Lessons Learned Over More than 500 Stroke Thrombectomies Using ADAPT With Increasing Aspiration Catheter Size

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BACKGROUND: Endovascular thrombectomy is currently the standard of care for acute ischemic stroke (AIS). Although earlier trials on endovascular thrombectomy were performed using stent retrievers, recently completed the contact aspiration vs stent retriever for successful revascularization (ASTER) and a comparison of direct aspiration versus stent retriever as a first approach (COMPASS) trials have shown the noninferiority of direct aspiration.

OBJECTIVE: To report the largest experience with ADAPT thrombectomy and compare the impact of advancement in reperfusion catheter technologies on outcomes.

METHODS: We reviewed a retrospective database of AIS patients who underwent ADAPT thrombectomy between January 2013 and November 2017 at the Medical University of South Carolina. Demographics and baseline characteristics, technical variables, and radiological and clinical outcomes were reviewed.

RESULTS: Among 510 patients (mean age: 67.7, 50.6% females), successful recanalization at first pass was achieved in 61.8%, and with aspiration only in 77.5%. Mean procedure time was 27.4 min, and the rate of good outcomes (mRS 0-2) at 90 d was 42.9%. The rate of recanalization with aspiration only was significantly higher, and procedure time was significantly lower in patients treated with larger catheters (ACE 064 and ACE 068) compared to smaller catheters (5 MAX and ACE, $P < .05$). There were no differences in complication rates or postoperative parenchymal hemorrhage across groups ($P > .05$); however, use of ACE 068 was an independent predictor of good outcomes at 90 d on multivariate regression analysis (odds ratio = 1.6, $P < .05$).

CONCLUSION: Refinement of ADAPT thrombectomy by incorporating reperfusion catheters with higher inner diameters and thus higher aspiration forces is associated with better outcomes, shorter procedure times, and lower likelihood of using additional devices without impacting complication rates.

KEY WORDS: Stroke, Thrombectomy, Aspiration

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Despite recent revolutionary advancements, acute ischemic stroke (AIS) remains a leading cause of morbidity and mortality among the adult US population.[1]

ABBREVIATIONS: ADAPT, A Direct Aspiration Approach as First Pass Technique; **AIS,** acute ischemic stroke; **CT,** computed tomography; **ICA,** internal carotid artery; **ID,** inner diameter; **LVO,** large vessel occlusion; **mRS,** modified Rankin Scale; **NIHSS,** National Institute of Health Stroke Scale; **OR,** odds ratio; **SR,** stent retriever; **TICI,** Thrombolysis in Cerebral Ischemia

Trials over the last 5 yr[2-10] have provided Level 1A evidence in support of recanalization of large vessel occlusions (LVO) using a stent retriever (SR) up to 24 h from symptom onset.[10] However, more recent randomized controlled trials[11,12] have established noninferiority of direct aspiration thrombectomy as front-line therapy compared to SR thrombectomy with respect to technical and clinical outcomes. This led to the expansion of the therapeutic arsenal available to treat acute stroke with LVO.

Introduced in 2013, the use of direct aspiration using ADAPT (A Direct Aspiration

Approach as First Pass Technique) provided the benefits of faster recanalization times and lower procedural cost.[12-16] The tenet of ADAPT is delivery of a large-bore catheter to the thrombus, with subsequent removal of the thrombus using aspiration. If direct aspiration fails to recanalize the vessel, the catheter is then used as a conduit for additional maneuvers such as SR thrombectomy. Since its first description in 2013,[14] the ADAPT technique has undergone refinements, in large part driven by technological advancements in the catheters themselves. Initial experience involved the use of the Penumbra 5Max^{TM} (0.054" diameter) and 5Max^{TM} ACE (0.060") reperfusion catheter[14] (both Penumbra, Alameda, California), which was followed by the introduction of ACE64 (0.064") and ACE68 (0.068") catheters (Penumbra). Technical advancements in catheters involved improvements in deliverability and larger inner diameters (ID) at both the distal end that engages the thrombus as well as the proximal end, leading to stronger aspiration forces. This study reports the largest experience with ADAPT thrombectomy and analyzes the effect of reperfusion catheter size on technical success and patient outcomes after ADAPT.

METHODS

Patient Selection

We retrospectively reviewed a prospectively maintained database of all AIS cases who underwent mechanical thrombectomy using a direct aspiration first pass technique (ADAPT) between January 2013 and November 2017. The institutional review board at the Medical University of South Carolina approved this study, and no patient consent was required as no identifying material has been included.

For patients presenting with anterior circulation AIS, ADAPT thrombectomy was performed if computed tomography (CT) perfusion imaging showed a mismatch between cerebral blood volume and blood flow that corresponds to their admission National Institute of Health Stroke Scale (NIHSS) as previously described.[14,16] Patients meeting the criteria for IV-tPA received thrombolytic therapy prior to thrombectomy.[17] Patients were included irrespective of age, time between onset to groin access, or whether IV-tPA was administered. For patients with posterior circulation stroke, ADAPT thrombectomy was performed unless procedural benefit was not anticipated based on extensive infarcts covering more than half of the brain stem on any axial slice. ASPECTS scoring on admission CT/CTP was retrospectively scored by a blinded fellowship-trained neuroradiologist.

ADAPT Thrombectomy

The ADAPT thrombectomy technique has been previously described.[14-16,18] Aspiration catheters used in ADAPT were based on the caliber of the target vessels. For basilar or M1 thrombi, 5 MAX, 5 MAX ACE, 064 or 068 (Penumbra) were used. For vessels with smaller caliber, 4 Max or 3 Max catheters (Penumbra) were used. Aspiration with ADAPT was performed for 3 to 4 attempts before the use of additional devices such as SR if adequate recanalization was not achieved. To assess for postprocedural hemorrhage, CT imaging was performed at 12 to 24 h and reviewed by a blinded neuroradiologist.

Data Collection

Patient charts and procedure notes were reviewed for demographics, preprocedural deficits, and procedural variables. Procedural variables included the time to achieve recanalization, IA tPA administration, the vessels subjected to ADAPT, the Thrombolysis in Cerebral Ischemia (TICI) scale after first pass, aspiration, and at end of procedure, intraprocedural complications, postprocedural hemorrhage, the number of devices and passes needed to achieve recanalization. The European Cooperative Acute Stroke Study radiological classification was used to score postprocedural hemorrhage as described.[19]

Clinical Outcomes

The primary functional outcome was the modified ranking score (mRS) at 90 d. An mRS of 0 to 2 was considered a good outcome and mRS scores above 3 were considered a poor outcome. The 90-d mRS scores was collected at the 3 mo follow-up visit (±14 d) by a stroke neurologist. The mRS scores for patient discharged to rehabilitation or who died before the 3-mo visit were collected via telephone encounters with rehabilitation facilities.

Statistical Analysis

Statistical analyses were performed using SPSS v24 (IBM Corporation, Armonk, New York) and Graphpad Prism 6 (Graphpad Software Inc, La Jolla, California). Comparisons were performed using the Student's *t*-test or ANOVA with Bonferroni's multiple comparisons for continuous measures. For noncontinuous variables, we used nonparametric *t*-test to compare 2 groups or Mann–Whitney test with Dunn's multiple comparisons for more than 2 groups. Categorical variables were compared using the $\chi 2$ test with likelihood ratios. Statistical significance was defined at $\alpha < 0.05$ using 2-sided tests.

RESULTS

Patient Baseline Characteristics

During the study period, 560 patients underwent ET for AIS. Fifteen patients were excluded from analysis since SR thrombectomy was used rather than ADAPT. Another 35 patients were lost to follow-up, and 510 patients were included in final analysis. Of the excluded patients, 5 patients (<1%) did not undergo ADAPT due to inability to deliver reperfusion catheter. The mean age at presentation was 67.7 ± 14.3 yr old (range: 21-96 yr), of which 50.6% were females and 56.5% were Caucasian (Table 1). Functional independence prior to stroke was present in 93.5% of the cases and the median mRS at baseline was 0. The average NIHSS on admission was 15.7 ± 7.4, and the average time from symptom onset to groin access was 438.8 ± 613.9 min. IV-tPA was received by 40.2% of patients prior to thrombectomy at our center or an outside hospital. Hypertension was the most common comorbidity among study patients (74.3%) and 16.3% had a prior stroke before admission.

Radiological Features

For patients with anterior circulation stroke (88% of all patients), the mean ASPECT stroke at presentation was 7.9 ± 2, ranging between 3 and 10 (Table 1). The distribution of vessels

TABLE 1. Patient Characteristics, Procedural Variables, and Outcomes of Patients Undergoing ADAPT Thrombectomy

Variable	n	Summary	Variable	n	Summary
Preprocedure			Initial device used (n [%])	510	
Age (yr)	510	67.7 (14.3)	3MAX		26 (5.1)
Female (n [%])	510	258 (50.6)	4MAX		32 (6.3)
White (n [%])	510	288 (56.5)	5MAX		55 (10.8)
Baseline NIHSS	503	15.7 (7.4)	5MAX ACE		132 (25.9)
Prestroke mRS (Med [IQR])	504	0 (1)	5MAX ACE 64		75 (14.7)
Prestroke mRS 0-2 (n [%])	504	471 (93.5)	5MAX ACE 68		180 (35.3)
Time from onset to groin (h)	479	438.8 (613.9)	Other		10 (2)
IV tPA (n [%])	510	205 (40.2)	Reperfusion at first pass (n [%])[a] ("One and done")	493	303 (61.8)
ASPECT Score (Anterior only)	481	7.9 (2.0)	Reperfusion by aspiration only (n [%])[a] ("One or more attempts")	493	380 (77.5)
Comorbidities (n [%])			Number of Passes (Med [IQR])	510	2 (3)
Diabetes	510	146 (28.6)	Final TICI flow (n [%])	510	
Hypertension	510	379 (74.3)	0		17 (3.3)
Afib	510	158 (31)	1		2 (0.4)
Hyperlipidemia	510	221 (43.3)	2A		19 (3.7)
Prior Stroke	509	83 (16.3)	2B		130 (25.5)
Anatomic Location			2C		75 (14.7)
Posterior Circulation	510	61 (12)	3		266 (52.3)
Vessels Involved (Med [IQR])	510	1 (1)	Complications (n [%])	510	16 (3.1)
Procedure			Hemorrhage, all types (n [%])	510	186 (36.5)
Time to recanalization (min)	493	27.4 (22.7)	Hemorrhage, PH2 (n [%])	510	25 (4.9)
IA tPA (n [%])	510	68 (13.3)	Outcome (90 d)		
Number of devices	510	2.1 (1.1)	mRS (Med [IQR])	510	3 (4)
Device type used (n [%])	510		mRS dichotomized (n [%])	510	
Reperfusion catheters only		324 (63.6)	mRS 0-2		219 (42.9)
Stent Retrievers		159 (31.2)	mRS > 2		291 (57.1)
Balloons		13 (2.5)	Death (n [%])	510	100 (19.6)
Stents		14 (2.7)	Length of stay (days)	510	10 (11.8)

AFIB, atrial fibrillation; IV tPA, intravenous tissue plasminogen activator; mRS, modified Rankin Scale; NIHSS, National Institutes of Health Stroke Scale; TICI, Thrombolysis in Cerebral Ischemia.

[a]Percentages reported are of the total number of ADAPT cases.

Values are n (%) or mean (SD) or Med (median) and IQR (inter quartile range).

subjected to ET among all patients is shown in Figure 1A. M1 occlusions were the most common (37%) followed by M2 (23.6%) and internal carotid artery (ICA) (13%), whereas basilar occlusions were the most common among posterior circulation strokes (7%; Figure 1A). The median number of vessels subjected to ET was 1 and the interquartile range was 1 to 2 (Table 1).

Procedural Variables

The average time to recanalization was 27.4 ± 22.7 min, and the median number of passes to achieve reperfusion was 2 with an interquartile range of 1 to 4 (Table 1). Overall, reperfusion (defined as TICI ≥ 2B) at first pass ("one and done") was achieved in 61.8% of the cases. Reperfusion was achieved with the use of reperfusion catheters alone with one or more attempts in 77.5% of all ADAPT cases. The average number of devices used per patient was 2.1 ± 1.1, and largest experience with the 4 reperfusion catheters involves the ACE 068 (35.3% of cases). Additional devices such as SR, balloons or stents were used in 31.2%, 2.5%, and 2.7% of cases, respectively (Table 1). Notably, in some instances SR were used in patients with TICI 2B after direct aspiration reperfusion to further improve flow or to revascularize additional branches. A final TICI flow of ≥2B was achieved in 92.5% of the cases of which 52.3% were rated as TICI 3 (Table 1). General anesthesia was used in 6% of patients with anterior circulation LVO and 31% of patients with posterior circulation LVO.

Complications and Clinical Outcomes

The overall complication rate was 3.1%, and documented complications included ST segment depression, nonflow limiting dissection of ICA, intraprocedural microperforation, and extravasation of contrast material (Table 1). The rate of

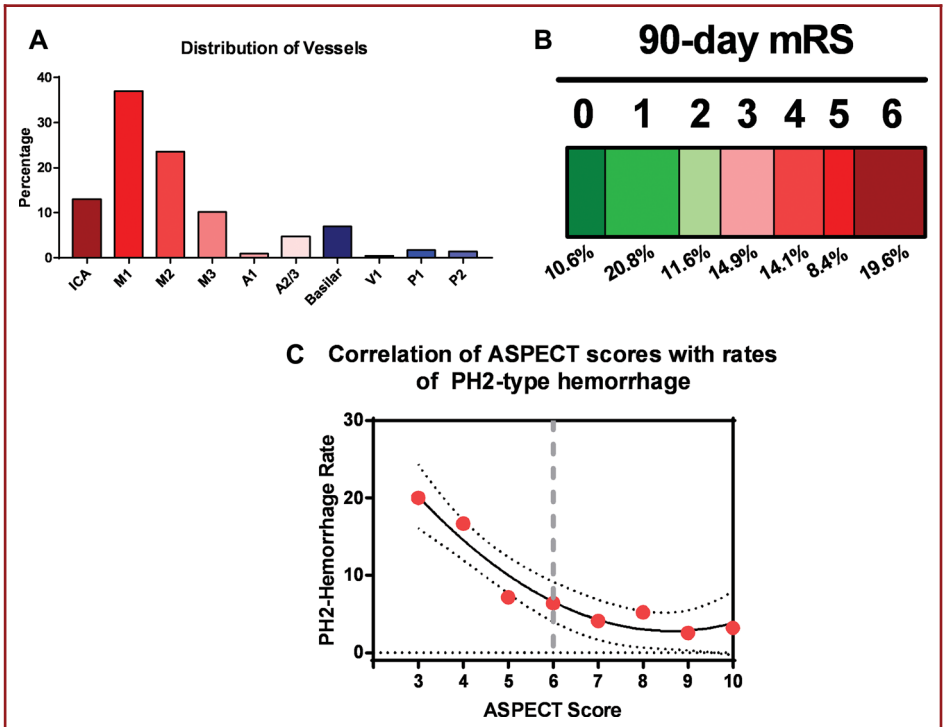

FIGURE 1. **A**, *Distribution of vessels among all patients undergoing ADAPT thrombectomy.* **B**, *Ninety-day functional outcomes among all patients undergoing ADAPT thrombectomy.* **C**, *Correlation of rates of PH2-type postprocedural hemorrhage and ASPECT scores among ADAPT patients. Decreasing ASPECT scores was associated with increase in rates of PH2-type hemorrhage with higher slopes between ASPECTs of 3 and 6. A second-degree polynomial was fitted to the data with* $R^2 = 0.9323$. *Dashed line represents the common threshold of ASPECT 6 used in the inclusion criteria of major trials.*

postprocedural hemorrhage was 36.5% of which only 4.9% were PH2-type hemorrhage (Table 1). A good outcome (mRS 0-2) at 90 d was achieved in 42.9% of all patients, and the median mRS at 90 d was 3 (Table 1; Figure 1B). Mortality rate at 90 d was 19.6% and the mean length of stay was 10 ± 11.8 d.

Our data also demonstrated the presence of negative correlation between the rates of PH2-type hemorrhage and the ASPECT scores at presentation with $R^2 = 0.9323$ (Figure 1C). The second-degree polynomial function shows a slow in decay and minimal variation after ASPECT score of 6 (Figure 1C).

Characteristics of Patients by Reperfusion Catheter

In order to evaluate whether the advances in catheter size between 5MAX, ACE 060, ACE 064 and ACE 068 reperfusion catheters (Penumbra) have impacted technical and clinical outcomes, we compared the population of AIS treated with one of these devices as the primary reperfusion catheter. Across the different devices, there were no significant differences in the patient demographics (age, gender, or race), or prestroke disability measured using the mRS ($P > .05$ for all variables). The mean NIHSS at presentation, use of IV-PA, and time from onset to groin access were also similar between the different device groups (Table 2). Although there were no significant differences in ASPECT scores between individual catheter pairs, comparison of larger catheters (ACE 64 and ACE 68) to smaller caliber catheters (5MAX and ACE) showed a significantly lower ASPECT scores in the former group (7.3 vs 7.9, $P < .05$). There were no significant differences in the percentage of patients who matched criteria used in major clinical trials across the different devices, and the rate across all patients was 31% (Table 2).

Technical Outcomes by Different Reperfusion Devices

Using larger catheters (ACE 068 and ACE 064), the likelihood of successful recanalization with aspiration only was significantly higher compared to 5MAX (80.5% and 84.9% compared to 61.1%, $P < .05$), but there was no significant difference between

TABLE 2. Patient Characteristics and Technical Outcomes Grouped by Different Reperfusion Catheters

Variable	5 MAX 0.054″ $n = 55$	ACE 0.060″ $n = 132$	ACE 64 0.064″ $n = 75$	ACE 68 0.068″ $n = 180$	*P*-value
Preprocedure					
Age (yr)	67.9 (15)	66.9 (13.2)	68.8 (14.6)	67.4 (15.1)	> .05
Female (n [%])	25 (45.5)	61 (46.2)	40 (53.3)	101 (56.1)	> .05
White (n [%])	28 (50.9)	79 (59.8)	50 (66.7)	90 (50)	> .05
Baseline NIHSS	16.1 (6.1)	15.2 (7.5)	16.5 (7.2)	17 (7.5)	> .05
Prestroke mRS (Med [IQR])	0 (1)	0 (1)	0 (1)	0 (1)	> .05
Prestroke mRS 0-2 (n [%])	48 (87.3)	121 (95.3)	72 (96)	166 (92.7)	> .05
Time from onset to groin (h)	317.4 (213.1)	486 (710.3)	399.8 (432.4)	493 (768.8)	> .05
IV tPA (n [%])	21 (38.2)	53 (40.2)	28 (37.3)	73 (40.6)	> .05
ASPECT Score (Anterior only)	7.8 (2)	7.9 (1.9)	8.4 (2.1)[a]	7.3 (1.9)[a]	> .05
Patients matching trial criteria [b] (n [%])	17 (30.9)	47 (35.6)	26 (34.7)	47 (26.1)	> .05
Technical variables					
Success with aspiration only (n [%])	34 (61)	103 (78)	**64 (85)***	**145 (81)***	**< .05**
Reperfusion at first pass (n [%])	30 (55)	83 (63)	47 (63)	123 (68)	> .05
Follow-up use of stent retriever (n [%])	23 (41)	45 (34)	**22 (29)***	**50 (28)***	**< .05**
Procedure time (min)	33 (28)	32 (27)	**19 (16)***	**24 (20)***	**< .05**
Tandem occlusions (n [%])	5 (9)	13 (10)	7 (9)	**35 (19)****	**< .05**
Complication rates (n [%])	2 (3)	3 (2)	2 (3)	5 (3)	> .05
Hemorrhage, PH2-type (n [%])	3 (6)	7 (5)	3 (4)	9 (5)	> .05

AFIB, atrial fibrillation; IV tPA, intravenous tissue plasminogen activator; mRS, modified Rankin Scale; NIHSS, National Institutes of Health Stroke Scale; TICI, thrombolysis in cerebral ischemia.

[a] $P < .05$ in comparison of combined ACE 64 and ACE 68 (7.3 ± 1.9) together to 5 MAX and ACE combined (7.9 ± 1.9).

[b] Trial criteria defined as anterior circulation (ICA/M1/M2) thrombectomy within 16 h of onset, admission NIHSS of at least 6, ASPECT of at least 6, and age between 18 and 80 yr.

*$P < .05$ compared to 5 MAX on multiple comparisons.

**$P < .05$ ACE 68 compared to each catheter.

Values are n (%) or mean (SD) or Med (median) and IQR (interquartile range).

Comparisons were made using chi-squared test with likelihood ratios for categorical data, Mann–Whitney test with Dunn's multiple comparisons for nonparametric data, and ANOVA with Bonferroni's test for multiple comparisons for parametric data.

Bolded values indicate statistical significance p < .05

ACE 060 and 5MAX ($P > .05$). There were no significant differences among all devices in the rates of reperfusion at first attempt (Table 2). Use of ACE 068 and ACE 064, but not ACE 060, was associated with significantly lower likelihood of requiring a SR compared to 5MAX (27.8% and 29.3% compared to 41.8%, $P < .05$; Table 2). Similarly, ACE 068 and ACE 064, but not ACE 060, resulted in significantly shorter procedure times compared to 5MAX ($P < .05$). We also compared the rates of tandem occlusions (ICA/MCA occlusions) performed under each catheter group showing that ACE 068 had significantly higher proportion of patients with tandem occlusions compared to ACE 064, ACE, or 5MAX ($P < .05$; Table 2). Finally, the overall trend showed a gradual decrease in use of SR and procedure times moving from smallest to largest catheter and an associated improvement in rates of successful recanalization with aspiration alone. There were no significant differences in intraprocedural complication rates or rates of PH2-type hemorrhage across the different devices (Table 2).

TABLE 3. Multivariate Logistic Regression for Predicting Good Outcome (mRS 0-2) at 90 d

Variable ($n = 476$)	OR	95% CI	*P*-value
Age	0.97	0.96-0.99	<.001
Female Gender	0.65	0.43-1.00	.05
White Race	0.88	0.57-1.34	.54
Admission NIHSS	**0.87**	**0.85-0.9**	**<.001**
Use of IV-tPA	0.92	0.6-1.42	.71
Complications	0.37	0.1-1.37	.14
Final TICI Flow (TICI 2B+)	**6.6**	**2.3-18.7**	**<.01**
PH2-type Hemorrhage	**0.32**	**0.1-0.99**	**<.05**
Time from onset to groin (min)	1	1.00-1.00	.33
Baseline Prestroke mRS	**0.68**	**0.52-0.9**	**<.01**
Number of treated branches	0.94	0.68-1.31	.72
Presence of Tandem Occlusions	0.97	0.32-2.96	.95
Use of ACE 068 Catheter	**1.6**	**1.00-2.46**	**<.05**

Bolded values indicate statistical significance p < .05

Clinical Outcomes by Different Reperfusion Devices

We then performed multivariate logistic regression analysis to assess for predictors of good outcomes in the context of different device sizes. As shown in Table 3, the use of ACE 068 reperfusion catheter was an independent predictor of good outcome (mRS 0-2) at 90 d (odds ratio [OR] = 1.6, $P < .05$). There were no differences in overall length of stay across the different device groups (average 10.2 d, $P > .05$).

DISCUSSION

The Case for Direct Aspiration

The year 2015 was a major landmark in the advancement of therapeutic options available for AIS care[2-10] since the NINDs trial of 1995,[20] with overwhelming evidence in support of thrombectomy over IV-tPA for LVO.[2-10] Following the results of 5 randomized controlled trials supporting the use of a SR as the primary method for thrombectomy, there is currently level 1A evidence for use of SR thrombectomy in acute stroke treatment as reflected in the most recently updated guidelines from the American Heart Association/American Stroke Association.[17] However, options for thrombectomy technique have now been expanded following the conclusion of the 2015 trials to include direct aspiration using ADAPT (Figure 2). Building on momentum from pilot data showing increased recanalization rates and decreased procedural times with direct aspiration,[13-16] 2 randomized controlled trials (Europe and US/Canada) of anterior circulation LVO treated within 6 h of symptom onset have recently reported the noninferiority of ADAPT compared to SR as the frontline modality for thrombectomy.[11,12] Thus, there is now level 1A evidence in support of direct aspiration as a front line strategy. While functional outcomes (90-d mRS) were equivalent, ADAPT was associated with faster recanalization times and lower procedural costs,[12] which may ultimately prove it the more cost-effective option. In this work, we report on our long-term experience with ADAPT thrombectomy, and assess the effect of technical advancement in reperfusion catheters on technical and clinical outcomes following ADAPT thrombectomy for ischemic stroke.

Patients included in our long-term experience reflect a real-world experience, and included patients who do not meet criteria for major trials. Older patients (80-96 yr old) along with both posterior circulation and distal anterior circulation strokes were taken for thrombectomy and longer symptom onset to treatment time was common (mean 7.3 h, range 0.5-72 h). Both baseline NIHSS and ASPECT scores were comparable to those reported in recent trials.[11,12] The rate of recanalization at first pass with ADAPT was 61.8%, and the rate of achieving TICI $\geq$ 2B by direct aspiration alone (without adjuncts) was 77.5% which is comparable to the numbers reported in both the ASTER and COMPASS trials.[11,12] The rate of functional independence at 90 d was 42.9% which is slightly lower outcomes reported in ASTER (45.3%)[11] and COMPASS (52%)[12]; however, this small difference is likely due to the fact that 33 patients underwent ADAPT in our cohort despite a baseline mRS of 3. Overall, our experience further supports the expansion of the application of ADAPT beyond the criteria used in clinical trials to include longer onset to groin access time and more distal occlusions and posterior circulation strokes, as this did not significantly affect our clinical outcomes in accordance with prior studies.[21,22]

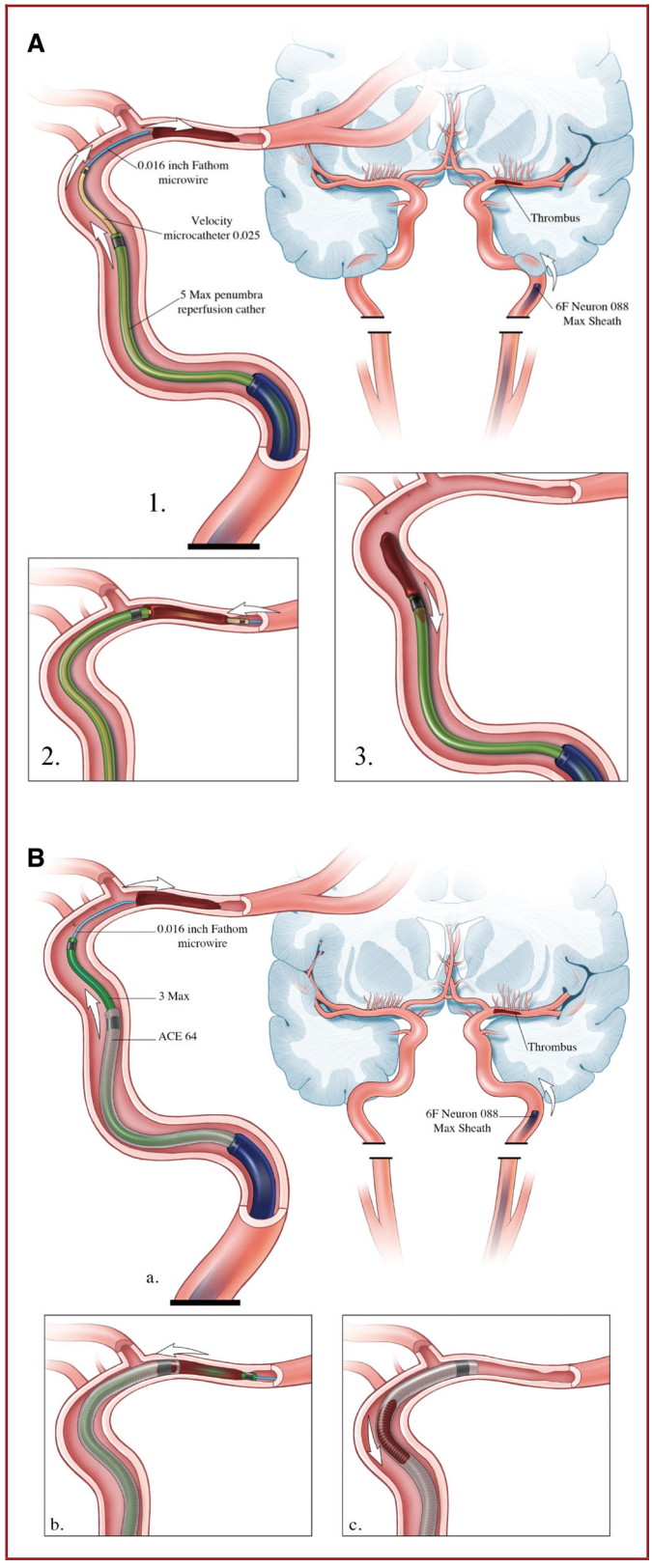

FIGURE 2. *Two versions of ADAPT.* **A**, *ADAPT 1.0 involved either the Penumbra 5MAX reperfusion catheter with an ID of 0.054" (Penumbra) or the 5MAX ACE (ID 0.060") for M1 or carotid terminus occlusions. 1. The 5Max or ACE 060 catheter is advanced, over a 025 Velocity microcatheter (Penumbra) and a 0.016-inch Fathom wire (Boston Scientific), to the proximal end of the thrombus. 2. Following the removal of the microcatheter and wire, the 5MAX or ACE 060 is gently advanced to the proximal aspect of the thrombus. 3. Direct aspiration applied to ensure firm purchase of the thrombus. Under continuous aspiration, the aspiration catheter is then slowly withdrawn, and the thrombi are typically removed en bloc.* **B**, *ADAPT 2.0 involved either the Penumbra ACE 064 or 068 reperfusion catheters (Penumbra) with ID of 0.064" and 0.068", respectively. a. The ACE 064 or 068 is advanced to the level of the thrombus over a 3Max (Penumbra) and an 0.016" Fathom wire (Boston Scientific Corp). b. The microcatheter and wire are then removed, and the catheter is gently advanced over the thrombus to "ingest" it. c. Direct aspiration is then applied and typically the thrombus is entirely ingested into the tubing of the aspiration system. After confirming patency of the lumen of the aspiration catheter, follow-up angiography can then be performed with injection of contrast directly into the aspiration catheter and further attempts at aspiration can be made without the need to deliver the catheter over the carotid siphon again.*

Catheter Advancements and Direct Aspiration Technique

Recent advances in catheter technology have allowed for direct aspiration to be performed by providing the capability of safe and quick navigation of large caliber aspiration catheters to the intracranial circulation to engage the thrombus.[13,14,16] The choice of aspiration catheter to perform ADAPT is based on the caliber of the target vessel while taking into account that larger diameters yield greater aspiration forces (Figure 3). The first iteration of ADAPT at our institution involved a Penumbra 5Max reperfusion catheter with an ID of 0.054" (Penumbra) for M1 or carotid terminus occlusions. In this first iteration, 5Max was advanced, over an 025 Velocity microcatheter (Penumbra) over a 0.016 inch Fathom wire (Boston Scientific Corp, Marlborough, Massachusetts), to the proximal end of the thrombus. Following the withdrawal of the microcatheter and wire, aspiration was applied using a 20 to 30 mL syringe or the Penumbra aspiration pump.[14] The catheter is then advanced slightly to allow for adequate engagement with the thrombus prior to withdrawal under continued aspiration. To prevent the detachment of the thrombus as the 5Max is withdrawn into the sheath, aspiration was applied to the guide catheter using the sideport. In the second iteration of the aspiration catheter using the 5Max ACE with increased ID of 0.060" at the distal 30 cm and 0.068" proximal end, a larger aspiration force can be applied. Utilizing the 5Max and ACE catheters, clots typically were engaged at the distal catheter tip and retrieved en bloc (Figure 2A). Pilot single and multicenter data from direct aspiration with these first iterations showed promising results with faster recanalization times and reduced cost.[13,14,18]

Further advances in catheter technology allowed for the safe delivery of even larger-bore catheters to the intracranial circulation. With the introduction of the ACE 064 and the ACE 068 (Penumbra), the direct aspiration technique was refined further. Due to their larger caliber, the 025 delivery catheter was replaced with a 3Max (Penumbra), intermediate catheter with an 035 tip. Owing to the larger aperture of these catheters, the aspiration catheter can now be advanced directly over the thrombus, to "ingest" the thrombus which is now typically aspirated directly into the catheter without having to remove it

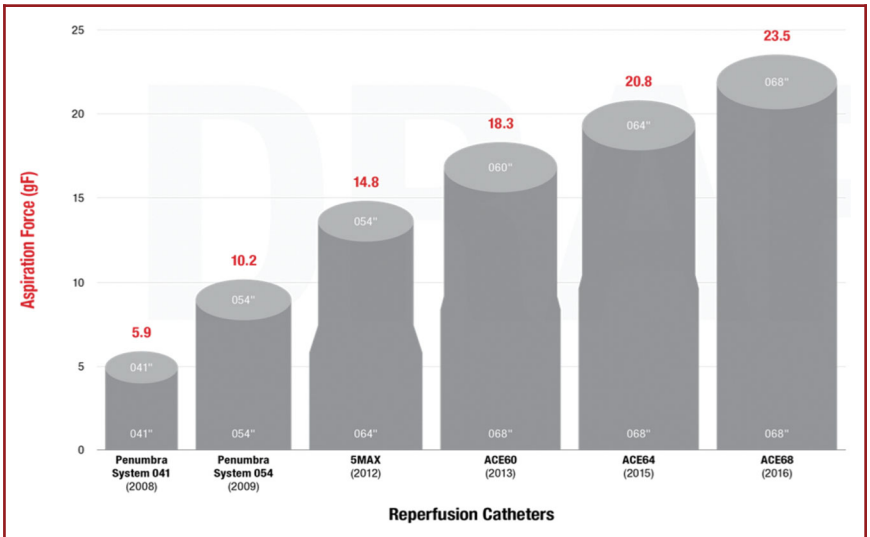

FIGURE 3. *Illustration depicting the iterations of direct aspiration catheters. Side by side depiction allows for ease of comparison between the various sizes of ID at the distal end which in conjuncture with larger proximal ID have led to greater aspiration force.*

(Figure 2B). To achieve "ingestion" of the thrombus, the 064 or 068 is advanced over the clot with forward advancement of the aspiration catheter and simultaneous withdrawal of the delivery catheter and microwire. The advantage of clot ingestion, over clot engagement and withdrawal into the guide catheter, is that it minimizes the likelihood of clot fragmentation and losing purchase of the thrombus. In addition, the aspiration catheter can remain in place for follow-up angiography and/or further aspiration attempts, if necessary, without having to renegotiate the carotid siphon and ophthalmic turn. For example, after ingestion of an M1 thrombus is achieved, rather than pulling the aspiration catheter through the guide and out of the patient, it remains at the M1 segment to serve as an immediate conduit for the next thrombectomy attempts. This provides significant technical advantages especially with procedural duration, an important predictor of outcome after thrombectomy.[15,18]

Catheter Size, Recanalization Success, and Outcomes

In the largest experience of ADAPT reported to date, we have demonstrated that larger catheter size has yielded more frequent technical success and better clinical outcomes while maintaining a similar safety profile to smaller catheters. The likelihood of successful recanalization with aspiration only was significantly higher with ACE 064 and 068 compared to 5MAX, with a concomitant lower likelihood of requiring a SR as a rescue modality if aspiration has failed. This finding has significant economic implications.[14,23] Additionally, larger bore catheters were associated with faster time to recanalization, while having equivalent rates of intraprocedural complications and postprocedural hemorrhages. The faster time of recanalization was seen in ACE 068 despite significantly higher proportion of tandem occlusions compared to smaller catheters (ACE or 5MAX), thus increasing the significance of the overall impact on procedure time. Improvement in technical outcomes with the use of ACE 068 was also clinically significant given the use of ACE 068 was an independent predictor of favorable outcomes at 90 d on multivariate analysis. This is anticipated given the impact of ACE 068 use on procedure time and rates of using additional devices that have been shown to be associated with less favorable outcomes.[15,18]

Limitations

The study is a retrospective review of patients undergoing endovascular thrombectomy (ET) at a single institution. In addition, the sample size in the 5MAX was relatively low (n = 55) compared to the other catheters which may have reduced the power to detect clinical improvement in outcomes with advanced catheter size. However, a low number of patients were included in the 5MAX group due to the shift toward using more efficient catheters during the study period. Finally, during the study period, larger catheters were used later in time, and thus the influence of increased institutional and individual experience on outcomes cannot be ruled out.

CONCLUSION

Since the initial investigation of ADAPT as an alternative to SR thrombectomy for AIS from LVO, direct aspiration catheter technology has undergone rapid iterative advancements. In our experience, the greater aspiration forces provided by the larger ID have resulted in greater success of aspiration, faster time to recanalization and lower procedural cost, without any demonstrable negative effect on the safety profile.

Disclosures

Dr Spiotta has the following disclosures: Penumbra, Consulting, Honorarium, Speaker Bureau; Pulsar Vascular, Consulting, Honorarium, Speaker Bureau; Microvention, Consulting, Honorarium, Speaker Bureau, Research; Stryker, Consulting, Honorarium, Speaker Bureau. Drs Turk, Turner, and Chaudry have the following disclosures: Codman, Consulting, Honorarium, Speaker Bureau, Research Funding; Covidien, Consulting, Honorarium, Speaker Bureau; Penumbra, Consulting, Honorarium, Speaker Bureau, Research Grants; Microvention, Consulting, Honorarium, Speaker Bureau, Research Grants; Blockade, Stock, Consulting, Honorarium, Speaker Bureau; Pulsar Vascular, Stock, Consulting, Honorarium, Speaker Bureau, Research; Medtronic, Consulting, Honorarium, Speaker Bureau. The other authors have no personal, financial, or institutional interest in any of the drugs, materials, or devices described in this article.

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COMMENTS

The authors present the largest series of intracranial thrombectomy using A Direct Aspiration Approach as First Pass Technique (ADAPT). During the interval of treatment from January 2013 to November 2017 they treated 510 patients with a successful recanalization rate of 77.5% with aspiration only. Also during this interval, newer catheters came onto the market possessing larger inner diameters and the ability to successfully navigate the intracranial circulation. The introduction of these larger catheters was correlated with increased recanalization rates as well as lower procedure times when compared to smaller catheters. This study shows the effectiveness of these larger catheters as well as the potential for further advances in technology. The authors outline a very standardized approach to acute ischemic stroke intervention and demonstrate quite well that in well-trained hands, the ADAPT thrombectomy is a very safe and effective method. It should also be noted that this study represents the work and effort at a high-volume comprehensive stroke center with fully-trained interventional neurosurgeons. Without proper training, it would be unwise to assume that their results could be easily replicated at a center without the same volume or comprehensive status.

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In this retrospective case series, the authors report their extensive experience using the A Direct Aspiration First Pass Technique (ADAPT) strategy for thrombectomy in more than 500 patients with acute large vessel occlusions (LVOs). The authors were able to access the proximal intraluminal clot with the reperfusion catheter in nearly all cases. First-pass reperfusion with ADAPT occurred in 62% of patients, and successful recanalization with ADAPT alone occurred in 78%. Subsequent alternative reperfusion strategies (mainly with a stent retriever) were employed in patients in whom recanalization was a failure after ADAPT. Overall reperfusion (modified Thrombolysis in Cerebral Ischemia [mTICI] 2b, 2c, or 3) occurred in 93% of patients. With the more recent larger inner-diameter reperfusion catheters (eg, ACE64 and ACE68 [Penumbra]) in comparison with the early smaller reperfusion catheters (eg, ACE and 5MAX [Penumbra]), the authors were able to recanalize the occluded arteries more quickly and were less likely to use alternative salvage endovascular strategies. The use of larger reperfusion catheters also increased the odds of good clinical outcome at 90 days and lowered procedural cost. The complication rate was low, regardless of reperfusion catheter type. The authors concluded that advancements in catheter technology and refinements in the ADAPT strategy have led to improved recanalization rates and clinical outcomes in patients with acute LVO.

When combining the data from the 5 major thrombectomy randomized trials in patients with anterior circulation LVO (MR CLEAN, ESCAPE, REVASCAT, SWIFT PRIME, and EXTEND IA), the HERMES collaborators demonstrated an overall 71% recanalization rate (mTICI 2b/3), using predominantly stent retrievers.[1] At the time, less was known about the outcomes using aspiration techniques such as ADAPT. Turk and colleagues[23] had published their promising results using ADAPT in their initial single-center series and supported with a subsequent larger multicenter series. Due to the effectiveness of thrombectomy in the randomized trials, The Randomized Concurrent Controlled Trial to Assess the Penumbra System's Safety and Effectiveness in the Treatment of Acute Stroke (THERAPY) trial, comparing aspiration thrombectomy after intravenous alteplase to intravenous alteplase alone, was terminated early due to loss of equipoise, leading to inconclusive results.[4] Randomized trials, including The Contact Aspiration vs Stent Retriever for Successful Revascularization (ASTER) and Comparison of Direct Aspiration vs Stent Retriever as a First Approach (COMPASS), have recently demonstrated noninferiority of aspiration thrombectomy to stent retrievers in patients with LVO.[5,6]

The authors are to be commended for publishing their results with ADAPT in a large series of patients, providing a benchmark for recanalization rates in very experienced hands. We suspect that the improved recanalization rates and clinical outcomes over time using ADAPT were due to not only improved reperfusion catheters with larger inner diameters and higher aspiration forces but also increased comfort and experience with the technique. Importantly, stent retrievers were still used by the authors in a minority of salvage cases and so both strategies are essential in the interventionist's armamentarium. Our center has had extensive experience with both techniques and has contributed extensively to these randomized trials. However, further improvements in thrombectomy devices and techniques are needed. We can all do better.

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