Original research

Comparative efficacy and safety of stent retrievers as a bailout strategy following failed contact aspiration technique in acute stroke thrombectomy

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ABSTRACT

Background The contact aspiration (CA) technique is often used to perform endovascular thrombectomy (EVT) for acute ischemic stroke (AIS); however, rescue strategies are necessary if CA fails to achieve recanalization. This study investigates the outcomes of incorporating stent retriever (SR) thrombectomy in the rescue strategy following failed CA.

Methods EVT patients with failed CA attempts were identified from a large multicenter registry and stratified by rescue technique: CA alone or incorporating SR in the rescue strategy. Outcomes included successful recanalization, 90-day functional outcomes (defined by the modified Rankin Scale (mRS) score), symptomatic intracranial hemorrhage (sICH), and 90-day mortality.

Results Among 1885 patients with failed CA attempts, conversion to SR was associated with higher recanalization rates (85.2% vs 80.6%; p=0.03), higher rates of second-pass recanalization (31.2% vs 23.4%; p<0.001), and better 90-day outcomes (mRS 0–2: 35.2% vs 29.9%; p=0.04) when compared with repeated CA attempts. Trevo SRs showed higher odds of successful recanalization (adjusted odds ratio (aOR)=1.9; p=0.02), second-pass recanalization (aOR=1.7; p=0.01), and reduced odds of sICH (aOR=0.3; p=0.02). EmboTrap SRs were associated with higher odds of 90-day mortality (aOR=2.6; p=0.004) and sICH (aOR=2.9; p=0.04) and lower odds of recanalization (aOR=0.5; p=0.03).

Conclusions Incorporating SR in the rescue strategy after a failed CA improves recanalization rates and functional outcomes. Trevo SRs demonstrated superior efficacy and safety when incorporated into the rescue strategy.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Contact aspiration (CA) and stent retrievers (SRs) are used as first-line endovascular thrombectomy techniques with similar efficacy. Prior studies have shown that converting techniques after a failed pass improves outcomes.

WHAT THIS STUDY ADDS

⇒ This study demonstrates that incorporating SRs in the rescue strategy after failed CA attempts improves recanalization rates and favorable functional outcomes. This is the first study to compare the safety and efficacy of various SRs as a rescue strategy. Trevo SRs were superior to other SRs, with higher recanalization rates, higher recanalization, and lower odds of symptomatic intracranial hemorrhage.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE, OR POLICY

⇒ These findings may influence clinical guidelines by supporting the decision to incorporate SRs in the rescue strategy after a failed CA.

INTRODUCTION

Endovascular thrombectomy (EVT) is the standard of care for the management of acute ischemic stroke (AIS) with large vessel occlusion (LVO) in certain patients.[1] Many initial studies that established the safety and efficacy of EVT-utilized stent retrievers (SRs) as the primary technique.[2] Early guidelines recommended that SRs be the first choice for EVT over alternative techniques such as contact aspiration (CA).[2] Subsequent studies established non-inferiority of CA compared with SR thrombectomy.[1] CA is often utilized as the initial technique during EVT as it offers reduced procedure times and costs, though this remains at the operator's discretion.[3]

In up to 45% of EVT cases, recanalization is achieved in the first pass; multiple attempts are often required to achieve successful recanalization for the remainder of the cases.[4] Additional EVT passes are commonly performed, and current data suggest improved outcomes with additional passes up to the third pass, after which increased number of attempts and associated prolonged procedural times and complications appear to compromise the chance of good functional outcomes.[5 6] Converting to an alternative technique for the second pass may increase the odds of recanalization and improve functional outcomes at 90 days.[4]

Multiple prior studies have failed to find significant differences between SR devices used for EVT.[7–9] However, one study found higher recanalization rates and shorter recanalization times with the Trevo (Stryker, Kalamazoo, MI, USA) device compared with the Solitaire (Medtronic, Dublin, Ireland) device, with no difference in clinical outcomes between SRs.[10] These studies compared different SRs in the first pass during EVT. It is unknown whether different SRs vary in safety and efficacy following failed CA frontline technique. This study assesses the outcomes of incorporating different SRs in a rescue technique after a failed CA during EVT.

METHODS

Data collection and patient population

This study was conducted according to Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines.[11] We utilized the Stroke Thrombectomy and Aneurysm Registry (STAR), a database of 37 thrombectomy-capable stroke centers in the US, Europe, and Asia.[12] Ethical approval was obtained from the institutional review board at each participating center. Our study spanned from 2013 to 2024. The primary study group comprised patients initially undergoing one or more CA attempts for occlusions at the internal carotid artery (ICA), M1, or M2 segments of the middle cerebral artery (MCA). Only those patients with subsequent attempts of mechanical thrombectomy on the same vessel and segment of the vessel (ie, the same thrombus) were included; those who had tandem occlusions or attempts on different vessels or segments of the same vessel were excluded. Patients with missing outcome data were excluded. For comparison in our study, the rescue technique was defined as 'contact aspiration (CA) only' if all subsequent attempts were performed using CA. If one or more of the following attempts involved using an SR, the rescue technique was classified as 'incorporating stent retriever (SR)'.

Outcomes

The primary outcome was a favorable clinical outcome at 90 days, defined as a 90-day modified Rankin Scale (mRS) score of 0–2. Secondary outcomes included 90-day mRS 0–3, 90-day mortality, recanalization status, distal embolization, any intracranial hemorrhage (ICH), and symptomatic ICH (sICH). The mRS score was assessed during follow-up visits or telephone encounters at 90±14 days. sICH was defined as hemorrhage associated with a ≥4 point increase in the National Institutes of Health Stroke Scale (NIHSS) score at 24 hours post-procedure.[13] Successful recanalization was defined as achieving modified Thrombolysis in Cerebral Ischemia (mTICI) 2B or higher, while complete recanalization was defined as mTICI 2C or higher.[14]

Statistical analysis

All statistical analyses were performed using R (version 4.2.2; RStudio Inc., Boston, MA, USA). Continuous variables were presented as median (interquartile range (IQR)), while categorical variables were reported as frequencies and percentages. Between-group comparisons of characteristics were conducted using the Wilcoxon rank-sum (Mann–Whitney) test and the $\chi 2$ test, as appropriate.

Propensity score matching (PSM) was applied to adjust for baseline characteristics and capture two matched cohorts. A 1:1 nearest neighbor greedy matching algorithm without replacement was used. Variables included in the model for matching are listed in online supplemental figure 1 and adjusted for the effect of different centers by employing generalized estimating equations (GEE) within the propensity-matched cohorts. The optimal caliper width for matching was set at 0.2 times the standard deviation of the logit of the propensity scores for all patients. Baseline characteristics were compared between the matched cohorts to validate the matching model. An adequate balance between the groups was confirmed if the absolute standardized difference for any baseline characteristic was <0.20.

Multivariable logistic regression analyses were performed to study the impact of SR subtypes used in the rescue attempt(s) on successful recanalization at the end of the procedure, successful recanalization in two attempts, ICH, sICH, 90-day functional outcomes (mRS 0–2, mRS 0–3), and mortality. The models adjusted for prior stroke, location of occluded vessel, use of thrombolytics, use of a balloon-guided catheter, onset to arterial puncture time, the number of thrombectomy attempts (either with CA or SR), age, sex, hypertension, atrial fibrillation, and baseline infarct size (defined by Alberta Stroke Program Early Computed Tomography Score (ASPECTS)<6). We also employed GEE in our multivariate regression analysis to account for within-center correlations and to adjust for center-specific effects. This method ensured that our estimates remained consistent even when observations within clusters (centers) were correlated. All reported p-values were two-tailed, with statistical significance at $p<0.05$.

RESULTS

Study population

Among 15 844 patients who underwent EVT for AIS in STAR, 1885 were eligible for inclusion. Of these, 1188 patients underwent CA alone, while 696 had SR incorporated in the rescue attempts (online supplemental figure 2). Propensity score matching resulted in two well-balanced groups regarding major baseline and procedural characteristics (online supplemental figure 1 and table 1). The incorporation of SRs in rescue treatment was associated with significantly increased total thrombectomy attempts (median=3; IQR (3–4) vs median=3; IQR (2–4); p=0.01), longer procedure times until achieving successful reperfusion (median=38; IQR (24–63) vs median=26; IQR (15–43); p<0.001), and longer total procedural times (median=51; IQR (34–80) vs median=33; IQR (22–52); p<0.001) compared with rescue attempts using CA alone (table 1).

Outcomes in PSM cohorts

Incorporating SR in the rescue EVT after failed CA attempts resulted in significantly higher overall rates of successful recanalization compared with continued CA attempts (85.2% vs

Table 1 Baseline characteristics of patients between rescue treatment groups; continued contact aspiration alone versus incorporating stent retrievers in the rescue attempts after propensity score matching.

Baseline characteristics – Rescue technique: CA technique only versus SR			
	CA technique (N=696)	SR (N=696)	P-value
Female sex, n (%)	346 (49.7)	336 (48.3)	0.63
Age, median (IQR)	70 (61–81)	70 (60–79)	0.44
Race/ethnicity, n (%)			0.9
White	473 (68.0)	426 (61.2)	
Black	145 (20.8)	160 (23.0)	
Hispanic	54 (7.8)	65 (9.3)	
Other	24 (3.4)	45 (6.5)	
Diabetes, n (%)	200 (28.7)	192 (27.6)	0.68
Hypertension, n (%)	535 (76.9)	525 (75.4)	0.57
Atrial fibrillation, n (%)	242 (34.8)	245 (35.2)	0.91
Hyperlipidemia, n (%)	324 (46.6)	325 (46.7)	0.99
Congestive heart failure, n (%)	117 (16.8)	104 (14.9)	0.38
Prior stroke, n (%)	157 (22.6)	150 (21.6)	0.7
Smoking, n (%)			0.33
Never smoker	385 (55.3)	404 (58.1)	
Former smoker	150 (21.6)	137 (19.7)	
Current smoker	161 (23.1)	155 (22.3)	
Occluded vessel location, n (%)			0.11
ICA	240 (34.5)	196 (28.2)	
M1	299 (43.0)	329 (47.3)	
M2	157 (22.6)	171 (24.6)	
ASPECTS<6	82 (11.8)	80 (11.5)	0.93
ASPECTs, median (IQR)	8 (7–10)	8 (7–10)	0.85
Admission NIHSS score, median (IQR)	16 (10–21)	15 (10–20)	0.54
Intravenous thrombolysis n (%)	235 (33.8)	237 (34.1)	0.71
Intra-arterial thrombolysis n (%)	81 (11.8)	60 (9.2)	0.13
Transradial approach, n (%)	26 (4.7)	29 (5.4)	0.75
Intracranial angioplasty and or stenting	56 (8.0)	59 (8.5)	0.85
Balloon guide catheter	72 (10.7)	74 (10.9)	0.93
Time from onset to arterial puncture (min), median (IQR)	327 (204–496)	325 (213–583)	0.4
Total thrombectomy attempts, median (IQR)	3 (2–4)	3 (3–4)	0.01
CA technique attempts, median (IQR)	3 (2–4)	2 (1–2)	0.21
Procedure time until successful recanalization (min), median (IQR)	26 (15–43)	38 (24–63)	<0.001
Total procedure time (min), median (IQR)	33 (22–52)	51 (34–80)	<0.001

ASPECTS, Alberta Stroke Program Early Computed Tomography Score; CA, contact aspiration; ICA, internal carotid artery; IQR, interquartile range; NIHSS, National Institutes of Health Stroke Scale; PSM, propensity score matching; SR, stent retriever.

80.6%; p=0.03), as well as successful recanalization after the second pass (31.2% vs 23.4%; p<0.001) (table 2). Additionally, the use of SRs increased the rates of favorable 90-day outcomes, measured by an mRS score of 0–2 (35.2% vs 29.9%; p=0.04) (table 2). No significant differences were seen in safety outcomes, including ICH, sICH, and mortality rates (table 2).

Table 2 Outcomes comparison between rescue treatment groups; continued contact aspiration alone versus incorporating stent retrievers in the rescue attempts after propensity score matching.

Outcomes – Rescue technique: CA technique only versus with SR				
	CA technique (N=696)	SR (N=696)	P value	OR (95% CI)
Successful recanalization in two attempts	163 (23.4)	217 (31.2)	<0.001	1.47 (1.16 to 1.88)
mTICI 2B or higher	561 (80.6)	593 (85.2)	0.03	1.13 (0.94 to 1.35)
mTICI 2C or higher	310 (44.5)	339 (48.7)	0.13	1.18 (0.98 to 1.41)
Any ICH	206 (31.6)	212 (31.6)	0.99	1.00 (0.85 to 1.17)
sICH	49 (7.7)	53 (8.0)	0.92	1.04 (0.71 to 1.52)
90-day mRS 0–3	308 (44.3)	336 (48.3)	0.15	1.18 [0.98 to 1.42)
90-day mRS 0–2	208 (29.9)	245 (35.2)	0.04	1.27 [1.04 to 1.55)
90-day mortality	208 (29.9)	177 (25.4)	0.07	0.83 [0.69 to 0.99)

CA, contact aspiration; CI, confidence interval; ICH, intracranial hemorrhage; mRS, modified Rankin Scale score; mTICI, modified Thrombolysis in Cerebral Infarction score; OR, odds ratio; PSM, propensity score matching; sICH, symptomatic intracranial hemorrhage; SR, stent retriever.

Outcomes by SR type

A comparison of subgroups was conducted among different SR types: Solitaire (Medtronic) (n=245), Trevo (Stryker) (n=159), EmboTrap (Cerenovus, Irvine, CA, USA) (n=46 cases), and other subtypes (n=246) (table 3 and online supplemental table 1). Univariate analysis revealed significant differences in baseline characteristics, including prior stroke incidence (p=0.02) and occluded vessel type (p<0.001), as well as procedural factors such as using thrombolytics and balloon-guided catheters, time from onset to arterial access (p=0.002), and number of EVT attempts (p<0.001) (table 3).

After adjusting for these subgroup differences using pairwise multivariate regression analysis, Trevo SRs were associated with higher odds of achieving successful recanalization (adjusted OR (aOR)=1.9; 95% CI=1.12–3.34; p=0.02) and successful recanalization within two attempts of EVT (aOR=1.7; 95% CI=1.13–2.61; p=0.01), with a reduced risk of sICH (aOR=0.3; 95% CI=0.07–0.84; p=0.02) (figure 1). EmboTrap SRs were associated with higher odds of 90-day mortality (aOR=2.6; 95% CI=1.36–5.09; p=0.004) and sICH (aOR=2.9; 95% CI=1.07–7.86; p=0.04), and lower odds of achieving successful recanalization (aOR=0.5; 95% CI=0.22–0.93; p=0.03) (figure 1). All results are reported after implementing GEE accounting for between-center differences.

DISCUSSION

This study contributes insights into using SRs as a rescue strategy after failed attempts with CA during EVT. Incorporating SR in the rescue strategy after CA failure improves successful recanalization rates and 90-day functional outcomes with no increase in complications. Univariate and multivariate regression analysis comparing different SRs supported the superiority of Trevo SRs, which were associated with higher odds of achieving successful recanalization, higher odds of achieving recanalization during the second pass (early technique switching), and lower odds of sICH. Additionally, our results suggest that EmboTrap SRs are associated with lower odds of recanalization, higher odds

Table 3 Baseline characteristics and outcome comparisons of patients between subtypes of stent retriever incorporated in rescue treatment.

Characteristics and outcomes	Solitaire (N=245)	Trevo (N=159)	EmboTrap (N=46)	Other SR types (N=246)	P value
Female sex, n (%)	113 (46.1)	73 (45.9)	26 (56.5)	124 (50.4)	0.47
Age, median (IQR)	69.5 (60.0–78.0)	70.0 (59.3–78.0)	72.5 (61.8–82.0)	70.0 (59.0–79.0)	0.47
Race/ethnicity, n (%)					0.27
White	132 (53.9)	103 (64.8)	37 (80.4)	154 (62.6)	
Black	71 (29.0)	29 (18.2)	2 (4.3)	58 (23.6)	
Hispanic	23 (9.4)	11 (6.9)	4 (8.7)	7 (2.8)	
Other	19 (7.8)	16 (10.1)	3 (6.5)	27 (11.0)	
Hypertension	192 (78.4)	116 (73.0)	32 (69.6)	185 (75.2)	0.47
Diabetes, n (%)	71 (29.0)	43 (27.0)	12 (26.1)	66 (26.8)	0.94
Atrial fibrillation, n (%)	78 (31.8)	59 (37.1)	16 (34.8)	92 (37.4)	0.57
Hyperlipidemia, n (%)	117 (47.8)	81 (50.9)	16 (34.8)	111 (45.1)	0.24
Congestive heart failure, n (%)	45 (18.4)	23 (14.5)	4 (8.7)	32 (13.0)	0.21
Prior stroke, n (%)	68 (27.8)	30 (18.9)	11 (23.9)	41 (16.7)	0.02
Smoking, n (%)					0.11
Never smoker	128 (52.2)	96 (60.4)	29 (63.1)	151 (61.4)	
Former smoker	55 (22.4)	35 (22.0)	4 (8.7)	43 (17.5)	
Current smoker	62 (25.3)	28 (17.6)	13 (28.3)	52 (21.1)	
Occluded vessel location, n (%)					<0.001
ICA	66 (26.9)	28 (17.6)	12 (26.1)	90 (36.6)	
M1	112 (45.7)	78 (49.1)	28 (60.9)	111 (45.1)	
M2	67 (27.3)	53 (33.3)	6 (13.0)	45 (18.3)	
ASPECTS<6	35 (14.3)	17 (10.7)	4 (8.7)	24 (9.8)	0.39
ASPECTS, median (IQR)	8 (7–10)	8 (7–9)	8 (6.25–9)	8 (7–10)	0.3
Admission NIHSS score, median (IQR)	16 (10–21.25)	14 (9.25–19)	16 (12–20.5)	16 (10–20)	0.12
Intravenous thrombolysis n (%)	67 (27.3)	56 (35.2)	19 (41.3)	95 (38.6)	0.04
Intra-arterial thrombolysis n (%)	18 (8.5)	10 (6.3)	1 (2.2)	31 (13.0)	0.03
Transradial approach, n (%)	20 (8.8)	4 (3.2)	0 (0)	5 (3.5)	0.02
Angioplasty or intracranial stenting	25 (10.2)	15 (9.4)	3 (6.5)	16 (6.5)	0.45
Balloon guide catheter	25 (10.5)	27 (17.0)	8 (17.4)	14 (6.0)	0.003
Time from onset to arterial puncture (min), median (IQR)	387 (234–595)	292 (195–507)	334 (231–729)	270 (186–450)	0.002
Total thrombectomy attempts, median (IQR)	3 (2–4)	3 (2–3)	3 (2–3)	4 (3–5)	<0.001
CA technique attempts, n (%)	2 (1–2)	1 (1–2)	1 (1–2)	2 (1–3)	<0.001
SR attempts, n (%)	1 (1–2)	1 (1–2)	1 (1–1.75)	1 (1–2)	0.5
Procedure time until successful recanalization (min), median (IQR)	36(26-59)	40 [20.5–63)	39.5 [26–60.5)	50(30-73)	0.002
Total procedure time (min), median (IQR)	50.5 [34–81.8)	50(32-84)	48 [33–71.5)	53 [37.5–79.5)	0.675
Successful recanalization in two attempts	66 (26.9)	51 (32.1)	14 (30.4)	32 (13.0)	<0.001
mTICI 2B or higher	202 (82.4)	139 (87.4)	32 (69.6)	188 (76.4)	0.009
mTICI 2C or higher	115 (46.9)	76 (47.8)	20 (43.5)	99 (40.2)	0.37
Any ICH	79 (32.2)	43 (27.0)	15 (32.6)	69 (28.0)	0.62
sICH	16 (6.5)	3 (1.9)	6 (13.0)	24 (9.8)	0.004
90-day mRS 0–3	105 (42.9)	85 (53.5)	17 (37.0)	101 (41.1)	0.04
90-day mRS 0–2	72 (29.4)	55 (34.6)	10 (21.7)	71 (28.9)	0.02
90-day mortality	68 (27.8)	37 (23.3)	22 (47.8)	81 (32.9)	0.009

ASPECTS, Alberta Stroke Program Early Computed Tomography Score; CA, contact aspiration; ICA, internal carotid artery; ICH, intracranial hemorrhage; IQR, interquartile range; mRS, modified Rankin Scale score; mTICI, modified Thrombolysis in Cerebral Infarction score; NIHSS, National Institutes of Health Stroke Scale; PSM, propensity score matching; sICH, symptomatic intracranial hemorrhage; SR, stent retriever.

of 90-day mortality, and higher odds of sICH, though these results should be interpreted with caution given the relatively low number of patients in this group.

Our results concur with findings reported in prior studies suggesting that switching to a different technique after a failed first attempt is superior to a second attempt using the same

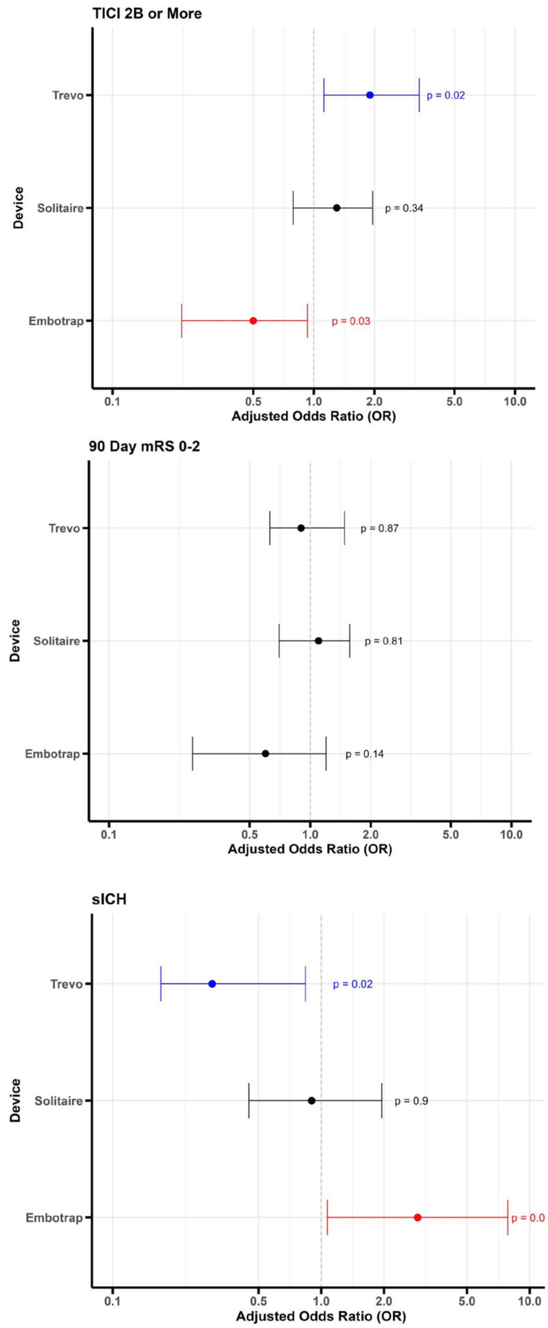

Figure 1 Multivariate logistic regression analysis for the impact of stent retriever type (Solitaire, Trevo, EmboTrap, or other types) on outcomes. Multivariate regression is adjusted for prior stroke, occluded vessel, use of thrombolysis, use of balloon guide catheter, onset to arterial puncture time, total number of attempts, age, sex, hypertension, atrial fibrillation, Alberta Stroke Program Early Computed Tomography Score (ASPECTS)<6, and clustering for centers. mRS, modified Rankin Scale score; sICH, symptomatic intracranial hemorrhage; TICI, Thrombolysis in Cerebral Infarction score.

technique.[4] This may be explained by the benefit of exposing the thrombus to different biomechanical forces, particularly if the initial force is insufficient to remove the thrombus.[4] It is important to note that while our analysis confirms the efficacy of incorporating SR in rescue attempts, it does not establish the optimal timing for such interventions. Our findings suggest a beneficial outcome from the inclusion of SR, but further studies are necessary to determine the best procedural stage for transitioning to SR to maximize patient outcomes. Another study on early switching techniques following failed passes of EVT found that switching from an SR to CA did not impact the odds of recanalization, whereas switching from an SR to a combined technique, CA to a combined technique, and CA to an SR were all associated with higher odds of recanalization.[15]

A prior retrospective study compared Trevo SRs to Solitaire SRs in 200 patients and found that Trevo SRs had a higher recanalization rate and shorter procedure time than Solitaire SRs, but found no significant differences in clinical outcomes.[16] A prior meta-analysis of 972 patients failed to find statistically significant differences between Trevo and Solitaire SRs in recanalization rate, functional outcomes, 90-day mortality, and sICH.[9] This is in contrast to another systematic review and meta-analysis, including 51 studies that compared EmboTrap, Solitaire, and Trevo SRs, and found that EmboTrap SRs were associated with a significantly higher proportion of patients achieving good functional outcomes (mRS 0–2) at 90 days compared with Solitaire and Trevo SRs, and higher rates of sICH and 90-day mortality with Solitaire SRs compared with Trevo and EmboTrap SRs.[17] Of note, these studies involved the first pass of EVT, which differs from our analysis, as we focused on rescue attempts after a failed CA technique attempt(s).

To our knowledge, no studies have compared the efficacy and safety of SRs as a rescue strategy after a CA. This is significant because the decision regarding subsequent technique can present unique challenges and may highlight variations in device efficacy. Failure of the technique may reflect that the thrombus is more compact and prosperous in fibrin or platelets than red blood cell (RBC)-rich thrombi.[18] Additionally, the structure of the thrombus may change between passes, as the first pass can compress or fragment the thrombus, which makes subsequent extraction more challenging.[18–20] Different SRs may vary in their ability to extract thrombi with these characteristics. Each SR device has unique designs and biomechanical properties, which may influence their effectiveness in various procedural contexts.

From a safety perspective, each additional pass increases the risk of vascular damage, and differences between SRs in safety may become more apparent during or after the subsequent pass. Notably, a prior study in a rabbit model of thrombectomy comparing Solitaire FR SR to Trevo XP ProVue SR concluded that Trevo SR induced less vascular damage than Solitaire SR.[18]

Because prior data have suggested that switching to an alternative device after a failed first pass is advantageous, examining the safety and efficacy of various SRs when used as a rescue strategy is important.[15]

Solitaire, EmboTrap, and Trevo were the three most common SRs used in our sample and, as such, they were the focus of this study. However, because our analysis included a large period over which SRs were iteratively developed, previous versions of SRs were included (in the 'other' category). Solitaire FR was the most commonly used SR in our sample, followed by Trevo XP ProVue and NXT, and, lastly, EmboTrap.

Our data suggest that SRs are superior to CA after a failed CA during EVT, showing higher odds of recanalization and improved outcomes. A predictor of successful recanalization during EVT is thrombus composition.[18 19] Thrombi vary based on their relative composition of fibrin, RBCs, platelets, and other minor endothelial components.[18] RBC-rich thrombi are the easiest to retrieve, with low frictional coefficients and higher conformability.[20] Fibrin-rich thrombi are more likely to require multiple passes before extraction during EVT.[19] In vitro data have shown that the coefficient of friction of fibrin-rich thrombi is three-fold higher than that of RBC-rich thrombi.[21] A prior meta-analysis suggested that SRs are more efficacious than CA for fibrin-rich thrombi, as high frictional resistance makes CA challenging.[22]

Because CA is a faster and more cost-effective technique, it is often employed for the first pass; if unsuccessful, it is common to convert to an SR as a backup strategy.[22] CA relies on generating a negative pressure force that must be sufficient to overcome the frictional coefficient of the thrombus, adhesive forces linking the thrombus to the vessel wall, and force of residual blood flow.[23] Conversely, SRs use radial force whereby the struts of the SR expand outward to deform the thrombus and embed the struts of the SR into the thrombus.[24] The radial force must be sufficient to embed the struts into the thrombus but not too high to compress or fragment the thrombus, which can lead to embolization.[25] As the SR is retracted, a force is applied by the operator to move the thrombus toward the guide catheter. Thus, SRs must generate sufficient radial and applied forces to overcome the frictional coefficient, adhesive forces, and the force of residual blood flow.[24]

Our data suggest that 90-day functional outcomes are more favorable when switching to an SR after a failed CA. This is understandable, as achieving successful recanalization is associated with better functional outcomes, and we observed higher rates of overall and second-pass successful recanalization with SRs. Conversely, longer procedure duration is associated with worse functional outcomes.[2 5] Interestingly, procedure duration was significantly longer when an SR was incorporated into the rescue technique. Despite increasing procedure duration, functional outcomes were better when an SR was used for the second pass instead of CA.

The fact that SRs involve the creation of a channel for central flow while they are being deployed may play a role in the improved functional outcomes that we observed, even in the setting of increased total procedure duration.[24] SRs are deployed for several minutes before retrieval to facilitate thrombus integration, and 30–50% of blood flow can be restored through the central channel created by the expanding SR during this time.[24] The early restoration of partial blood flow may confer a functional benefit to patients, although this remains to be studied.

While SRs appear to improve functional outcomes by facilitating recanalization and restoring blood flow, their mechanical interaction with the vasculature draws attention to the importance of minimizing vascular damage. Frictional resistance during SR retrieval can potentially cause mechanical damage to the vasculature and may influence complication rates.[26] A prior in vitro study compared the frictional resistance forces of various SRs and found that Trevo XP SRs had an initial retrieval force (IRF) of 0.09 ± 0.04 N and a maximal retrieval force (MRF) of 0.36 ± 0.07 N. In comparison, Solitaire 2 SRs had an IRF of 0.25 ± 0.07 N and MRF of 0.54 ± 0.06 N.[26] Solitaire SRs have more rigid struts, which may contribute to higher frictional forces than Trevo SRs (the EmboTrap SR was not included in this study).[26] Our results suggest that Trevo SRs are associated with lower odds of sICH than other SRs, possibly due to the sodium hyaluronate hydrophilic coating designed to reduce friction during deployment.[27]

Limitations

This study's results should be interpreted cautiously due to several limitations. First, the decision to switch from CA to SR rescue was not randomized, introducing potential selection bias influenced by operator preference or institutional protocols rather than standardized criteria. This variability, combined with the study's multicenter design, likely introduced differences in procedural approaches that could affect outcomes and complicate comparisons. Additionally, differences in CA and SR techniques, subtypes, devices' generations, and sizes were not fully captured, limiting the understanding of device properties on outcomes as these granularities in outcomes reporting are usually limited in retrospective, large registry studies. We addressed the possible effects of intravenous and intra-arterial thrombolysis by employing PSM and multivariate regression analysis. However, the impacts of different thrombolytic regimens remain critical for exploration, especially in cases involving multiple attempts or the need for rescue treatment.[28] A limitation of our study is the potential influence of outliers and center-specific practices, as certain centers may predominantly use specific devices, potentially confounding the observed association between device type and outcomes. This was partially addressed through multivariate regression with clustering against centers.

Additionally, self-adjudicating and non-blinded radiological and functional variables (ASPECTS, mTICI, mRS) at each site may introduce assessment bias. While the sample size was substantial, it may still be underpowered to detect subtle differences across SR subtypes, indicating the need for future studies with standardized protocols. Our study spanned from 2013 to 2024, during which time large-bore catheters and stroke intervention techniques, including the CA technique, have evolved significantly. The CA technique has become more efficient, especially with newer catheters.[29] Although patients in the early phase of our study may not have had access to the latest catheter models, all patients were treated with the most advanced technology available at the time, ensuring that any differences would be uniformly distributed across the CA cohort. Thus, this should not have a significant impact on the overall results of our study.

CONCLUSIONS

After a failed EVT attempt(s) using CA, switching to an SR improved functional outcomes and successful reperfusion compared with repeat CA attempts. The Trevo SRs may be superior to other SR devices in successful reperfusion and with lower rates of sICH.

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Ethics approval This study involves human participants but HCA Houston Healthcare Kingwood Institutional Review Board has determined this retrospective research activity to be exempt or excluded from Institutional Review Board (IRB) oversight in accordance with current regulations and institutional policy. The internal reference number for this determination is 2022-398. There was no direct patient contact in performing this study. In addition, the authors' patients signed a data usage form at registration related to data collection and utilization of their data for research. The research was overseen in the authors' research protocol submitted for IRB review and the research committee that holds monthly ethics reviews exempted this study. Participants gave informed consent to participate in the study before taking part.

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REFERENCES

1 Powers WJ, Rabinstein AA, Ackerson T, *et al*. Guidelines for the Early Management of Patients With Acute Ischemic Stroke: 2019 Update to the 2018 Guidelines for the Early Management of Acute Ischemic Stroke: A Guideline for Healthcare Professionals From the American Heart Association/American Stroke Association. *Stroke* 2019;50:e344–418.
2 Powers WJ, Rabinstein AA, Ackerson T, *et al*. 2018 Guidelines for the Early Management of Patients With Acute Ischemic Stroke: A Guideline for Healthcare Professionals From the American Heart Association/American Stroke Association. *Stroke* 2018;49:e46–110.
3 Jankowitz B, Grandhi R, Horev A, *et al*. Primary manual aspiration thrombectomy (MAT) for acute ischemic stroke: safety, feasibility and outcomes in 112 consecutive patients. *J Neurointerv Surg* 2015;7:27–31.
4 Matsukawa H, Matouk C, Uchida K, *et al*. Improved technical outcomes with converting thrombectomy techniques after failed first pass recanalization. *J Neurointerv Surg* 2024.
5 Tekle WG, Hassan AE, Jadhav AP, *et al*. Impact of Periprocedural and Technical Factors and Patient Characteristics on Revascularization and Outcome in the DAWN Trial. *Stroke* 2020;51:247–53.
6 Hassan AE, Shariff U, Saver JL, *et al*. Impact of procedural time on clinical and angiographic outcomes in patients with acute ischemic stroke receiving endovascular treatment. *J Neurointerv Surg* 2019;11:984–8.
7 Liang CW, Toor HJ, Duran Martinez E, *et al*. First Pass Recanalization Rates of Solitaire vs Trevo vs Primary Aspiration: The Kaiser Southern California Experience. *Perm J* 2020;25:1–3.
8 Dippel DW, Majoie CB, Roos YB, *et al*. Influence of Device Choice on the Effect of Intra-Arterial Treatment for Acute Ischemic Stroke in MR CLEAN (Multicenter Randomized Clinical Trial of Endovascular Treatment for Acute Ischemic Stroke in the Netherlands). *Stroke* 2016;47:2574–81.
9 Grech R, Pullicino R, Thornton J, *et al*. An efficacy and safety comparison between different stentriever designs in acute ischaemic stroke: a systematic review and meta-analysis. *Clin Radiol* 2016;71:48–57.
10 Baek JW, Heo YJ, Kim ST, *et al*. Comparison of the Solitaire and Trevo Stents for Endovascular Treatment of Acute Ischemic Stroke: A Single.Center Experience. *Neurol India* 2021;69:378–82.
11 von Elm E, Altman DG, Egger M, *et al*. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. *J Clin Epidemiol* 2008;61:344–9.
12 Spiotta AM. Letter: Twinkle, Twinkle Little STAR, How I Wonder What You Are: The Case for High-Quality, Large-Scale, 'Real-World' Databases. *Neurosurg* 2020;87:E271–2.
13 Hacke W, Kaste M, Fieschi C. Intravenous Thrombolysis With Recombinant Tissue Plasminogen Activator for Acute Hemispheric Stroke. *JAMA* 1995;274:1017.
14 Ghozy S, Kacimi SEO, Azzam AY, *et al*. Successful mechanical thrombectomy in acute ischemic stroke: revascularization grade and functional independence. *J Neurointerv Surg* 2022;14:779–82.
15 Martins PN, Nogueira RG, Tarek MA, *et al*. Early technique switch following failed passes during mechanical thrombectomy for ischemic stroke: should the approach change and when? *J Neurointerv Surg* 2024.
16 Yi HJ, Lee DH, Kim SU. Effectiveness of Trevo stent retriever in acute ischemic stroke: Comparison with Solitaire stent. *Medicine (Baltimore)* 2018;97:e10747.
17 Zaidat OO, Ikeme S, Sheth SA, *et al*. MASTRO I: Meta-Analysis and Systematic Review of thrombectomy stent retriever outcomes: comparing functional, safety and recanalization outcomes between EmboTrap, Solitaire and Trevo in acute ischemic stroke. *J Comp Eff Res* 2023;12:e230001.
18 Arai D, Ishii A, Chihara H, *et al*. Histological examination of vascular damage caused by stent retriever thrombectomy devices. *J Neurointerv Surg* 2016;8:992–5.
19 Delvoye F, Di Meglio L, Consoli A, *et al*. High thrombus platelet content is associated with a lower rate of first pass effect in stroke treated by endovascular therapy. *Eur Stroke J* 2022;7:376–83.
20 Ye G, Cao R, Lu J, *et al*. Association Between Thrombus Density and Reperfusion Outcomes Using Different Thrombectomy Strategies: A Single-Center Study and Meta-Analysis. *Front Neurol* 2019;10:843.
21 Gunning GM, McArdle K, Mirza M, *et al*. Clot friction variation with fibrin content; implications for resistance to thrombectomy. *J Neurointerv Surg* 2018;10:34–8.
22 Bhambri A, Adapa AR, Liu Y, *et al*. Thrombus Histology as It Relates to Mechanical Thrombectomy: A Meta-Analysis and Systematic Review. *Neurosurgery* 2021;89:1122–31.
23 Boisseau W, Escalard S, Fahed R, *et al*. Direct aspiration stroke thrombectomy: a comprehensive review. *J Neurointerv Surg* 2020;12:1099–106.
24 Kühn AL, Vardar Z, Kraitem A, *et al*. Biomechanics and hemodynamics of stent-retrievers. *J Cereb Blood Flow Metab* 2020;40:2350–65.
25 Abbasi M, Arturo Larco J, Mereuta MO, *et al*. Diverse thrombus composition in thrombectomy stroke patients with longer time to recanalization. *Thromb Res* 2022;209:99–104.

26 Kwak Y, Son W, Kim B-J, *et al*. Frictional force analysis of stent retriever devices using a realistic vascular model: Pilot study. *Front Neurol* 2022;13:964354.
27 Ahmed SU, Chen X, Peeling L, *et al*. Stentrievers : An engineering review. *Interv Neuroradiol* 2023;29:125–33.
28 Elawady SS, Kasem RA, Matsukawa H, *et al*. The effect of intravenous thrombolysis in stroke patients with unsuccessful thrombectomy. *Interv Neuroradiol* 2024;12.
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