Stroke: Vascular and Interventional Neurology

ORIGINAL RESEARCH

Endovascular Thrombectomy in Cancer-Related Stroke: Comparison of Thrombectomy Methods

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BACKGROUND: The optimal first-line device choice for endovascular treatment (EVT) of cancer-related stroke remains largely unknown. In this study, we evaluated the efficacy and safety of the EVT methods for treating cancer-related stroke thrombi.

METHODS: We retrospectively analyzed 78 patients with cancer-related stroke who underwent EVT between February 2011 and July 2024. Patients were compared based on the first-line EVT technique (combined [$n = 29$] versus stent retriever [SR] only [$n = 35$] versus contact aspiration [CA, $n = 14$]) and the type of the SR (the dual-layered stent retriever [Embotrap] [$n = 13$], the single-layered stent retriever (Trevo [$n = 16$], and the Solitaire [$n = 35$]) group. The primary efficacy end point was the first-pass effect (achieving a modified Thrombolysis in Cerebral Infarction score of 2c or 3 after the first pass). The primary safety end point was the symptomatic intracranial hemorrhage rate.

RESULTS: The primary efficacy did not differ between the first-line EVT techniques (first-pass effect: combined 34.5% versus SR only 17.1% versus CA 35.7%; $P = 0.2$). Among the SR groups, the dual-layered stent retriever group showed a higher rate of first-pass effect compared with the single-layered stent retriever (Trevo) and the single-layered stent retriever (Solitaire) groups (53.8% versus 25.0% versus 14.3%, $P = 0.023$). The dual-layered stent retriever group was independently associated with a higher rate of first pass effect (adjusted odds ratio, 11.0 [95% CI 1.4–126.0]; $P = 0.031$). The incidence of symptomatic intracranial hemorrhage after the procedure did not significantly differ between the groups.

CONCLUSIONS: In EVT for cancer-related stroke, the dual-layered stent retriever device demonstrated superior efficacy in higher rates of first-pass effect without increasing the risk of symptomatic intracranial hemorrhage. These findings suggest that the dual-layered SR may be preferred as the first-line treatment option for EVT in cancer-related stroke.

Key Words: cancer ■ cancer-related stroke ■ endovascular thrombectomy ■ ischemic stroke ■ stent retriever ■ thrombus

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Endovascular thrombectomy (EVT) is the gold standard treatment modality for acute ischemic stroke.[1] Recent advances in devices and techniques have elevated the successful recanalization rates to as high as 85%.[2] Recent studies have shown that not only achieving recanalization but also the speed and the completeness of recanalization are critical factors linked to better clinical outcomes.[3,4] In this regard, the first-pass effect (FPE) is reported in ∼50% of cases, which leaves significant room for improving the procedural efficacy.[5] As FPE is a strong predictor of favorable outcomes, including functional independence at 3 months, procedural strategies aimed at increasing the likelihood of FPE are of great clinical relevance.[3] One of the main obstacles to procedural efficacy is the firm and rubbery thrombus composed of fibrin-rich thrombi (< 20% red blood cell [RBC] content) that is resistant to current retrieval approaches.[6] A tailored device selection strategy, based on the physical characteristics of the occluding thrombus, is needed to enhance the procedural efficacy of EVT.[6]

Cancer-related stroke (CRS) occurs due to distinctive mechanisms induced by cancer-related hypercoagulability.[7] Approximately 1 in 10 patients with ischemic stroke are reported to have concomitant cancer, and this incidence is increasing due to advances in cancer treatment.[7] As a result, the rising occurrence of CRS may lead to a growing number of cases requiring EVT.[8] Given the clinical context and the well-studied platelet-/fibrin-rich characteristics of the CRS thrombi, it is often possible to plan an EVT strategy based on the anticipated mechanical properties of the occluding thrombus.[9,10] However, prospective data directly comparing different EVT strategies for CRS thrombi remain scarce. In real-world clinical practice, device selection is often influenced by thrombus characteristics, vascular anatomy, and operator preference. We hypothesized that the EVT technique and the design of the stent retriever (SR) device may demonstrate different procedural efficacy in these patients with CRS. In this study, we aim to compare the procedural efficacy and safety of the EVT techniques and the effect of different SR devices in patients with CRS.

Nonstandard Abbreviations and Acronyms

CA	contact aspiration
CRS	cancer-related stroke
DLSR	dual-layered stent retriever
FPE	first pass effect
SLSR	single-layered stent retriever
SR	stent retriever
SRT	successful reperfusion within 3 passes

CLINICAL PERSPECTIVE

What Is New?

- This study identifies the better efficacy of the dual-layered stent retriever over conventional single-layered stent retrievers in achieving first-pass effect in cancer-related stroke.
- The dual-layered stent retriever significantly enhances early reperfusion outcomes, resulting in fewer thrombectomy passes and shorter procedure times.
- Despite the improved procedural outcomes with dual-layered stent retrievers, rates of symptomatic intracranial hemorrhage remain comparable to conventional devices.

What Are the Clinical Implications?

- Using a dual-layered stent retriever as the first-line treatment device could optimize endovascular thrombectomy outcomes in patients with cancer-related stroke.
- Improved first-pass recanalization with dual-layered stent retrievers may lead to procedural efficiency, potentially reducing complications related to prolonged intervention.
- Understanding thrombus composition and selecting devices accordingly can enhance tailored therapeutic strategies for endovascular treatment of ischemic stroke.

METHODS

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Study Population

The study population of this retrospective study consisted of patients from the Yonsei Stroke Cohort (Clinicaltrials.gov NCT03510312).[11] Each patient, including those who received reperfusion therapy at the Severance Hospital, was prospectively enrolled in the Yonsei Stroke Cohort since February 2001. During hospitalization, all patients underwent a comprehensive assessment that included a review of their medical history, blood tests, computed tomography, magnetic resonance imaging, carotid ultrasound, transcranial Doppler, 12-lead electrocardiography, echocardiography, and Holter monitoring or continuous electrocardiogram monitoring. Stroke severity was also evaluated using the National Institutes of Health Stroke Scale (NIHSS). Reperfusion therapy was performed according to guideline-based protocols and the attending physician's discretion, depending on the patient's clinical status. Written informed consent was obtained from the prospectively enrolled patients or their families included in this study. This study was approved by the Institutional Review Board of the Yonsei University College of Medicine (approval number: 4-2024-1556).

Study Groups and Criteria for Selecting Cancer-Related Stroke

From the registry, we reviewed the records of consecutive patients with ischemic stroke and active cancer treated with EVT between sFebruary 2011 and July 2024. Active cancer was defined as a newly diagnosed cancer within the past 6 months, cancer requiring chemotherapy or surgical treatment within the past 6 months, or cases of recurrent, metastatic, or inoperable cancer.[9] To include CRS thrombi, the following criteria were implemented: (1) patients with elevated D-dimer level (>1.11 µg/mL),[12–14] and (2) patients without other specific etiologies, such as atrial fibrillation or large artery atherothrombosis. Exclusion criteria were (1) early termination of EVT due to procedure-related complications ($n = 4$), (2) cases with tandem occlusion ($n = 3$), (3) thrombectomy performed for multiple vascular territory occlusions ($n = 1$), or (4) cases with cervical dissection ($n = 2$). Finally, study groups were categorized and compared based on 2 criteria: (1) the first-line EVT technique (combined technique, SR-only, or contact aspiration [CA]) and (2) the structural characteristics of the stent retriever used. Devices were classified as either dual-layered stent retriever (DLSR; Embotrap [CERENOVUS, CA, USA]) or single-layered stent retriever (SLSR; Trevo [Stryker, CA, USA] and Solitaire [Medtronic, CA, USA]) (Figure 1).

Endovascular Treatment

Endovascular procedures were carried out via a femoral artery approach under local anesthesia with conscious sedation as needed. All procedures were performed by 2 experienced neurointerventionists (B.M.K. and D.J.K.). The choice of the first-line technique and device was left to the discretion of the treating operator. A balloon guide catheter was routinely used in the anterior circulation. Combined therapy was defined as the simultaneous use of the SR and CA techniques for thrombectomy. Rescue therapy was performed if successful reperfusion was not achieved with the first-line device by switching to another strategy.

Data Collection and Outcome Measure

Two experienced radiologists from the independent core laboratory adjudicated the angiograms and assessed the reperfusion status. The investigators were blinded to any clinical data during image analysis. All neurologic examinations were performed by board-certified neurologists. Routine evaluations determining the stroke etiology were performed for all patients (Supplemental Methods). During the follow-up sessions, the stroke neurologists and research nurses regularly contacted patients or their caregivers through in-person visits or telephone interviews, with or without a medical chart review, to assess the clinical outcomes, including the modified Rankin Scale score. Reperfusion status was assessed on the final angiogram and was classified according to the modified Thrombolysis in Cerebral Infarction (mTICI) scale. The primary efficacy outcome was the FPE. The FPE was defined as achieving near-complete recanalization (mTICI 2c or 3) with a single attempt of thrombectomy.[3] Secondary outcomes included successful reperfusion within 3 passes (SRT; achieving mTICI ≥2b within 3 attempts without rescue therapy, complete reperfusion (defined as mTICI 3 at the end of procedure), successful reperfusion (defined as achieving mTICI 2b or more at the end of procedure), total number of passes, procedure time, and the rate of any ICH at 24 hours. Procedure time was defined as the interval (in minutes) from femoral puncture to the first achievement of an mTICI score of 2b in cases of successful reperfusion or to the time of the last angiographic series in cases of unsuccessful recanalization. The primary safety outcome was symptomatic intracranial hemorrhage (sICH). sICH was defined by the European Cooperative Acute Stroke Study III as any intracranial hemorrhage associated with neurological deterioration of ≥4 points on the NIHSS score at 24 hours.[15] Clinical outcomes such as functional independence (defined as achieving modified Rankin Scale score 0–2) and mortality were assessed 3 months after stroke onset. Mortality attributable to the index stroke was recorded if death occurred due to the stroke itself or its related complications during the admission period.

Immunohistochemistry Analysis

For additional analysis, histopathologic data were obtained from the SMART-CLOT (Specialized Multi-Center Attributed Registry of Stroke–Clot) registry, which includes data from patients who underwent EVT for large vessel occlusions.[16] Thrombi retrieved during EVT were collected and processed according to standardized protocols. (Supplemental Methods). Thrombi

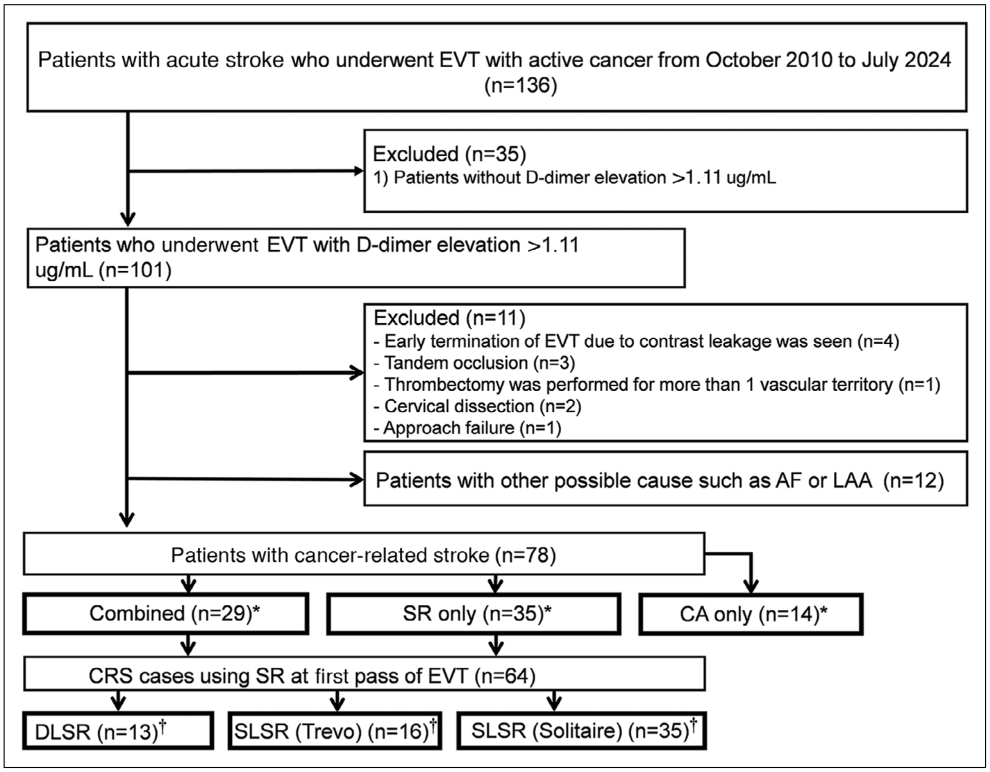

Figure 1. Case selection diagram.
AF indicates atrial fibrillation; CA, contact aspiration; DLSR, dual-layered stent retriever; EVT indicates endovascular thrombectomy; LAA, large artery atherothrombosis; SLSR, single-layered stent retriever; and SR, stent retriever.
*Study groups divided to compare first-line EVT technique.
†Study groups divided to compare first-line SR for EVT.

were classified as platelet rich, fibrin rich, or RBC rich if they contained >50% of the respective component. Thrombi without a predominant component (>50%) were categorized as heterogeneous.[17]

Statistical Analysis

Data are presented as the mean±SD, median (interquartile range [IQR]), or percentage (%), as appropriate. Differences in the baseline characteristics, treatment, and clinical outcomes between the study groups were compared. Continuous variables were compared using Student's *t*-tests or analysis of variance, whereas categorical variables were compared using the chi-square or Fisher's exact tests, as appropriate. To identify the independent factors associated with the outcomes, multiple regression analyses were performed after adjusting for age, sex, intravenous tissue plasminogen use, interval from onset to puncture, NIHSS score before EVT, and occlusion site. The statistical *P* value was set at <0.05. Statistical analyses were conducted using the R software package version 4.3.1 (http://www.R-project.org) or SPSS for Windows (version 27; SPSS, Chicago, IL, USA).

RESULTS

Study Population and Baseline Characteristics

Among the 136 patients who met the initial identification criteria, 58 patients were excluded. Exclusions were due to D-dimer level not exceeding 1.11 μg/mL ($n = 35$), unsuitable angiographic evaluations ($n = 11$), or other determined etiology of stroke (large artery atherothrombosis or atrial fibrillation) ($n = 12$). Finally, a total of 78 patients with CRS (mean age, 67.6±12.3 years; male, 39 [50.0%]) were included for analysis. First-line EVT consisted of combined [$n = 29$], SR only [$n = 35$], and CA [$n = 14$]. The types of SR used were DLSR ($n = 13$), SLSR (Trevo) ($n = 16$), and SLSR (Solitaire) ($n = 35$).

The baseline characteristics of study participants are shown in Table 1. Overall, 10 patients (12.8%) received intravenous tissue plasminogen before EVT. The median interval from stroke onset to femoral puncture was 307.5 minutes (IQR, 168.5 to 564.8). Occlusion locations were as follows: middle cerebral artery M1 segment ($n = 46$ [59.0%]), M2 segment (21

Table 1. Baseline Characteristics

	DLSR (*n* = 13)	SLSR (Trevo) (*n* = 16)	SLSR (Solitaire) (*n* = 35)	CA only (*n* = 14)	*P* value
Age, y	68.6 ± 15.9	66.1 ± 9.2	69.0 ± 13.0	64.6 ± 10.7	0.4
Male sex	7 (53.8)	8 (50.0)	18 (51.4)	8 (57.1)	>0.9
IV tPA use	1 (7.7)	3 (18.8)	4 (11.4)	2 (14.3)	0.8
Interval from onset to puncture, min	438.0 (154.3–838.3)	357.5 (241.0–574.3)	246.0 (174.0,–488.5)	215.0 (145.0–406.0)	0.5
NIHSS score before EVT	9.0 (8.5–13.0)	9.5 (7.8–14.3)	15.0 (11.5–18.5)	10.0 (8.0–13.0)	0.02
Risk factors					
Hypertension	9 (69.2)	8 (50.0)	20 (57.1)	6 (42.9)	0.5
Diabetes	5 (38.5)	5 (31.3)	11 (31.4)	5 (35.7)	>0.9
Dyslipidemia	2 (15.4)	6 (37.5)	7 (20.0)	3 (21.4)	0.5
Atrial fibrillation	1 (8.3)	1 (6.3)	2 (5.7)	2 (15.4)	0.8
Smoking					0.6
Unknown	2 (15.4)	0 (0.0)	1 (2.9)	0 (0.0)	
Never smoker	8 (61.5)	10 (62.5)	25 (71.4)	9 (64.3)	
Ex-smoker	3 (23.1)	4 (25.0)	8 (22.9)	4 (28.6)	
Current smoker	0 (0.0)	2 (12.5)	1 (2.9)	1 (7.1)	
Coronary artery disease	2 (16.7)	0 (0.0)	8 (22.9)	2 (15.4)	0.2
EVT technique					0.7
Combined	7 (53.8)	6 (37.5)	16 (45.7)		
Stent retrieval only	6 (46.2)	10 (62.5)	19 (54.3)		
Occlusion site					0.2
MCA M1	7 (53.8)	9 (56.3)	21 (60.0)	9 (64.3)	
MCA M2 or more	4 (30.8)	6 (37.5)	10 (28.6)	1 (7.1)	
Distal ICA	2 (15.4)	0 (0.0)	2 (5.7)	4 (28.6)	
Others*	0 (0.0)	1 (6.3)	2 (5.7)	0 (0.0)	
Laboratory variables					
Hemoglobin, mmol/L	6.7 ± 1.4	7.0 ± 0.8	6.7 ± 1.3	7.0 ± 1.5	0.7
White blood cell count, 10^9/L	11,949.2 ± 5,488.5	7,651.9 ± 3,261.5	13,206.6 ± 18,185.4	11,949.2 ± 5,488.5	0.12
Platelet count, 10^9/L	148.6 ± 91.5	131.6 ± 75.7	166.1 ± 97.8	123.0 ± 66.7	0.4
D-dimer, μg/mL	8.8 ± 8.3	11.9 ± 13.5	6.9 ± 6.1	7.3 ± 4.5	0.6
C-reactive protein, mg/L	76.1 ± 57.3	58.4 ± 53.2	48.6 ± 44.3	65.1 ± 49.0	0.4

Values are number (%), median (interquartile range), or mean±SD. CA indicates contact aspiration; DLSR, dual-layered stent retriever; EVT, endovascular thrombectomy; ICA, internal carotid artery; IV tPA, intravenous tissue plasminogen activator; MCA, middle cerebral artery; NIHSS, National Institutes of Health Stroke Scale; and SLSR, single-layered stent retriever.

*Other occlusion sites included 1 anterior cerebral artery A2 segment, 1 basilar artery, and 1 posterior cerebral artery.

[26.9%]), distal internal carotid artery (8 [10.3%]), and other arteries (3 [3.8%]). The SLSR (Solitaire) group had the highest NIHSS score before EVT with a median of 15.0 (IQR, 11.5–18.5); *P* = 0.015). The proportion of patients treated with a combined technique at the first EVT attempt was similar between the SR study groups (DLSR, 53.8% [*n* = 7] versus SLSR [Trevo], 37.5% [*n* = 6] versus SLSR [Solitaire], 45.7 [*n* = 16]; *P* = 0.7).

Treatment Outcome

For the primary efficacy outcomes, the overall rate of FPE was 26.9% (21/78) and was not significantly different between first-line EVT techniques (combined 34.5% [*n* = 10] versus SR only 17.1% [*n* = 6] versus CA only 35.7% [*n* = 5]; *P* = 0.2. Secondary outcomes (rates of SRT, complete/successful reperfusion, total number of passes, procedural time, and any ICH), primary safety outcome (symptomatic ICH), and functional independence were also not significantly different between the first-line EVT techniques (Table 2). Mortality at 3 months was lowest with the SR-only technique (combined 86.2% [*n* = 25] versus SR only 51.4% [*n* = 18] versus CA only 71.4% [n = 10]; *P* = 0.01). However, mortality attributable to the index stroke was comparable across groups (combined: 2/29 [6.9%]; SR only: 4/35 [11.4%]; aspiration only: 1/14 [7.1%]; *P* = 0.68).

Among the SR groups, the DLSR group showed a significantly higher rate of FPE (DLSR, 53.8% versus SLSR [Trevo], 25.0% versus SLSR [Solitaire], 14.3%; *P* = 0.023). For the secondary outcomes, the DLSR group achieved significantly higher rate of SRT (100%; *P* = 0.012), complete reperfusion (76.9%; *P* = 0.019), lower total number of passes (median [IQR], 1.0 [1.0–2.0]; *P* = 0.012), and shorter procedure time (median

Table 2. Treatment Outcomes According to the First-Line EVT Technique

	First-line EVT technique			
	Combined (*n* = 29)	SR only (*n* = 35)	CA only (*n* = 14)	*P* value
Primary efficacy outcomes				
First pass effect	10 (34.5)	6 (17.1)	5 (35.7)	0.2
Secondary outcomes				
SRT*	16 (84.2)	20 (69.0)	7 (87.5)	0.4
Complete reperfusion	16 (55.2)	12 (34.3)	8 (57.1)	0.2
Successful reperfusion	24 (82.8)	27 (77.1)	12 (85.7)	0.8
Total number of passes	2.0 (1.0–3.0)	2.0 (2.0–3.0)	3.0 (1.0–4.5)	0.4
Procedure time, min	43.0 (29.0–60.0)	56.0 (45.5–93.0)	48.5 (31.3–107.0)	0.2
Any ICH	14 (48.3)	14 (40.0)	4 (28.6)	0.5
Primary safety outcome				
symptomatic ICH	4 (13.8)	7 (20.0)	2 (14.3)	>0.9
Clinical outcomes				
Functional independence	1 (3.4)	7 (20.0)	2 (14.3)	0.12
Mortality at 3 mo	25 (86.2)	18 (51.4)	10 (71.4)	0.01

Values are numbers (%) or median (interquartile range).
CA indicates contact aspiration; EVT, endovascular thrombectomy; ICH, intracranial hemorrhage; SR, stent retriever; and SRT, successful reperfusion within 3 passes.
*Analyzed 56 patients after excluding cases of rescue therapy before completing 3 attempts.

Table 3. Treatment Outcomes According to the First-Line SR Device

	Total patients (*n* = 64)	DLSR (*n* = 13)	SLSR (Trevo) (*n* = 16)	SLSR (Solitaire) (*n* = 35)	*P* value
Primary efficacy outcomes					
First-pass effect	16 (25.0)	7 (53.8)	4 (25.0)	5 (14.3)	0.02
Secondary outcomes					
SRT*	36 (75.0)	10 (100.0)	11 (84.6)	15 (60.0)	0.01
Complete reperfusion	28 (43.8)	10 (76.9)	7 (43.8)	11 (31.4)	0.02
Successful reperfusion	51 (79.7)	13 (100.0)	12 (75.0)	26 (74.3)	0.11
Total number of passes	2.0 (1.0–3.0)	1.0 (1.0–2.0)	2.0 (1.8–3.0)	3.0 (2.0–4.0)	0.01
Procedure time, min	49.0 (32.8–77.3)	33.0 (28.0–49.0)	48.0 (37.3–72.8)	57.0 (43.0–116.0)	0.01
Any ICH	28 (43.8)	4 (33.3)	8 (50.0)	16 (45.7)	0.5
Primary safety outcome					
Symptomatic ICH	11 (17.2)	0 (0.0)	4 (25.0)	7 (20.0)	0.2
Clinical outcomes					
Functional independence	8 (12.5)	2 (15.4)	2 (12.5)	4 (11.4)	0.9
Mortality at 3 mo	43 (67.2)	10 (76.9)	8 (50.0)	25 (71.4)	0.3

Values are number (%) or median (interquartile range). DLSR indicates dual-layered stent retriever; EVT, endovascular thrombectomy; ICH, intracranial hemorrhage; SLSR, single-layered stent retriever; SR, stent retriever; and SRT, successful reperfusion within 3 passes.
*Analyzed in 48 patients after excluding cases of rescue therapy before completing 3 attempts.

[IQR], 33.0 [28.0-49.0] min; $P = 0.013$) (Table 3). The safety outcomes were not significantly different across the study groups (sICH, DLSR, 0.0% versus SLSR [Trevo], 25.0% versus SLSR [Solitaire], 20.0%; $P = 0.2$). Clinical outcomes were also not significantly different (for mortality at 3 months, $P = 0.3$; for functional independence, $P = 0.9$) (Table 3).

Multivariable analysis showed that the DLSR group was independently associated with an increased rate of FPE (adjusted odds ratio [aOR] 11.0, 95% CI 1.4–126.0; $P = 0.031$) and complete reperfusion (aOR, 6.8, 95% CI 1.3–47.1; $P = 0.033$) compared with the SLSR (Solitaire) group (Table 4).

Microscopic Analysis of Thrombi

Among the 78 patients included, thrombi causing stroke were obtained in 54 patients. Microscopic analysis was performed in these 54 (54/78, 69.2%) patients. The mean±SD proportions of thrombus components were 45.3%±23.2% for platelets, 26.7%±19.0% for fibrin, and 7.9%±13.9% for RBC. Platelet-rich or fibrin-rich thrombi accounted for 69.8 % of all analyzed cases, whereas only 2 thrombi (3.7%) were RBC rich. There were no significant differences in thrombus classification or mean microscopic composition between the study groups. (Table S1).

Table 4. Multivariable Analysis for Treatment Outcomes

	DLSR (*n* = 13)		SLSR (Trevo) (*n* = 16)		SLSR (Solitaire) (*n* = 35)
	aOR or B (95% CI)	*P* value	aOR or B (95% CI)	*P* value	
Primary efficacy outcomes					
First pass effect	11.0 (1.4 to 126.0)	0.03	3.1 (0.5 to 20.8)	0.2	Ref
Secondary outcomes					
SRT	NA	>0.9	5.8 (0.8 to 86.9)	0.13	Ref
Complete reperfusion	6.8 (1.3 to 47.1)	0.03	2.5 (0.5 to 12.3)	0.3	Ref
Successful reperfusion	NA	>0.9	1.0 (0.2 to 5.6)	>0.9	Ref
Total number of passes	−29 (−61 to 2.8)	0.07	−17 (−45 to 11)	0.2	Ref
Procedure time, min	−26 (−58 to 5.4)	0.10	−15 (−43 to 14)	0.3	Ref
Any ICH	0.43 (0.1 to 2.2)	0.3	2.4 (0.6 to 11.6)	0.2	Ref
Primary safety outcome					
Symptomatic ICH	NA	>0.9	2.6 (0.5 to 18.2)	0.3	Ref
Clinical outcomes					
Functional independence	1.5 (0.2 to 12.1)	0.7	1.0 (0.1 to 7.3)	>0.9	Ref
Mortality at 3 mo	1.1 (0.2 to 6.3)	>0.9	0.4 (0.1 to 1.4)	0.14	Ref

Adjusted values were age, sex, intravenous tissue plasminogen use, interval from onset to puncture, National Institutes of Health Stroke Scale score before endovascular thrombectomy, and occlusion site.

aOR indicates adjusted odds ratio; B, beta coefficient; DLSR, dual-layered stent retriever; ICH, intracranial hemorrhage; NA, not applicable; SLSR, single-layered stent retriever; and SRT, successful reperfusion within 3 passes.

DISCUSSION

This study compared the procedural efficacy and safety of various thrombectomy techniques and the SR devices in performing EVT for patients with CRS. The first-line EVT technique did not show significant differences in overall outcome, but in terms of the SR design, using the DLSR significantly improved the procedural outcomes by more than doubling the FPE rate (53.8%) compared with other SRs (SLSR [Trevo]; 25.0%, SLSR [Solitaire]; 14.3%). Also, the DLSR group achieved substantial recanalization at the early phase of EVT, as reflected by the high SRT rate, higher rates of complete recanalization, fewer passes, and shorter procedure time. Despite these enhancements, sICH rates were not significantly different when compared across other study groups.

To the best of our knowledge, this is the first study showing the improved efficacy of a dual-layered SR device for EVT in patients with CRS. Most prior research primarily focused on the clinical outcomes, underscoring the necessity of EVT for CRS. Prior meta-analyses suggested that EVT should be considered for with CRS acute large vessel occlusion CRS, highlighting that a considerable proportion of patients with CRS regained functional independence following the procedure.[18–20]

CRS thrombi are characterized by a high platelet/fibrin content, particularly rich in platelets, and a low RBC composition.[7,9,10] The histopathologic findings of our study confirmed the findings of the previous studies and validated the inclusion of the typical CRS thrombi in our study. Mechanical properties of the platelet-/fibrin-rich, RBC-poor thrombi with higher stiffness and friction coefficient may strongly influence the EVT outcomes. Specifically, the stiffness of the thrombus may limit stent engagement into the thrombus, and the high friction of the thrombus may increase the thrombus–vessel interaction, resulting in slippage of the thrombus during retrieval.[6,21] Prior studies have also reported lower successful reperfusion rates, longer procedure time, and secondary embolism associated with platelet-/fibrin-rich, RBC-poor thrombi.[6,21,22] Consistently, a recent analysis of 1430 ischemic stroke thrombi showed that fibrin- and platelet-rich clots required more retrieval attempts than RBC-rich and mixed clots (median 2 and 1.5 versus 1, respectively) and were linked to significantly lower FPE rates.[17]

Only a few studies have specifically compared the procedural outcomes across different EVT strategies for CRS stroke, with inconsistent results.[23,24] A retrospective study with 62 patients with CRS suggested that CA, whether used alone or combined with SR, resulted in more rapid and successful reperfusion compared with using SR alone as the first-line EVT technique.[23] On the other hand, another study involving 19 patients with CRS reported that CA did not improve the recanalization rate.[24] Rather, the recanalization rate was significantly reduced when CA was performed with a small-caliber aspiration catheter.[24] Our study largely aligns with the latter findings, showing no significant differences in the outcome between the first-line EVT techniques. However, our study showed that the differences in the stent design may have an impact on the procedural outcome.

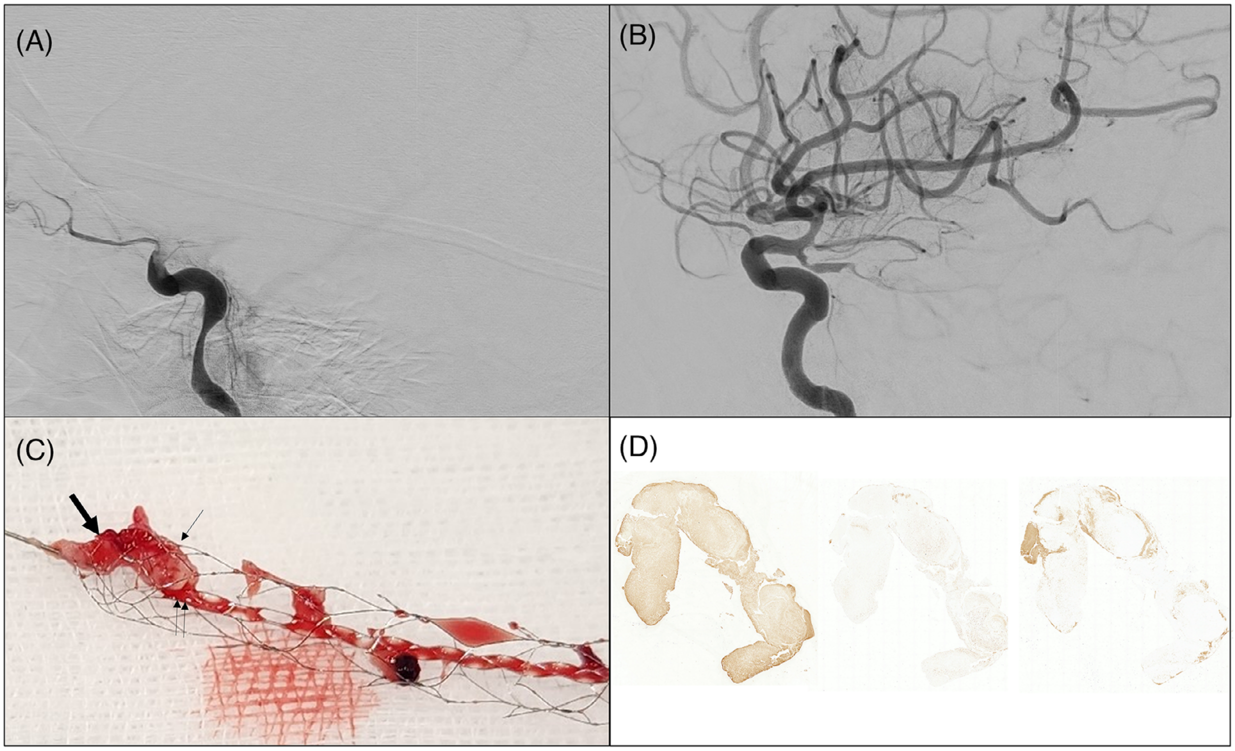

Figure 2. Cancer-related white thrombus captured by the dual-cage and distal mesh structure of dual-layered stent retriever.
A 24-year-old male with underlying metastatic cardiac sarcoma presented with an acute onset left-sided weakness and underwent emergent endovascular thrombectomy. **A**, Right distal internal carotid artery occlusion was noted on DSA. **B,** Complete recanalization was achieved. **C,** Notice the white clot trapped between the outer (single arrow) and the inner (double arrows) cages and the distal mesh (thick arrow) of the dual-layered stent retriever. **D**, Immunohistochemical staining demonstrates the distribution of fibrin (left), platelets (middle), and RBCs (right). The thrombus was composed predominantly of platelet-/fibrin-rich material (40%) with a low RBC content (9%). Although the patient showed marked improvement of the neurological symptoms (initial/7-day National Institutes of Health Stroke Scale scores of 17/0) the patient died about 40 days later due to symptoms of heart failure. RBC indicates red blood cell.

The commonly used conventional SLSRs have a single-layered, closed-cell, self-expandable design that primarily relies on radial force to capture thrombus.[2,6,25,26] During deployment, these devices apply radial pressure, expanding the stent outward to embed the struts into the thrombus for extraction.[6,25,26] In comparison, the DLSR uses a hybrid dual-layered articulated nitinol structure, comprising an inner closed-cell stent with high radial force designed for immediate flow restoration and an outer segmented cage with relatively lower radial force with the distal mesh at the stent tip.[27,28] This segmented and dual-layered structural design may have effectively aided in capturing and retaining the stiff CRS thrombi-, which may be resistant to embedding of the struts into the thrombi during retrieval between the inner channel and the outer cage.[26–30] (Figure 2)

In this study, better procedural outcomes did not necessarily translate into better clinical outcomes. The lower mortality at 3 months observed in the SR-only group may be attributed to factors related to underlying baseline characteristics differences, such as the inclusion of cases with less advanced malignancy, rather than procedural efficacy alone. Indeed, mortality attributable to the index stroke was comparable across groups (combined: 2/29 [6.9%]; SR only: 4/35 [11.4%]; aspiration only: 1/14 [7.1%]; $P = 0.68$).

An important area for improving the technical and clinical results of EVT may be distinguishing the characteristics of the occlusive lesion and tailoring the procedure accordingly. Recent advances in the various imaging markers of the occlusion, including the hyperdense/susceptibility vessel sign, thrombus permeability, occlusive-clot silhouette, and device–clot interaction, provide some valuable insight into this topic.[31,32] Absence of the hyperdense/susceptibility vessel signs may be suggestive of the fibrin predominant thrombus.[31] Thrombus permeability, as well as the occlusive-clot silhouette markers, such as the claw sign, may be associated with a cardioembolic source of the clot.[31,32] Device-clot interaction, such as the degree of the stent opening, may provide information on the physical consistency of the thrombus.[33] These advances in knowledge provide valuable pre- and intraprocedural information in characterizing the occlusive thrombus. In this context, our results show the potential advantages of the segmented and dual-layered design of the DLSR in the CRS-related stiff fibrin-rich thrombi and may potentially be extrapolated to other physically stiff non-CRS-related white thrombi that are frequently encountered in association with various stroke etiologies.

Limitations

This study has limitations. First, the retrospective nature of the analysis may introduce inherent biases as the selection of the first-line device is subject to the operator's discretion. Also, the later introduction of the DLSR may have allowed bias in terms of the skillfulness of the operator in comparison to the SLSRs (Trevo or Solitaire). However, analysis of the cohort, including only the patients treated after the introduction of DLSR (March 2020), shows consistent favorable procedural outcome, albeit statistical non-significance due to the small number of cases (Table S2). Second, although we performed the analysis with a larger cohort of CRS patients than previous studies, the limited number of cases and the absence of a formal sample size or power calculation raise the possibility of sampling error and insufficient power to detect modest differences. Lastly, although the inclusion criteria of our study may better define CRS cases, they may not fully reflect real-world scenarios in which procedural decisions must be made before EVT. Some variables used in our study (eg, D-dimer level) are often unavailable at the time of device selection, whereas other clinically valuable information—such as clot burden, vascular anatomy, the presence of a hyperdense vessel sign, or significant ipsilateral proximal artery stenosis—was not included. Lastly, our study population was homogeneous (Korean patients), which may limit the generalizability of the findings to more diverse racial and ethnic groups. Nonetheless, a sensitivity analysis using refined selection criteria demonstrated consistently better procedural outcomes with the DLSR (Table S3). Larger future studies incorporating robust patient and imaging data could further elucidate the impact of SR design on procedural outcomes and its relationship with the clinical results.

CONCLUSION

In conclusion, this study demonstrates that the design of the SR may influence the procedural outcome of EVT in patients with CRS. DLSR with dual-layered, caged, and distal mesh design enabled better procedural efficacy with higher FPE and complete recanalization compared with other conventional SRs. These findings suggest that DLSR may be an effective and safe first-line treatment option for EVT in CRS.

ARTICLE INFORMATION

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Author Contributions

J. Y. and D.J.K. conceptualized and designed the study, drafted the manuscript, and prepared the figures; J.Y., K.H.K., S.K., K.S.J., Y.D.K. H.S.N., J.H.H., B.M.K. and D.J.K. acquired and analyzed the data; J. Y., Y.D.K. and D.J.K. reviewed and edited the draft; Y.D.K. granted funding for this study; Y.D.K. and D.J.K. supervised and investigated this study.

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Disclosures

None.

Ethics Statement

This research study was conducted retrospectively from data obtained for clinical purposes. We consulted extensively with the institutional review board of Yonsei University College of Medicine. who determined that our study did not need ethical approval. An institutional review board official waiver of ethical approval was granted from the institutional review board of the Yonsei University College of Medicine (approval number: 4-2024-1556)

Supplemental Materials

Table S1. Histopathologic result of extracted thrombi
Table S2. Treatment outcomes after introduction of the dual-layered stent retrieval device
Table S3. Procedural outcomes according to first-line device selection based on refined inclusion criteria

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