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Comparison of Mechanical Thrombectomy with Contact Aspiration, Stent Retriever, and Combined Procedures in Patients with Large-Vessel Occlusion in Acute Ischemic Stroke

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Background: We investigated the properties and effects of 5 mechanical thrombectomy procedures in patients with acute ischemic stroke. The relationships between the type of procedure, the time required, the success of recanalization, and the clinical outcome were analyzed.

Material/Methods: This prospective comparative analysis included 500 patients with acute ischemic stroke and large-vessel occlusion. We compared contact aspiration thrombectomy (ADAPT, n=100), stent retriever first line (SRFL, n=196), the Solubra technique (n=64), mechanical thrombectomy plus stent implantation (n=81), and a combined procedure (n=59).




Results: ADAPT provided shorter procedure ($P<0.001$) and recanalization times ($P<0.001$) than the other techniques. Better clinical outcome was achieved for ischemia in the anterior circulation than ischemia in the posterior fossa ($P<0.001$). Compared to the other techniques, patients treated with ADAPT procedure had increased odds of achieving better mTICI scores ($P=0.002$) and clinical outcome (NIHSS) after 7 days ($P=0.003$); patients treated with SRFL had increased odds of achieving better long-term clinical status (3M-mRS=0–2; $P=0.040$). Patients with SRFL and intravenous thrombolysis (IVT) had increased odds of better clinical status (3M-mRS=0–2; $P=0.031$) and decreased odds of death ($P=0.005$) compared to patients with SRFL without IVT. The other treatment approaches had no additional effect of IVT. Patients with SRFL with a mothership transfer had increased odds of achieving favorable clinical outcome (3M-mRS) compared to SRFL with the drip-and-ship transfer paradigm ($P=0.015$).

Conclusions: Our results showed that ADAPT and SRFL provided significantly better outcomes compared to the other examined techniques. A mothership transfer and IVT administration contributed to the success of the SRFL approach.

MeSH Keywords: **Stroke • Thrombectomy • Thrombolytic Therapy**

Abbreviations: **ADAPT** – a direct aspiration first-pass technique; **A2-ACA** – A2 segment of anterior cerebral artery; **CP** – combined procedure; **CT** – computed tomography; **DSA** – digital subtraction angiography; **ICH** – intracerebral hemorrhage; **IQR** – interquartile range; **IVT** – intravenous thrombolysis; **LVO** – large-vessel occlusion; **M2-MCA** – M2 segment of middle cerebral artery; **MT** – mechanical thrombectomy; **mTICI** – modified thrombolysis in cerebral infarction; **MRI** – magnetic resonance imaging; **3M-mRS** – 3-month modified Rankin Scale; **NIHSS** – National Institutes of Health Stroke Scale; **P2-PCA** – P2 segment of posterior cerebral artery; **SAH** – subarachnoid hemorrhage; **SRFL** – stent retriever first line

Full-text PDF: <https://www.medscimonit.com/abstract/index/idArt/913458>

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Background

The beginnings of mechanical thrombectomy can be traced to 1998, when the Amplatz Goose Neck extraction loop was first used to extract a thrombus from the brain. This technique was successfully used in Gothenburg [1]. Since then, other devices were developed, including the Neuronet (Mayer 2002), the InTime, and the EnSnare. A breakthrough was made with the helical loop „corkscrew“ (Concentric Medical Mountain View, CA). In the MERCI trial, the extractor was used together with a balloon-occlusive guiding catheter [2,3]. The first stent retriever was the Solitaire (EV3; then Medtronic Neurovascular, Irvine, CA). In 2012, comparative studies were conducted to compare the MERCI to the Solitaire (SWIFT trial) [4] and Trevo (TREVO II study) stent retrievers [5].

In March 2013, 3 randomized trials were published, and none showed that endovascular treatments provided any benefit over standard therapy, including intravenous thrombolysis (IVT). In the MR RESCUE trial, the MERCI Retriever and Penumbra System were tested and compared to standard treatment [6]. In the IMS-III trial, patients were treated with IVT and randomized into the following 2 groups within 3 h: in the first group, IVT was followed by a subsequent mechanical thrombectomy; in the second group, IVT was not followed by endovascular treatment [7]. In the SYNTHESIS trial, patients were treated with IVT alone or IVT followed by intra-arterial thrombolysis, mechanical thrombus disruption, or thrombus retrieval within the therapeutic window of 4.5 h [8].

Five new randomized trials published in 2015 successfully showed the benefit of endovascular treatment: (1) The MR CLEAN – Multicenter Randomized Trial of Endovascular Treatment for Acute Ischemic Stroke in the Netherlands was published in January 2015. The study included 500 patients, and convincingly demonstrated superiority of mechanical thrombectomy by stent retriever together with standard treatment (89% IVT) compared with standard treatment (90% IVT alone) [9]. (2) The ESCAPE trial, which was focused on proximal occlusion of the arteries in the anterior circulation within the therapeutic window of 12 h from the onset of symptoms. They compared IVT followed by endovascular treatment versus a standard IVT treatment [10]. (3) The Solitaire Retriever Study (SWIFT-PRIME) was conducted in 39 centers in the USA and Europe, and it included 196 patients [11]. (4) The EXTEND-IA study was conducted in Australia and New Zealand and they tested whether better imaging technologies, new intervention products, and earlier interventional performance could improve clinical results [12]. (5) The REVASCAT trial was a randomized study that included 206 patients, performed in Catalonia, Spain [13]. These 5 studies changed the approach to acute ischemic stroke and led to the ESO-ESMINT-ESNR-EAN consensus statement, published in 2016 [14].

Blood clot aspiration was originally performed in lower limbs peripheral arterial interventions and manual aspiration was applied. Briefly, 4–8 F aspiration catheters were inserted close to the thrombus; then, the thrombus was simply sucked out by applying vacuum manually with a syringe [15]. In 2009, Penumbra Systems (Alameda, CA, USA) launched aspiration catheters for use in the brain. The first results, presented in 2009 in The Penumbra Pivotal Stroke Trial, showed successful revascularization, with high thrombolysis in myocardial infarction – TIMI score (2–3), in 82% of patients, a low modified Rankin Scale – mRS (0–2) in 25% of patients, and 33% mortality [16]. Later results were more encouraging, with a low mRS (0–2) in 43% of patients [17].

Later, 2 techniques were introduced: the forced aspiration suction thrombectomy (FAST) in 2011, and a direct aspiration first-pass technique (ADAPT) in 2014 [18,19]. These catheters had a smaller lumen than those of the later Penumbra catheters (5MAX and 3MAX) and the aspiration was performed by hand with a syringe. The use of occlusive balloon guiding catheters was demonstrated in the SWIFT and SWIFT-PRIME studies, where extractions were performed with larger stent retrievers. Their benefit was that fragmentation and distal embolization of the aspirated thrombus was inhibited when blocking the flow through the internal throat of the guiding catheter. The ADAPT technique uses a rapid, distal approach and newer catheters (ACE64 or ACE68) with a larger internal lumen. The aspiration is performed with a dedicated vacuum pump that provides continuous suction. A 3MAX aspiration catheter is often used for distal access to the M2-MCA, A2-ACA, and P2-PCA branches. Various aspiration catheters with various internal lumen parameters are currently available for use in aspiration techniques [20].

Currently, a combined technique is increasingly being used because it has the advantages of both the FAST and ADAPT techniques. The combination is based on the use of a large internal diameter aspiration catheter (Penumbra ACE64, ACE68) and stent retrievers, like Solitaire FR, pREset, Catch, and Tiger triever. Concurrent aspirations during thrombus extraction can reduce fragmentation and distal embolization during mechanical thrombectomy [21,22]. In September 2016, the results of the THERAPE study were published [23], which evaluated the Penumbra aspiration system combined with IVT compared to IVT administration alone in the control group. The ASTER study recently presented results on their comparison between the primary use of aspiration versus a stent retriever [24,25].

The present study investigated the properties and effects of these 5 types of mechanical thrombectomy procedures in patients with acute ischemic stroke. The relationships between the type of procedure, the time required for the procedure, the success of recanalization, and the clinical outcome were analyzed.

Material and Methods

Study population and data collection

This prospective study included 500 patients with acute ischemic stroke and large-vessel occlusion (LVO) who were treated with contact aspiration technique (ADAPT) or first-pass stent retriever (SRFL) or aspiration plus extraction technique (Solombra) or combined procedure (CP) with mechanical thrombectomy plus angioplasty and/or stenting. We performed a comparative study on the efficacy and safety of these techniques. We recorded the times from the onset of stroke to the hospital arrival (onset-to-door), from onset to the insertion of the needle for IVT (onset-to-needle), from the hospital door to the angiography suite arrival (door-to-DSA), and from the onset of stroke to recanalization of the target blood vessel (onset-to-recanalization).

Early ischemic changes and collateral circulation were assessed with the e-Alberta stroke program for early computed tomography (CT) ischemic score (e-ASPECTS) and with computed tomography angiography (CTA) localization of the LVO. We also recorded data from the neurointerventional procedure (modified thrombolysis in cerebral infarction score [mTICI], type of procedure, and procedure duration). Neurological clinical status was evaluated with the National Institutes of Health Stroke Scale score (NIHSS) obtained at patient admission, after 24 h, and on day 7, and with the modified Rankin Scale after 3 months (3M-mRS). Outcome safety data included symptomatic or non-symptomatic intracerebral hemorrhage (ICH) and death (3M-mRS=6). Safety outcomes were compared among the examined treatment methods.

Eligibility criteria

Inclusion criteria

1. Age 18 and older (i.e., patients must have had their 18th birthday).
2. NIHSS ≥ 8 at the time of neuroimaging.
3. Presented symptoms or symptoms persisted within 6 h of obtaining a groin puncture.
4. Neuroimaging demonstrated an LVO.
5. Stroke appropriately treated with the ADAPT approach or conventional first-line stent retriever approach or combined procedure.
6. Pre-event mRS score=0–1.
7. CT/CTA eligibility confirmed.

Exclusion criteria

1. Patient admission later than 6 h from symptom onset.
2. NIHSS < 4 at the time of neuroimaging.

3. Absence of LVO on non-invasive imaging.
4. Presence of an existing or pre-existing large-territory infarction.
5. Chronic LVO in the symptomatic territory.
6. Excessive vascular access tortuosity that was likely to result in unstable access platform.
7. Severe contrast allergy or absolute contraindication to iodinated contrast.
8. Head CT or MRI scan exclusion criteria:
 - Subarachnoid hemorrhage (SAH), intracerebral hemorrhage (ICH),
 - High-density lesion consistent with hemorrhage of any degree,
 - Significant mass effect with midline shift, core infarct lesion volume > 50 cc,
 - Large ($> 1/3$ of the middle cerebral artery) regions of clear hypodensity on the baseline CT scan or e-ASPECTS < 5 ,
 - Sulcal effacement and/or loss of grey-white differentiation alone were not taken as contraindications for treatment.

Interventions

Patients with acute ischemic stroke were treated according to the ESO-EAN-ESMINT recommendations for the LVO [14]. Patients eligible for IVT received it, according to the guidelines, after exclusion of ICH. After the LVO confirmation, patients were transported from the primary stroke center (with the drip-and-ship paradigm) either to the neurointerventional department for an acute revascularization procedure, or directly to the mother-ship comprehensive stroke center. Mechanical thrombectomies that were performed with a stent retriever, Penumbra aspiration device, or a combined technique were conducted at the University Hospital Ostrava, Interventional Neuroradiology and Angiology Department. A GE-Innova IGS 630 biplane system (GE Healthcare, Buc, France) was used to image the 3D-XRA angiography reconstructions during and after the stroke procedure. The type of anesthesia used was recorded during the procedure (e.g., local anesthesia, intravenous analgo-sedation with a laryngeal mask, or general anesthesia). Brain vessels were accessed with a Flexor 6–7 F/90 cm guiding sheath (Cook Medical, Bjaeverskov, Denmark) or Terumo Destination guiding catheter (Terumo Medical Corp., Elkton, MD, USA). Large-vessel occlusions (LVOs) were recanalized with the ADAPT first-pass technique using the Prowler Select Plus microcatheter (Codman & Shurtleff, Inc., Raynham, MA) over several types of 0.014" microwires. The aspiration catheter was pushed into direct contact with the thrombus. For the contact aspiration technique, we used ACE64, ACE68, and 3MAX Penumbra aspiration systems (Penumbra, Inc., Alameda, CA) with the original suction pump. When the ADAPT technique failed due to complex tortuosity or atherosclerosis in the brain supplying vessel, a stent retriever was used as the rescue technique. For the SRFL mechanical thrombectomy, we used a pREset thrombectomy

Table 1. Patient demographics and medical history. Demographics and medical history of patients with large-vessel occlusion in acute ischemic stroke that were treated with different mechanical thrombectomy techniques.

Variable	ADAPT (n=100)	SRFL (n=196)	Solumbra (n=64)	MT+stent (n=81)	CP (n=59)
Gender (Female)	47 (47)	106 (54)	30 (47)	32 (40)	16 (27)
Hypertension	82 (82)	157 (80)	53 (85)	58 (72)	48 (83)
Diabetes mellitus	24 (24)	39 (20)	10 (16)	12 (15)	16 (28)
Arrhythmia	62 (62)	107 (55)	39 (62)	27 (33)	10 (18)
Hyperlipidemia	58 (58)	75 (38)	32 (50)	25 (31)	27 (46)
IVT (yes)	74 (74)	131 (67)	50 (78)	53 (65)	41 (70)
(yes, Mothership)	58 (58)	70 (36)	37 (58)	30 (37)	24 (41)
(yes, Drip-and-ship)	16 (16)	61 (31)	13 (20)	23 (28)	17 (29)
Antithrombotics (yes)	52 (52)	85 (43)	33 (52)	26 (32)	18 (30)
Anesthesia (analgo-sedation)	35 (35)	44 (22)	22 (34)	13 (16)	9 (15)
(general)	53 (53)	93 (47)	33 (52)	42 (52)	42 (71)
mTICI (2–3)	98 (98)	170 (87)	56 (88)	72 (89)	51 (86)
3M-mRS (0–2)	44 (44)	87 (44)	16 (25)	27 (33)	15 (25)
Mortality	21 (21)	40 (21)	13 (20)	14 (17)	14 (24)

Values represent the absolute frequency and relative frequency (%), in parentheses.

device (Phenox GmbH, Bochum, Germany), Catch retriever (Balt Extrusion, Montmorency, France), or Solitaire stent retriever (Medtronic, Dublin, Ireland). When necessary, a combination of procedures was used, with either extracranial or intracranial stent implantation and extracranial or intracranial angioplasty, in cases of tight residual stenosis.

Statistical analyses

Numerical variables are described with the median and interquartile range (IQR). Graphical representations (with boxplots) were used to explore the structure of selected variables and to facilitate comparisons among several groups of interest. The Kruskal-Wallis test was used to identify significant differences among the examined groups. We analyzed the relationship between 2 categorical variables with contingency tables, 100% stacked bar charts, and the chi-square test of independence. Finally, we used the odds ratio (OR) to evaluate the association between the presence of a risk factor and the outcome. All statistical analyses were performed with maximum available data.

Results

The cohort comprised 500 patients, including 269 men (54%) and 231 women (46%), with a median age of 69 years (IQR:

61–75 years), with LVO and acute ischemic stroke symptoms. All patients underwent a mechanical thrombectomy with one of the following techniques: aspiration thrombectomy, first line procedures, with a Penumbra device (ADAPT, 100 patients); stent retriever, first-line procedures (SRFL, 196 patients); Solumbra technique (64 patients); mechanical thrombectomy and stent implantation (MT + stent, 81 patients); or a combined procedure (CP, 59 patients).

The degree of stroke-related disability/dependence, based on the 3M-mRS, was not significantly different between sexes ($P=0.693$). However, on average, 3M-mRS scores indicated that better clinical outcome was achieved by significantly younger patients ($P<0.001$). Table 1 describes the distribution (occurrence) of selected risk factors, expressed in terms of absolute and relative frequencies (%). We did not find a significant relationship between the 3M-mRS score and the presence of hypertension, diabetes mellitus, arrhythmia, or hyperlipidemia ($P=0.335$, $P=0.215$, $P=0.196$ and $P=0.169$, respectively). However, better mTICI scores (2–3) were significantly related to better 3M-mRS clinical outcomes ($P<0.001$). We observed no significant difference in outcomes ($P=0.316$) among patients who received different types of anesthesia for mechanical thrombectomy procedures (Figure 1).

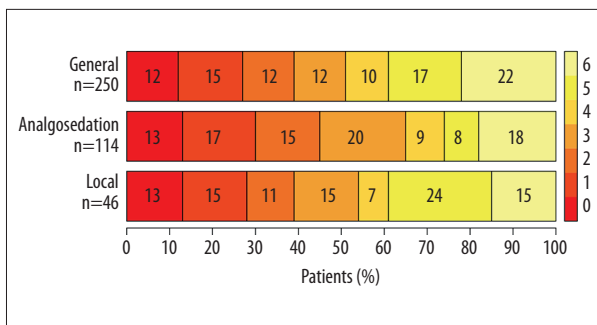


Figure 1. Clinical outcome comparison by the type of anesthesia. Comparison of clinical outcomes for patients treated with different types of anesthesia. Clinical outcome was the degree of stroke-related disability/dependence, based on the 3M-mRS score (color-coded: 0=no symptoms, 6=death).

Comparisons of important time variables are shown in Figure 2 and Table 2. Patients treated with the ADAPT technique had significantly shorter procedure times ($P<0.001$) and recanalization times ($P<0.001$) compared to the other recanalization methods. The shorter time for the ADAPT procedure was due to its simple, rapid set-up for preparing the neurointerventional procedure and repeated aspiration runs.

We also analyzed the location of the LVO. The right hemisphere was affected in 206 cases, the left hemisphere in 232 cases, and an LVO in the posterior fossa circulation was observed 62 times. We analyzed the distribution of specific therapeutic approaches used in the different affected brain areas (Figure 3, Table 3). We found no significant differences in the use of different procedures for the different brain areas ($P=0.297$). Approximately 60% of procedures were performed with ADAPT or SRFL, regardless of the affected brain area.

However, the clinical outcome of mechanical thrombectomy procedures differed according to the stroke location. Procedures performed in the anterior (right hemisphere) circulation achieved significantly better clinical outcomes than those performed in the posterior fossa ($P<0.001$; Figure 4). The poor clinical outcome (3M-mRS=6 in 48%) in the posterior fossa was influenced by the higher NIHSS scores in that patient group at the time of hospital admission (NIHSS ≥ 15 in 63%). Patients transferred with drip-and-ship paradigm from other centers or directly admitted to a mothership center were typically intubated and put under general anesthesia.

We analyzed the relationship between the type of endovascular treatment procedure and clinical outcome. Outcomes were evaluated with the NIHSS (at 24 h and 7 days after the

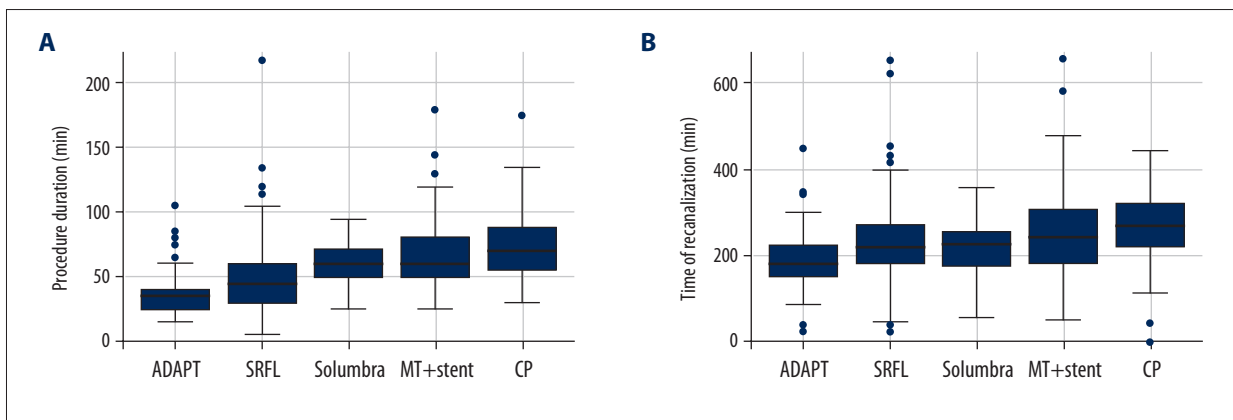


Figure 2. Selected time variables by the type of procedure. Comparisons of time required for different procedures. (A) Total procedure durations ($P<0.001$). (B) Recanalization times ($P<0.001$).

Table 2. Descriptive characteristics of selected time variables.

Technique	Total procedure duration (min)	Time of recanalization (min)
ADAPT	35 (25–40)	180 (152–225)
SRFL	45 (30–60)	220 (180–271)
Solumbra	60 (50–71)	225 (175–258)
MT+stent	60 (50–80)	242 (182–310)
CP	70 (55–88)	270 (220–320)

Procedural times for different types of mechanical thrombectomy techniques. Values are the median (IQR).

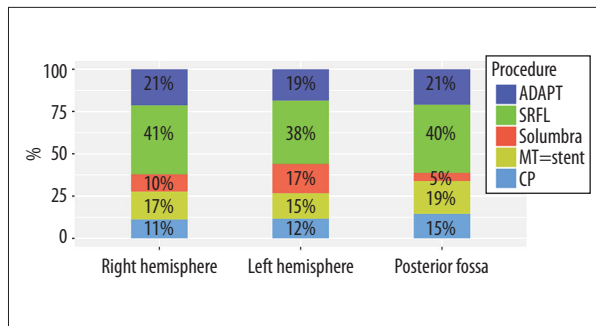


Figure 3. Distribution of the types of procedure by the affected area. Distribution of the types of procedure used in 3 brain areas affected by large-vessel occlusions.

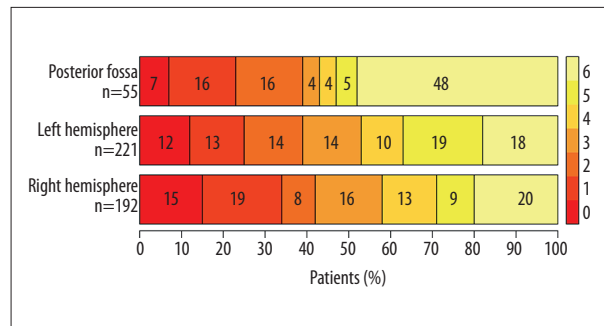


Figure 4. Clinical outcome comparison by the affected brain area. Clinical outcomes among patients treated for large-vessel occlusions in different brain areas. Clinical outcome was the degree of stroke-related disability/dependence, based on the 3M-mRS score (color-coded: 0=no symptoms, 6=death).

Table 3. Contingency table for the affected brain area and the type of procedure. Numbers of procedures used in 3 different affected brain areas.

Brain area	ADAPT	SRFL	Solumbra	MT +stent	CP	Total
Right hemisphere	44	84	21	34	23	206
Left hemisphere	43	87	40	35	27	232
Posterior fossa	13	25	3	12	9	62
Total	100	196	64	81	59	500

procedure) and with the 3M-mRS (Figure 5). Significant differences between groups were observed in the NIHSS evaluated 7 days after the endovascular procedure ($P=0.004$). However, from a practical point of view, patients achieved better 3M-mRS scores with the ADAPT and SRFL techniques compared to the other procedures (Figure 5C).

Patients treated with ADAPT had significantly increased odds of achieving better perfusion (high mTICI scores; $P=0.002$) and better clinical outcome (low NIHSS scores after 7 days; $P=0.003$) compared to those treated with other techniques (Table 4). Patients treated with SRFL had significantly increased odds of achieving a better long-term clinical status (3M-mRS=0–2; $P=0.040$) than those treated with the other techniques. On the other hand, with a combined procedure, where several devices were used for LVO recanalization, patients had significantly lower odds of achieving a favorable 3M-mRS score compared to those treated with the other techniques ($P=0.035$). However, the type of procedure did not significantly affect the death rate (3M-mRS=6).

We further investigated whether an IVT prior to the mechanical thrombectomy procedure was related to clinical outcome and the occurrence of symptomatic ICH after different endovascular procedures (Table 5). Patients treated with SRFL and IVT

had significantly higher odds of achieving a favorable clinical status (3M-mRS=0–2) than patients treated with SRFL without IVT ($P=0.031$). Also, patients treated with SRFL and IVT had significantly decreased odds of death compared to patients with SRFL without IVT ($P=0.005$; Table 5).

Discussion

Recently, several studies have compared the contact aspiration ADAPT and SRFL techniques. The ASTER randomized clinical trial found no significant difference in successful revascularization rates at the end of the procedure (ADAPT: 85.4% versus SRFL: 83.1%; $P=0.530$) [24,25]. Almandoz et al. compared the Solumbra and ADAPT techniques for LVO recanalization in 100 patients, showing that patients in the ADAPT group achieved significantly higher rates of favorable 90-day clinical outcomes than patients in the Solumbra group ($P=0.015$). They also found that the use of the ADAPT technique ($P=0.049$) was an independent predictor of a favorable clinical outcome at 90 days in their cohort [26].

Primiani et al. performed a systematic PubMed search and statistical analysis to compare ADAPT and primary SRFL thrombectomy. They identified 38 publications and a total of 3028

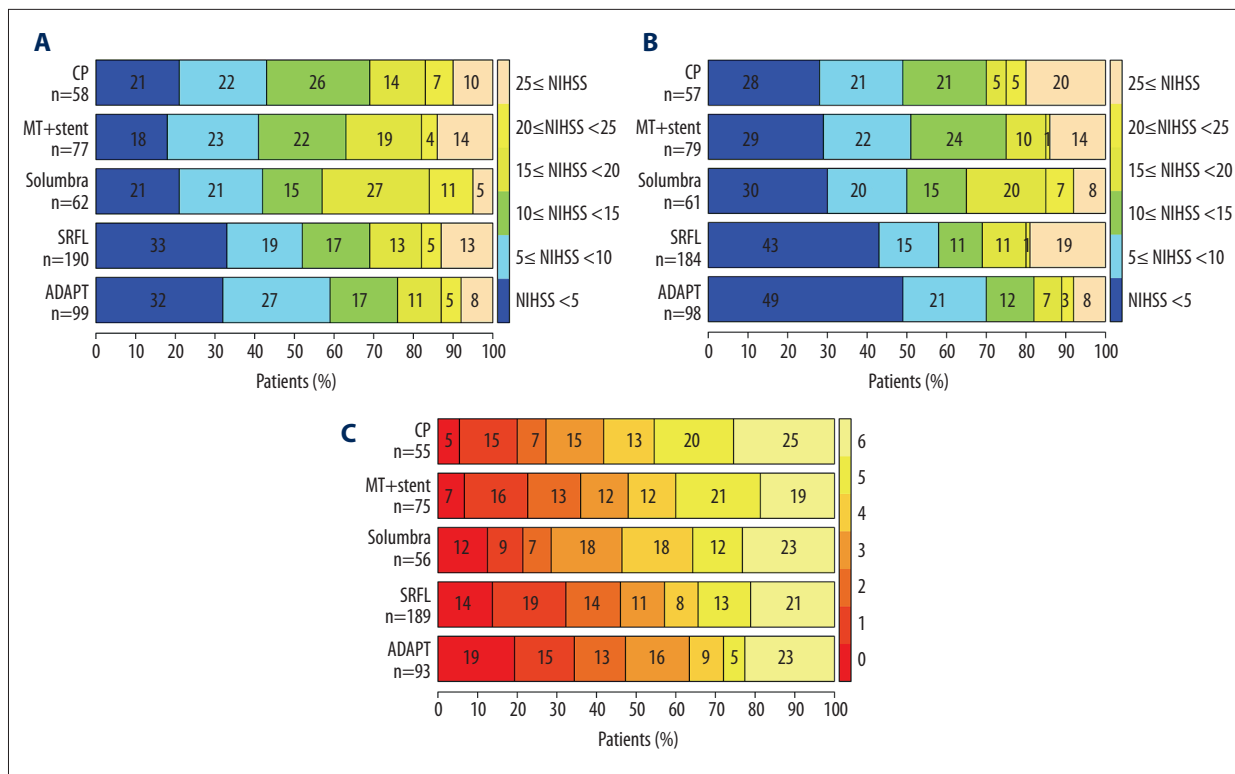


Figure 5. Clinical outcome comparison by the type of procedure. Clinical outcomes in patients with acute ischemic stroke, treated with different mechanical thrombectomy procedures. Outcomes were measured as (A) NIHSS (color-coded: 0=normal function, 42=severe impairment) after 24 h; (B) NIHSS after 7 days; and (C) 3M-mRS (color-coded: 0=no symptoms, 6=death).

Table 4. Comparison of the types of procedure. Odds of achieving favorable outcomes or death (3M-mRS=6) with the different types of procedures.

Procedure	mTICI (2-3) OR (95% CI)	P	3M-mRS (0-2) OR (95% CI)	P
ADAPT	7.41 (1.76; 31.15)	0.002	1.42 (0.90; 2.25)	0.128
SRFL	0.75 (0.41; 1.38)	0.362	1.48 (1.02; 2.16)	0.040
Solumbra	0.58 (0.25; 1.32)	0.189	0.55 (0.30; 1.02)	0.055
MT+stent	1.00 (0.44; 2.24)	0.993	0.80 (0.48; 1.34)	0.398
CP	0.54 (0.23; 1.25)	0.144	0.52 (0.28; 0.96)	0.035

Procedure	NIHSS after 7 days (<10) OR (95% CI)	P	3M-mRS (6) OR (95% CI)	P
ADAPT	2.04 (1.27; 3.30)	0.003	1.06 (0.61; 1.83)	0.838
SRFL	1.07 (0.73; 1.55)	0.740	0.94 (0.60; 1.47)	0.786
Solumbra	0.69 (0.40; 1.18)	0.175	1.10 (0.57; 2.13)	0.784
MT+stent	0.73 (0.45; 1.18)	0.197	0.80 (0.42; 1.49)	0.474
CP	0.69 (0.40; 1.20)	0.189	1.26 (0.66; 2.42)	0.484

Values are odds ratio (OR) and 95% confidence intervals (95% CI); P-values were evaluated with the chi-square test of independence.

Table 5. IVT influence analysis. The influence of IVT on favorable outcomes, symptomatic ICH (SICH), or death (3M-mRS=6) with different treatment procedures.

	mTICI (2–3)/IVT+	mTICI (2–3)/IVT–	OR (95% CI)	P
Procedure				
ADAPT	76/78	27/28	1.41 (0.12; 16.15)	0.783
SRFL	114/130	56/63	0.89 (0.35; 2.29)	0.810
Solumbra	42/50	15/15	Insufficient number of observations	NA
MT + stent	46/52	26/28	0.59 (0.11; 3.14)	0.532
CP	34/42	17/17	Insufficient number of observations	NA
	3M-mRS (0–2)/IVT+	3M-mRS (0–2)/IVT–	OR (95% CI)	P
Procedure				
ADAPT	35/69	9/25	1.83 (0.71; 4.70)	0.185
SRFL	66/129	21/61	2.00 (1.06; 3.75)	0.031
Solumbra	14/44	2/12	2.33 (0.45; 12.09)	0.303
MT + stent	18/48	9/27	1.20 (0.45; 3.23)	0.718
CP	12/40	3/15	1.71 (0.41; 7.20)	0.458
	3M-mRS (6)/IVT+	3M-mRS (6)/IVT–	OR (95% CI)	P
Procedure				
ADAPT	14/69	8/25	0.54 (0.19; 1.51)	0.236
SRFL	21/129	21/61	0.37 (0.18; 0.75)	0.005
Solumbra	11/44	2/12	1.67 (0.32; 8.80)	0.544
MT + stent	8/48	6/27	0.70 (0.21; 2.28)	0.553
CP	9/40	5/15	0.58 (0.16; 2.14)	0.411
	SICH/IVT+	SICH/IVT–	OR (95% CI)	P
Procedure				
ADAPT	12/78	2/28	2.36 (0.49; 11.30)	0.269
SRFL	23/132	9/61	1.22 (0.53; 2.82)	0.643
Solumbra	13/50	2/13	1.93 (0.38; 9.90)	0.423
MT + stent	5/53	3/28	0.87 (0.19; 3.93)	0.854
CP	11/41	7/17	0.52 (0.16; 1.72)	0.282

Values are the number of patients with the indicated outcome/the total number in that group; OR – odds ratio; 95% CI – 95% confidence interval; *P*-values were evaluated with the chi-square test of independence.

patients who underwent thrombectomy with a stent retriever device and 29 publications and a total of 2413 patients who underwent a thrombectomy with ADAPT. They found no significant difference in successful recanalization rates (mTICI score=2b or 3) between the ADAPT (83.2%) and SRFL (75.9%)

approaches (*P*=0.404). They also found no significant difference in the frequency of favorable clinical outcomes (3M-mRS=0–2) between the ADAPT (46.7%) and SRFL (46.5%) approaches (*P*=0.955) [27].

The choice between general anesthesia and conscious sedation is a controversial issue for mechanical thrombectomy procedures. Bekelis studied 1174 patients and found that, compared to conscious sedation, general anesthesia was associated with 6.4% increased fatality and 8.4 days longer stay in the hospital after mechanical thrombectomy. However, a comparative literature review by Illyas showed no significant differences in the favorable outcome rates ($P=0.510$) or successful reperfusion rates ($P=0.390$) between these 2 types of anesthesia. General anesthesia showed a significantly higher association with the development of pneumonia compared to conscious sedation ($P=0.010$) [28,29]. In our study, no significant difference was found in clinical outcomes with the different types of anesthesia used for LVO recanalization (Figure 1). The outcomes mostly depended on the times associated with patient transportation (mothership vs. drip-and-ship paradigm) or the procedure duration.

The latest types of neurointerventional devices were strongly associated with higher recanalization rates, better clinical outcomes, and shorter procedure times [30-33]. Our observations suggested that the ADAPT and SRFL procedures could be characterized by shorter procedure times compared to the Solumbra, MT + stent, or CP techniques (Figure 2).

The clinical outcome of the mechanical thrombectomy procedures also significantly differed according to the stroke location. The worst outcomes were found in posterior fossa procedures, despite the lack of significant differences among the different types of mechanical thrombectomy procedures used (Figure 3) [34].

Mechanical thrombectomies performed with a newer device for the ADAPT or SRFL techniques had higher rates of successful recanalization than mechanical thrombectomies performed with the older techniques like intra-arterial thrombolysis or with the first types of thrombectomy devices [35,36]. In our study, LVO recanalization of mTICI scores 2–3 were achieved in 98 (98%) patients with the ADAPT and 170 (87%) patients with the SRFL technique. Also, successful recanalization, with mTICI scores 2–3, were related to favorable clinical outcomes. Patients treated with ADAPT had significantly increased odds of achieving favorable mTICI scores and favorable clinical outcome (NIHSS after 7 days) compared to patients treated with the other techniques. Patients treated with SRFL had significantly increased odds of achieving a favorable long-term clinical status (3M-mRS=0–2; Table 4) compared to patients treated with the other techniques.

Despite great progress in recanalization techniques for treating brain LVOs, around 40–45% of procedures fail to achieve favorable clinical outcomes. This can be explained by failures to extract cardiac-origin emboli; IVT failure due to old organized

thrombi with a large amount of Von Willebrand factor, neutrophils, fibrin, platelets, and free DNA (NETosis); and a resistance to fibrinolytic therapy and inflammatory brain reactions to the ischemia [37–40].

Prior IVT administration efficacy in the LVO has an important influence on the mechanical thrombectomy outcome. Lapergue et al. found significantly higher recanalization rates with the ADAPT than with the SRFL technique. However, they found an imbalance in prior rt-PA use; it was used more often in the ADAPT group (66.1%) than in the Solitaire group (45.4%). Nevertheless, the adjusted analysis for all confounding factors, including rt-PA use, confirmed a higher rate of recanalization in the ADAPT group [41].

Our analysis suggests that treatments with/without IVT only affected the SRFL procedure outcomes (Table 5) and the use of IVT had no effect on the outcomes of other treatment approaches. The direct effect of IVT use with adjunctive mechanical thrombectomy remains controversial. This controversy is linked to the uncertain roles played by IVT resistance to the “old-cardiac” emboli and the rate of periprocedural embolization in the new territory of the partially lysed and fragmented thrombi [42–44].

Prior IVT administration can increase the risk of symptomatic or non-symptomatic ICH [7,42,45,46]. We did not find any significant differences in the number of symptomatic ICH events between treatment groups treated with/without IVT prior to mechanical thrombectomy (Table 5).

The times between stroke onset and the diagnostic CT scan and between onset and the endovascular treatment in eligible patients with LVO are critical factors that influence the 3M-mRS clinical outcome. Recent research discussed the mothership and drip-and-ship paradigm and related time parameters [47–49]. The ESCAPE trial confirmed that every 30-min increase in the CT-to-reperfusion time significantly reduced the probability (by 8.3%) of achieving an outcome of functional independence (3M-mRS=0–2). Also, the onset-to-arrival (at the endovascular hospital) time was 42% (34 min) longer among patients who received intravenous alteplase at the referring hospital (drip-and-ship) compared to patients who underwent a direct transfer (to the mothership) [47]. In our study, patients treated with the SRFL procedure who received a mothership transfer had significantly increased odds of achieving a favorable clinical status (3M-mRS) than patients treated with SRFL who underwent a drip-and-ship transfer (Table 6).

The present study has certain limitations and defects. Firstly, the results are based on the collected data from the prospective observational study, which is at risk of confounding bias. A prospective randomized study could be more valid but also

Table 6. Comparison of mothership and drip-and-ship paradigm. Comparison of favorable outcomes, symptomatic ICH (SICH), or death (3M-mRS=6) among patients treated at the mothership or the drip-and-ship paradigm for the different treatment procedures.

	mTICI (2–3)/Mothership	mTICI (2–3)/Drip-and-Ship	OR (95% CI)	P
Procedure				
ADAPT	72/74	25/25	Insufficient number of observations	NA
SRFL	96/104	73/87	2.3 (0.92; 5.78)	0.070
Solumbra	39/46	16/17	0.35 (0.04; 3.06)	0.323
MT + stent	40/44	31/35	1.29 (0.30; 5.57)	0.732
CP	30/34	19/23	1.58 (0.35; 7.08)	0.549
	3M-mRS (0–2)/Mothership	3M-mRS (0–2)/Drip-and-Ship	OR (95% CI)	P
Procedure				
ADAPT	32/69	12/23	0.79 (0.31; 2.04)	0.630
SRFL	55/101	32/87	2.06 (1.14; 3.69)	0.015
Solumbra	11/42	5/13	0.57 (0.15; 2.11)	0.395
MT + stent	16/41	11/34	1.34 (0.52; 3.47)	0.549
CP	10/33	5/20	1.30 (0.37; 4.58)	0.678
	3M-mRS (6)/Mothership	3M-mRS (6)/Drip-and-Ship	OR (95% CI)	P
Procedure				
ADAPT	15/69	6/23	0.79 (0.26; 2.35)	0.667
SRFL	18/101	22/87	0.64 (0.32; 1.29)	0.212
Solumbra	9/42	4/13	0.61 (0.15; 2.46)	0.488
MT + stent	11/41	3/34	3.79 (1.00; 14.94)	0.046
CP	7/33	6/20	0.63 (0.18; 2.24)	0.471
	SICH/Mothership	SICH/Drip-and-Ship	OR (95% CI)	P
Procedure				
ADAPT	9/74	5/25	0.55 (0.17; 1.84)	0.331
SRFL	15/105	17/86	0.68 (0.32; 1.45)	0.313
Solumbra	9/45	5/17	0.60 (0.17; 2.14)	0.429
MT + stent	5/44	3/36	1.41 (0.31; 6.35)	0.653
CP	8/33	8/23	0.6 (0.19; 1.93)	0.390

Values are the number of patients with the indicated outcome/the total number in that group; OR – odds ratio; 95% CI – 95% confidence interval; *P*-values were evaluated with the chi-square test of independence.

could violate ethical standards. Also, analyzing very specific groups of patients entails smaller sample sizes. Hence, it cannot be excluded that some significant differences were overlooked. Importantly, some specific groups were not represented at all, especially for the collateral scoring and CT perfusion analysis.

Conclusions

We showed that using the latest types of neurointerventional devices for ADAPT and SRFL procedures provided significant improvements in the properties of these procedures compared to the other examined single and combined techniques. These

novel techniques (ADAPT and SRFL) provided shorter procedure times, higher recanalization rates, and more favorable clinical outcomes after treating an LVO with mechanical thrombectomy. A mothership transfer and IVT administration had direct effects on the SRFL approach for treating acute ischemic stroke. Our results suggest that the clinical outcome of mechanical thrombectomy procedures could be improved by further shortening the recanalization time, including a shorter drip-and-ship transfer time.

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Conflicts of interest

None.

Ethics

The design of the study and informed consent were approved by the local ethics committees 639/2017.

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