Am J Transl Res 2026;18(4):3617-3625
www.ajtr.org /ISSN:1943-8141/AJTR0170416

Original Article

Efficacy of SWIM technology combined with direct aspiration first pass technique for large vessel occlusion in acute ischemic stroke

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Received November 30, 2025; Accepted March 12, 2026; Epub April 25, 2026; Published April 30, 2026

Abstract: Objective: To evaluate the safety and efficacy of Solitaire Flow Restoration stent retriever with intracranial support catheter for mechanical thrombectomy (SWIM) combined with direct aspiration first pass technique (ADAPT) for acute large vessel occlusive stroke (AIS-LVO). Methods: A retrospective analysis was conducted on AIS-LVO patients admitted to the Affiliated Hospital of Shandong University of Traditional Chinese Medicine from April 2021 to April 2022. The patients were divided into an observation group (n=68), who received ADAPT combined with SWIM, and a control group (n=67), who received SWIM only. The time from puncture to recanalization, postoperative vascular recanalization rate, National Institutes of Health Stroke Scale (NIHSS) and Barthel Index scores, and good prognosis rate at 90 days after surgery were compared between the two groups. Results: There was no significant difference in the reperfusion rate or time from puncture to reperfusion between the two groups ($P > 0.05$). The observation group had a significantly higher rate of excellent and good prognosis at 90 days post-surgery compared to the control group (58.82% vs. 32.84%; χ^2=6.672, P=0.010). Significant differences were found between the two groups in NIHSS scores (6.58±1.47 *vs.* 5.63±1.0; t=2.874, P=0.010) and Barthel Index scores (72.35±8.77 *vs.* 76.43±7.83; t=3.120, $P < 0.001$). Surgical approach, ≥ 2 thrombectomy passes, and puncture-to-recanalization time ≥ 60 min were identified as predictive factors for prognosis. Conclusion: ADAPT combined with SWIM is safe and effective for AIS-LVO and may improve clinical prognosis.

Keywords: Acute ischemic stroke, SWIM technique, direct aspiration first pass technique

Introduction

Stroke is the second leading cause of death and the third leading cause of disability worldwide [1]. As one of the two main subtypes of stroke, acute ischemic stroke (AIS) results from cerebral ischemia caused by thrombosis of cerebral vessels [2, 3]. Strong evidence indicates that large vessel occlusion (LVO) is an independent predictor of unfavorable outcomes in patients with AIS. The traditional approach to restoring perfusion in patients with cerebral infarction is intravenous thrombolysis within a narrow time window. Although intravenous thrombolysis plays a significant role in the treatment of cerebral infarction, the time window is relatively short, and only a limited number of patients can receive it. In addition, the reperfusion rate for LVO stroke after intravenous thrombolysis is low, and the clinical outcomes are often unsatisfactory.

In recent years, advances in thrombectomy devices (such as stent retrievers and suction catheters) have enabled detailed analysis of the morphological and histological composition of stroke thrombi [4, 5]. Following the positive results of five randomized controlled trials in 2015, mechanical thrombectomy (MT), particularly stent retriever thrombectomy, has become the standard treatment for AIS due to LVO (AIS-LVO) [6-10]. With the rapid development of endovascular devices, various thrombectomy techniques have been developed and utilized in

https://doi.org/10.62347/ULXW3353

clinical practice, and have been shown to effectively improve first-pass effect and clinical outcomes [11-13]. Solitaire Flow Restoration stent retriever with intracranial support catheter for mechanical thrombectomy (SWIM) technology has become a standard approach for AIS-LVO. This technique can effectively improve the complete recanalization rate and enhance patients' prognosis. Although this method has significant efficacy, it also has limitations, including long operation time, high technical requirements, and the risk of vascular damage [14]. Direct aspiration thrombectomy has emerged in recent years. Research has shown that aspiration thrombectomy as a first-line strategy is non-inferior to stent retriever thrombectomy. In particular, the use of large-bore aspiration catheters for the direct aspiration first pass technique (ADAPT) has proven effective for stroke treatment [15]. ADAPT can achieve rapid vascular recanalization in a single pass using an aspiration catheter. The main advantages of ADAPT are its efficiency and ease of use, which can improve the efficacy while shortening procedure time and reducing complications [16]. Clinical application and reports of ADAPT in China remain limited, and no studies have reported the efficacy of ADAPT combined with SWIM thrombectomy for acute LVO stroke. Therefore, investigating the feasibility, safety, and technical advantages of ADAPT in clinical practice is important for promoting this emerging technique and improving treatment outcomes in patients with acute stroke. This study compares the efficacy of ADAPT combined with SWIM versus SWIM alone in patients with AIS-LVO, providing evidence for the treatment of AIS-LVO in clinical practice.

Patients and methods

Patients

This retrospective analysis included patients with AIS-LVO who were admitted to the Affiliated Hospital of Shandong University of Traditional Chinese Medicine from April 2021 to April 2022.

Inclusion criteria: (1) Diagnosis of AIS with a National Institutes of Health Stroke Scale (NIHSS) score > 6; (2) Imaging-confirmed LVO. (3) Time from symptom onset to procedure < 6 hours for anterior circulation occlusion and ≤ 24 hours for posterior circulation occlusion; (4) Modified Rankin Scale (mRS) score ≥ 3 upon admission; (5) Complete clinical data available for all patients.

Exclusion criteria: (1) History of cranial surgery or trauma; (2) Patients with intracranial arterial dissection, moyamoya disease, or vasculitis; (3) Patients with severe cardiac, hepatic, or renal dysfunction; (4) Patients with active bleeding or known bleeding tendency.

A total of 135 patients were included in this study and were divided into an observation group (n=68) and a control group (n=67) based on treatment choice and physician recommendation. The control group received SWIM alone, while the observation group received ADAPT combined with SWIM. All study procedures were approved by the Ethics Committee of Shandong University of Traditional Chinese Medicine, China (approval number: 2023-023-KY), and were conducted in accordance with the ethical standards for human research as set forth in the Declaration of Helsinki (2014) [17]. We collected demographic information, clinical data, as well as procedural details and medications for all patients. The patient screening flowchart is shown in **Figure 1**.

Treatment method

Patients who presented within 4.5 hours of symptom onset with indications for thrombolysis and no contraindications received intravenous thrombolysis with recombinant tissue-type plasminogen activator. For patients with onset time > 4.5 hours, endovascular treatment was performed within the MT window (≤ 24 hours) if imaging criteria were met.

SWIM thrombectomy technology

The patient was placed in a supine position. After anesthesia, the Seldinger technique was used to puncture the femoral artery, upper limb artery, or common carotid artery, and a 6F or 8F arterial sheath was inserted. A guiding catheter was inserted into the intracranial segment of the internal carotid artery, vertebral artery, or subclavian artery, and a 5F or 6F intermediate catheter was placed into the intracranial segment of the internal carotid artery, middle cerebral artery, vertebral artery, or basilar artery. The microguidewire and microcatheter were passed through the occluded segment, and a retrievable stent system was placed across the

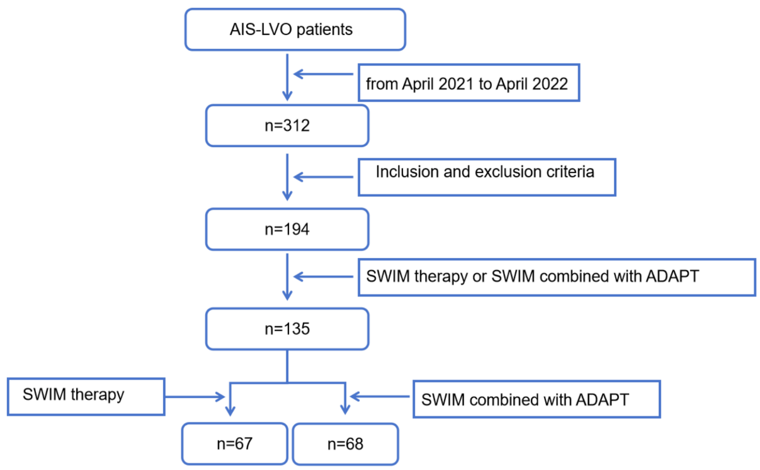

Figure 1. Patient enrollment flowchart. AIS-LVO: acute large vessel occlusive stroke; SWIM: Solitaire Flow Restoration stent retriever with intracranial support catheter for mechanical thrombectomy; ADAPT: direct aspiration first pass technique.

occluded segment. The intermediate catheter was used to partially retrieve the stent, and both the intermediate catheter and the guiding catheter were used for dual continuous negative pressure aspiration. The procedure was repeated up to 3 times if necessary. After thrombectomy was completed, angiography was performed to confirm recanalization. Finally, local suture and pressure bandaging were performed. During SWIM thrombectomy, difficulties may be encountered in placing the intermediate catheter in patients with type III aortic arch, bovine arch, or vascular tortuosity. Therefore, to avoid prolonged PRT, it is recommended to select an optimal access route (radial, femoral, brachial, or carotid artery), use a coaxial technique, and employ a multipurpose catheter to advance the long sheath into place. In addition, it is important to enhance support for the intermediate catheter, and the anchor technique may be used to facilitate advancement of the catheter. These techniques can facilitate proper placement of the intermediate catheter.

ADAPT combined with SWIM thrombectomy technique

The patient was placed in a supine position. After anesthesia, the Seldinger technique was used to puncture the femoral artery, upper limb artery, or common carotid artery, and a 6F or 8F arterial sheath was inserted. A guiding catheter was inserted into the intracranial segment of the internal carotid artery, vertebral artery, or subclavian artery. A suction catheter was inserted directly into the occluded segment of the culprit artery, with its tip positioned against the thrombus. Negative pressure was applied using a pump or syringe. After alternating strong and weak negative pressure aspiration, negative pressure was maintained, and the suction catheter was withdrawn, removing the thrombus en bloc. The procedure was repeated up to 3 times if necessary. If recanalization was not achieved, the procedure was switched to SWIM technology.

All thrombectomy procedures were performed by the same experienced neurointerventionist. Both groups received supportive care, including oxygen therapy, electrocardiographic monitoring, and neuroprotective treatment. Antiplatelet therapy was initiated 24 hours after the procedure.

Outcome measures

Demographic and clinical data: The following data were recorded for all patients: age, sex, history of hypertension, diabetes, smoking, alcohol consumption, and comorbidities.

Functional outcomes: Functional outcomes were assessed using the mRS. The mRS has a maximum score of 6. Scores of 0-1 were defined as excellent outcomes, and scores of 2-6 as poor outcomes. The rates of excellent and good outcomes were compared between the two groups.

Procedural outcomes: The time from puncture to recanalization (PRT) and the rate of successful recanalization were compared between the two groups. Recanalization was assessed using the modified Thrombolysis in Cerebral Infarction (mTICI) grading system. Grade 0 indicates no perfusion in the occluded vessel. Grade 1 indicates minimal passage of blood flow through the occluded segment, with little or no distal perfusion. Grade 2a indicates forward flow perfusing less than half of the downstream ischemic territory. Grade 2b indicates

Table 1. Baseline characteristics of patients

Characteristic	Control group (n=67)	Observation group (n=68)	$t/Z/\chi^2$	*P*
Sex, n (female/male)	40/27	40/28	0.011	0.917
Age (years), mean ± SD	63.34±8.03	63.92±11.48	-0.912	0.154
BMI (kg/m^2), median (IQR)	23.5 (20.6, 25.7)	24.1 (21.3, 26.2)	-1.342	0.095
NIHSS score, mean ± SD	14.12±4.29	14.56±3.11	-0.736	0.201
mRS score ≥ 3, n (%)	47 (70.15)	53 (77.94)	1.067	0.302
History of ischemic stroke, n (%)	5 (7.46)	7 (10.29)	0.334	0.563
History of atrial fibrillation, n (%)	55 (82.09)	54 (79.41)	0.156	0.693
History of diabetes, n (%)	7 (10.45)	10 (14.71)	0.556	0.456
History of hypertension, n (%)	36 (53.73)	39 (57.35)	0.164	0.686
Systolic blood pressure at admission (mmHg), median (IQR)	125 (113, 150)	132 (121, 155)	-1.415	0.075
Blood glucose at admission (mmol/L), mean ± SD	6.78±1.38	6.42±1.31	0.991	0.098

SD: standard deviation; IQR: interquartile range; NIHSS: National Institutes of Health Stroke Scale; BMI: body mass index; mRS: modified Rankin scale.

forward flow perfusing more than half of the downstream ischemic territory. Grade 3 indicates complete perfusion of the downstream ischemic territory. A mTICI grade of ≥ 2b was defined as successful recanalization. The complete recanalization rate was calculated as: (number of patients with mTICI grade 2b or 3/ total number of patients) × 100%.

Clinical prognosis evaluation: (1) We compared neurological function and activities of daily living between the two groups before treatment and at 2 weeks after surgery. Neurological function was assessed using the NIHSS, which consists of 11 items with a total score of 42 points; higher scores indicate greater neurological impairment. Activities of daily living were assessed using the Barthel Index, with a maximum score of 100 points; higher scores indicate better functional independence. (2) The incidence of postoperative complications, including asymptomatic/symptomatic intracranial hemorrhage, vascular reocclusion, and distal embolization, was recorded. (3) Functional outcomes at 90 days after surgery were compared between the two groups using the mRS. A score ≤ 2 was defined as a good prognosis, and a score > 2 as a poor prognosis.

Statistical analysis

Statistical analyses were performed using SPSS (IBM SPSS Statistics, version 25.0, IBM Corp., Armonk, NY, USA). First, all continuous variables were assessed for normality using the Kolmogorov - Smirnov test. Normally distributed variables were presented as means ± standard deviation, and non-normally distributed variables were presented as median (interquartile range) or as number of cases (percentage) (n, %). For comparisons between the groups, the independent samples t-test was used for normally distributed data, and the Mann - Whitney U test was used for non-normally distributed data. The paired t-test was used for comparisons before and after treatment. A *P* value < 0.05 was considered statistically significant.

Results

Baseline characteristics of the two groups

There were no significant differences between the two groups in gender, age, body mass index, NIHSS score, history of previous stroke, mRS score, history of atrial fibrillation, history of diabetes, history of hypertension, hypertension at admission, or blood glucose at admission (all P > 0.05) (**Table 1**).

Comparison of recanalization rate and 90-day prognosis between the two groups

There was no significant difference in the PRT or vascular recanalization rate between the two groups of patients ($P > 0.05$) (**Table 2**). The mean number of thrombectomy passes in the control group and the observation group was 2.10±0.36 and 1.21±0.43, respectively, with a significant difference between the two groups (t=2.521, P=0.036). The rate of excellent and

Table 2. Comparison of procedural and clinical outcomes between the two groups

Variable	Control group (n=67)	Observation group (n=68)	t/χ^2	P
Puncture-to-recanalization time (min), mean ± SD	69.49±12.32	58.44±11.87	1.873	0.065
Number of thrombectomy passes, mean ± SD	2.10±0.36	1.21±0.43	2.521	0.036
Complete recanalization rate, n (%)	60 (89.55%)	64 (94.12%)	0.940	0.332
Good prognosis at 90 days, n (%)	22 (32.84%)	40 (58.82%)	6.672	0.010

SD: standard deviation.

Table 3. Comparison of NIHSS and Barthel Index scores between the two groups before and after treatment

Group	NIHSS score				Barthel Index score			
	Before treatment	After treatment	*t*	*P*	Before treatment	After treatment	*t*	*P*
Control group (n=67)	20.38±3.47	6.58±1.47	8.692	< 0.001	56.49±7.76	72.35±8.77	9.361	< 0.001
Observation Group (n=68)	21.41±4.53	5.63±1.02	10.282	< 0.001	55.32±8.02	76.43±7.83	11.998	< 0.001
t	-0.719	2.874			0.241	-3.120		
P	0.218	0.010			0.452	< 0.001		

NIHSS: National Institutes of Health Stroke Scale.

good outcomes at 90 days was 40 (58.82%) in the observation group and 22 (32.84%) in the control group, and this difference was statistically significant (χ^2=6.672, P=0.010).

Comparison of NIHSS and Barthel Index scores before and after treatment

In both groups, NIHSS scores decreased significantly after treatment compared to before treatment, while Barthel Index scores increased significantly. The post-treatment NIHSS score was 6.58±1.47 in the control group and 5.63±1.02 observation group. The post-treatment Barthel Index score was 72.35±8.77 in the control group and 76.43±7.83 in the observation group. The differences between the two groups were statistically significant (both P < 0.05) (**Table 3**).

Multivariate regression analysis of factors predicting good prognosis

Multivariate logistic regression analysis showed that mTICI grade ≥ 2b, age ≥ 60 years, male sex, and baseline NIHSS score ≥ 16 were not independent predictors of good prognosis (all P > 0.05). Treatment approach (SWIM combined with ADAPT), number of thrombectomy passes ≥ 2, and PRT ≥ 60 min were significant predictors of prognosis (all P < 0.05). The combined treatment approach was an independent predictor of good prognosis, while ≥ 2 thrombectomy passes and PRT ≥ 60 min were predictors of poor prognosis (**Table 4**).

Comparison of postoperative complications between the two groups of patients

All cases in both groups were operated on by the same neurosurgeon, and 135 patients had previously completed cerebral angiography independently. Within 90 days after surgery, 3 patients in the control group died, with an all-cause mortality rate of 4.48%. 2 patients in the observation group died, with an all-cause mortality rate of 2.94%. Secondary intracranial hemorrhage (2 cases in the control group *vs* 1 case in the observation group) and postoperative vascular reocclusion (1 case in the control group *vs* 1 case in the observation group) were the main causes of death. There was no significant difference in the incidence of complications between the two groups (Fisher's P= 0.680).

Discussion

AIS can be caused by a variety of factors, particularly embolism from arterial or cardiac sources, as well as arterial wall disease or anatomical variation [18, 19]. Most cases of AIS occur suddenly and progress rapidly, leading to brain injury within minutes. SWIM is one of the most

Table 4. Multivariate logistic regression analysis of factors associated with good prognosis

Variable	*β*	*SE*	*Wald*	*P*	*OR*	*95% CI*
Surgical approach (SWIM combined with ADAPT)	1.087	0.448	5.880	0.015	2.967	1.232-7.145
Number of thrombectomy passes (≥ 2)	-1.659	0.460	12.996	0.000	0.190	0.077-0.469
Puncture-to-recanalization time (≥ 60 min)	-2.058	0.512	16.132	0.004	0.128	0.047-0.349
Preoperative NIHSS score (≥ 16)	-0.716	0.442	2.624	0.105	0.489	0.206-1.162
mTICI grade ≥ 2b	0.234	0.423	0.307	0.579	1.264	0.553-2.896
Age (≥ 60 years)	0.210	0.424	0.245	0-.621	1.233	0.537-2.830
Gender (male)	0.339	0.415	0.666	0.414	1.403	0.622-3.164
Constant	1.353	0.596	5.149	0.023	3.869	

mTICI: modified Thrombolysis in Cerebral Infarction; NIHSS: National Institutes of Health Stroke Scale; SWIM: Solitaire Flow Restoration stent retriever with intracranial support catheter for mechanical thrombectomy; ADAPT: direct aspiration first pass technique; *SE*: standard error; *OR*: odds ratio; *95% CI*: 95% confidence interval.

advanced intracranial thrombectomy techniques and offers a promising treatment option for stroke patients [20]. ADAPT, as a novel thrombectomy technique, has achieved favorable outcomes in clinical practice. Multicenter studies abroad have reported that the successful reperfusion rate and rate of good prognosis at 90 days in patients treated with ADAPT alone were 81.4% and 51.9%, respectively [21-23]. However, there are currently few reports on the safety and efficacy of ADAPT combined with SWIM for AIS-LVO.

SWIM technology establishes a stable delivery pathway using an intermediate catheter to reduce proximal resistance, allowing the thrombectomy stent to reach the target vessel more effectively, making it especially suitable for tortuous intracranial vessels. In addition, the retrievable stent can reduce direct contact between the stent and the vessel wall via the intermediate catheter, thereby minimizing damage to the vascular endometrium and reducing device-related bleeding complications. These factors significantly improve the success rate of stent thrombectomy [24]. Studies have shown that SWIM is safe thrombectomy technique, with a vascular recanalization rate of approximately 92.0% and a good prognosis rate (mRS ≤ 2) of 60.00%, both of which are superior to those of traditional stent thrombectomy [25, 26].

ADAPT is mainly used to remove thrombi by placing the tip of the aspiration catheter against the thrombus and applying continuous negative pressure at the proximal end. Theoretically, it is more suitable for acute stroke caused by thromboembolic occlusion [27]. Kang et al. [28] compared aspiration alone with ADAPT and found that the ADAPT group tended to have a higher rate of TICI grade ≥ 2b recanalization. ADAPT achieves recanalization by directly aspirating thrombi, offering advantages over SWIM in terms of procedure time and complexity [29]. Lapergue et al. [30] retrospectively analyzed 243 patients with AIS-LVO, of whom 124 underwent ADAPT thrombectomy and 119 underwent Solitaire stent retriever thrombectomy. Patients treated with ADAPT had a higher reperfusion rate (82.3% vs. 68.9%, *P*=0.022). The main advantage of ADAPT is its ability to remove thrombus directly by aspiration, avoiding the stent-thrombus integration process, reducing thrombus fragmentation, and lowering the risk of distal embolization. Furthermore, ADAPT causes minimal mechanical trauma to the vessel, reducing intimal damage and promoting faster patient recovery. Although ADAPT may not be superior to SWIM in terms of complete recanalization, it offers notable advantages in functional recovery and reducing complications [31]. In summary, ADAPT combined with SWIM may complement each other and offer greater efficacy in the treatment of AIS-LVO. Unfortunately, this study is a retrospective analysis and has limitations caused by selection bias and other confounding factors. Therefore, a randomized clinical trial is needed in the future to validate the results of this study.

In this study, we found no significant difference between the two groups in vascular recanalization rate and PRT. However, the 90-day clinical outcomes of patients treated with ADAPT combined with SWIM were significantly better than those of the SWIM alone group. This finding suggests that the combination of ADAPT and

SWIM integrates the advantages of both techniques and may achieve better clinical efficacy than SWIM alone in the treatment of AIS-LVO. In addition, patients in the ADAPT + SWIM group had significantly better Barthel Index and NIHSS scores than those in the SWIM alone group. Multivariate logistic regression analysis showed that combined treatment (SWIM + ADAPT), number of thrombectomy passes, and PRT were independent predictors of good prognosis. This finding suggests that SWIM combined with ADAPT is more effective in improving neurological function and activities of daily living in patients with anterior circulation LVO. In addition, there were 5 deaths among 135 patients, indicating that with the accumulation of operator's experience, the safety of SWIM and ADAPT thrombectomy continues to improve. After the number of independent operations reached 25, the technique could be further improved to reduce the mortality rate. All deaths occurred within 14 days after surgery. Secondary hemorrhagic transformation and postoperative vascular re-occlusion were the main causes of death. Postoperative re-occlusion was considered to be related to incomplete thrombus clearance, in situ stenosis, dissection, vascular intima damage, insufficient antiplatelet therapy, and other factors; however, vascular perforation and rupture were caused by surgical mechanical injury, which was related to the operator's skill and proficiency. One patient who underwent posterior circulation thrombectomy died of airway obstruction. After general anesthesia, the tracheal tube was removed too early, and oropharyngeal mucosal hemorrhage led to asphyxia, indicating that this complication was related to a lack of experience in perioperative airway management.

Conclusions

In conclusion, SWIM combined with ADAPT demonstrates favorable clinical efficacy in the treatment of AIS-LVO. However, further well-designed controlled trials are needed to validate the efficacy of this approach.

Disclosure of conflict of interest

None.

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