recanalization and favorable clinical outcomes, with low procedural complications. The safety and efficacy profiles of modern and older thrombectomy techniques appear to be comparable. These findings suggest that EVT can be an effective treatment for CVST, particularly in severe cases where early intervention may improve outcomes. Although thrombectomy techniques have evolved and differ in approach, this analysis did not identify significant differences in clinical and angiographic outcomes, reinforcing that EVT can be an appropriate treatment option for CVST, regardless of the specific technique used.

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Authors' contribution

Conceptualization: RG. Data curation: DG, OS, SN, MTB, AS, JJM, RCR, CK, KPB, and RG. Methodology: DG, SN, MTB, and RG. Formal analysis: DG and OS. Writing—original draft: DG, OS, and RG. Writing—review & editing, DG, OS, SN, MTB, AS, JJM, RCR, CK, KPB, and RG. Supervision: RG.

Data availability statement

The data on which this paper was based were previously published.

Declaration of conflicting interests

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Supplemental material

Supplemental material for this article is available online.

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