

Treatment of Acute Cerebral Artery Occlusion Using the Penumbra System: Our Early Experience

Atsushi SHINDO,¹ Masahiko KAWANISHI,¹ Kenya KAWAKITA,¹
Masanobu OKAUCHI,¹ Nobuyuki KAWAI,¹ Naoki HAYASHI,²
Naohiro OSAKA,² and Takashi TAMIYA¹

¹*Department of Neurological Surgery, Kagawa University Faculty of Medicine, Kita-gun, Kagawa;*

²*Department of Neurological Surgery, Osaka Neurosurgical Hospital, Takamatsu, Kagawa*

Abstract

Intravenous recombinant tissue-type plasminogen activator (rt-PA) therapy is highly recommended to patients who are diagnosed with ischemic stroke within 4.5 hours after the onset while mechanical clot retrieval can be attempted in patients who are not indicated for or cannot effectively receive intravenous rt-PA therapy. In this article, we report early treatment outcomes and discuss the usefulness of mechanical clot retrieval using the Penumbra system (Penumbra Inc., Alameda, California, USA), especially in terms of technical cautions during the procedure and adaptability to elderly and high National Institutes of Health Stroke Scale (NIHSS) patients. We included 7 patients with thromboembolic occlusion. Pre-treatment NIHSS score ranged from 11 to 36 (mean: 24.9). All patients achieved good recanalization [thrombolysis in cerebral infarction (TICI) grade 2a or greater] without complications. The NIHSS score at 30 days after the treatment ranged between 0 and 28 (mean: 12.4), and improved more than 10 points in 4 of the 7 patients (57.1%). To obtain good recanalization without complications, selection of suitable reperfusion catheter and careful manipulation of separator prefiguring the occluded distal vessels are essential. The improved NIHSS score at 30 days after the treatment may have led to favorable results, such as an increased participation in available rehabilitation programs and the alleviation of the burden of care. Our findings suggest that the Penumbra system might be effective for treatment in elderly patients or patients with high NIHSS score wherein rt-PA therapy is inadvisable or ineffective in ischemic stroke secondary to large vessel occlusion. Recanalization can improve their quality of life on condition that the procedure is performed successfully without serious complications.

Key words: Penumbra system, ischemic stroke, clot retrieval, recanalization

Introduction

Intravenous recombinant tissue-type plasminogen activator (rt-PA) therapy is generally administered to patients within 4.5 hours after the onset of symptoms associated with ischemic stroke. Conversely, mechanical clot retrieval using the Penumbra system (Penumbra Inc., Alameda, California, USA) is an alternative approach to attempt recanalization in patients whereby intravenous rt-PA therapy is not advised or is not effective.^{1–3)} The Penumbra system is a mechanical clot retriever for acute occlusion of the intracranial artery, which has been available in Japan since October 2011. Here, we report our early treatment outcomes and discuss the usefulness

of mechanical clot retrieval using the Penumbra system especially in terms of technical cautions during the procedure and adaptability to elderly and high National Institutes of Health Stroke Scale (NIHSS) patients in cases of embolic intracranial arterial occlusion.

Materials and Methods

Between November 2011 and October 2012, mechanical clot retrieval was performed at our hospital by using the Penumbra system. The patients who did not undergo intravenous rt-PA therapy due to delayed arrival or unclear onset time, and those whose recanalization could not be observed in DSA 1 hour after the intravenous rt-PA therapy, were included in the study. A high signal intensity area was examined

on diffusion-weighted imaging (DWI) in all patients, which accounted for less than 50% of the area supplied by the occluded vessel. The extent of early ischemic change on DWI was assessed by the Alberta Stroke Programme Early Computed Tomography Score (ASPECTS) +W proposed by the ASIST-JAPAN (<http://asist.umin.jp/>). During this period, the Penumbra system was used in 8 patients. However, to evaluate only the patients treated for embolic occlusion, 1 patient with acute occlusive disease caused by arteriosclerotic stenosis was excluded from the study. In the Penumbra system, aspiration and retrieval of the thrombus are achieved by introducing a reperfusion catheter for aspiration to the site of occlusion with thrombus and putting an attached separator into and out of the catheter to apply negative pressure with a pump.^{1,2,4-6} The treatment was performed under general anesthesia or deep sedation in all patients. The Penumbra reperfusion catheters 054 and 032 were used in 6 patients, and the Penumbra 041 was used in 1 patient. The patients were 4 men and 3 women, aged 64 to 86 years (mean: 71.7 years). The sites of occlusion included the internal carotid artery in 1 patient, anterior and middle cerebral arteries in 1 patient, middle cerebral artery in 4 patients, and basilar artery in 1 patient (Table 1). Three of the 7 patients had atrial fibrillation. We assessed pre-treatment Glasgow Coma Scale (GCS) scores, NIHSS scores, post-treatment thrombolysis in cerebral infarction (TICI) grades, duration of treatment, pre- and post-treatment magnetic resonance imaging (MRI), and modified Rankin Scale (mRS) scores at 30 and 180 days after the treatment.

Results

The patient characteristics and treatment results are

summarized in Tables 1 and 2. The pre-treatment NIHSS score ranged from 11 to 36 (mean: 24.9), and GCS score from 6 to 12 (mean: 8.0). The time from onset to puncture ranged from 180 to 380 min (mean: 269.0 min, onset time was unknown in 2 patients), the time from onset to recanalization from 240 to 465 min (mean: 346.0 min), and the time from admission to puncture from 60 to 168 min (mean: 119.9 min).⁷ The time from puncture to recanalization spanned from 46 to 105 min (mean: 75.9 min), the time from the start of aspiration to recanalization from 11 to 50 min (mean: 26.1 min), and the actual aspiration time from 6 to 20 min (mean: 11.1 min). The mean volume of blood aspirated was 134.3 mL (range: 100 to 250 mL). All patients showed complete or near-complete recanalization of the occluded arteries with the post-treatment TICI grades of 2a or more, and 5 of the 7 patients (71.4%) had the TICI grades of 2b or more. No patients experienced complications including intracranial hemorrhage in association with the procedure. The NIHSS score at 30 days after the treatment ranged from 0 to 28 (mean: 12.4) and improved more than 10 points in 4 of the 7 patients (57.1%). The mRS scores at 30 days after the treatment were 0 in 1 patient, 4 in 5 patients, and 5 in 1 patient; and the mRS scores at 180 days after the treatment were 0 in 1 patient, 3 in 1 patient, 4 in 4 patients, and 5 in 1 patient. Representative cases are presented below.

I. Case 2: A 71-year-old woman (Fig. 1)

The time of onset was unclear. The patient was lethargic and showed right hemiplegia with a GCS score of 12 (E4V2M6) and NIHSS score of 11. Electrocardiogram showed arterial fibrillation. Magnetic resonance angiography (MRA) showed occlusion of the left internal carotid artery although DWI showed

Table 1 Patient characteristics and clinical outcome

Case	Age/ Sex	Location	GCS	NIHSS	ASPECTS + W pre/post	NIHSS (30 days)	mRS (30 days)	mRS (180 days)	Complication
1	71/F	R.ICA	7	19	5/4	13	4	4	(-)
2	71/F	L.A1&M1	12	11	11/10	0	0	0	(-)
3	64/M	R.M1	11	20	7/7	8	4	4	(-)
4	68/F	L.M1	6	36	5/4	28	5	5	(-)
5	78/M	L.M1	6	23	5/4	16	4	4	(-)
6	86/M	L.M2	7	30	9/7	16	4	3	(-)
7	64/M	BA top	7	35	NA	6	4	4	(-)

(-): absent. ASPECTS: Alberta Stroke Programme Early Computed Tomography Score, BA: basilar artery, F: female, GCS: Glasgow Coma Scale, ICA: internal carotid artery, L.: left, M: male, mRS: modified Rankin Scale, NA: not available, NIHSS: National Institutes of Health Stroke Scale, R.: right.

Table 2 Summary of treatment and radiological result

Case	Device	Onset to puncture time (min)	Onset to recanalization time (min)	Admission to puncture time (min)	Puncture to recanalization time (min)	Aspiration time (min)	Aspiration volume (mL)	TICI
1	054 032	260	315	111	55	10	100	2a
2	054 032	(-)*	(-)*	60	46	8	110	3
3	054 032	180	240	150	60	8	120	2b
4	054 032	325	430	115	105	6	100	2b
5	054 032	380	465	68	85	11	120	2a
6	041	200	280	168	80	20	140	2b
7	054 032	(-)*	(-)*	167	100	15	250	2b

*Onset time is unknown. TICI: thrombolysis in cerebral infarction.

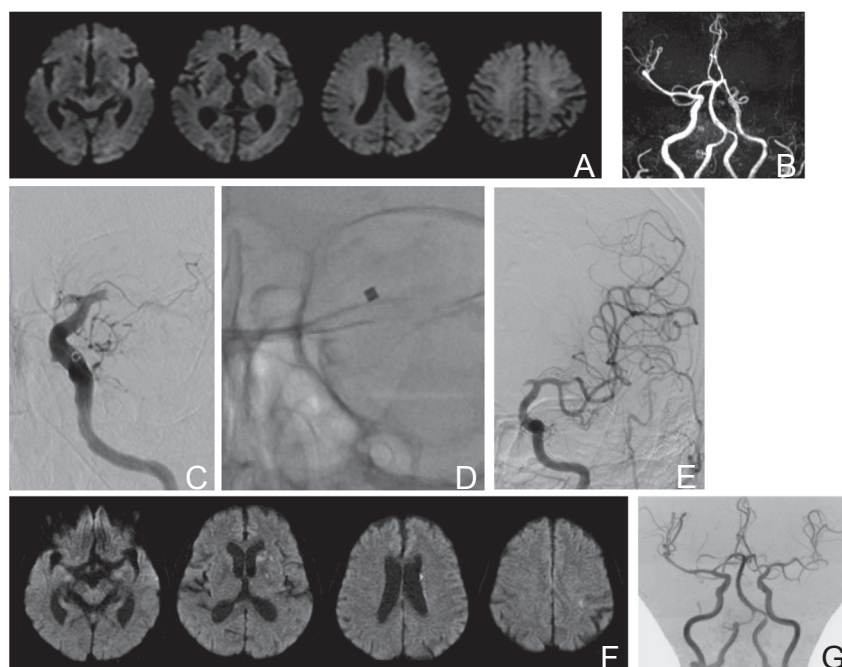


Fig. 1 A: The DWI on admission showed no acute cerebral infarction. B: Occlusion at the end of the left internal carotid artery was shown on MRA. C: The end of the left internal carotid artery was visualized and occlusion of the A1 and M1 segments were shown on cerebral angiography. D: The Penumbra reperfusion catheter 054 was guided to the left M1 segment. E: A complete recanalization of the left middle cerebral artery was achieved. F: The DWI performed on the following day of recanalization therapy showed a small cerebral infarction of the left basal ganglia, which was asymptomatic. G: The MRA performed on the following day of recanalization therapy demonstrated a complete recanalization. DWI: diffusion-weighted imaging, MRA: magnetic resonance angiography.

no high signal intensity area (ASPECTS+W score of 11). After general anesthesia, cerebral angiography was performed, showing visible end of the left internal carotid artery but occluded A1 and M1 segments. We attempted mechanical recanalization of the left

middle cerebral artery alone because good collateral blood flow was noted in the area of the left anterior cerebral artery through the anterior communicating artery. A 7-Fr guiding sheath was placed in the left internal carotid artery and a micro guide wire was

introduced to the M2 segment of the left middle cerebral artery. The Penumbra 054 was advanced just before the thrombus in the M1 segment with the Penumbra 032 arranged coaxially, and aspiration through the Penumbra 054 was initiated using a separator. The thrombus was located in the M1 segment, and the angle of the M1–M2 bifurcation was obtuse and the separator could easily be advanced to the M2 segment. A complete recanalization of the middle cerebral artery was achieved in a short period of time. The TICI score of the M1 segment was 3, and no hemorrhagic complications were observed in brain CT after the treatment. The time from puncture to the start of aspiration was 26 min, and the time from the start of aspiration to recanalization was 20 min (the actual aspiration time was 8 min). The volume of blood aspirated was 110 mL. The DWI obtained on the following day showed a small cerebral infarction in the basal ganglia, and the ASPECTS+W score was 10. At 30 days after the onset, both NIHSS and mRS scores were 0. The patient was discharged on foot 19 days

after the onset. mRS score remained 0 at 180 days after the onset.

II. Case 4: A 68-year-old woman (Fig. 2)

The patient was admitted to the hospital 210 min after the onset of stroke. The patient was semicomatose and showed right hemiplegia with a GCS score of 6 (E1V1M4) and NIHSS score of 36. Electrocardiogram showed arterial fibrillation. MRA showed occlusion of the M1 segment of the left middle cerebral artery, and DWI revealed a high signal intensity in approximately 50% of the area including the left middle cerebral artery. The ASPECTS+W score was 5. We attempted recanalization because the DWI showed no high signal intensity in the area supplied by the superior trunk of the left middle cerebral artery and the perforating branches of the M1 segment, and we considered that recanalization might prevent infarction of these areas. After general anesthesia, a 7-Fr guiding sheath was placed in the left internal carotid artery and a micro guide wire was introduced to the left M2 segment.

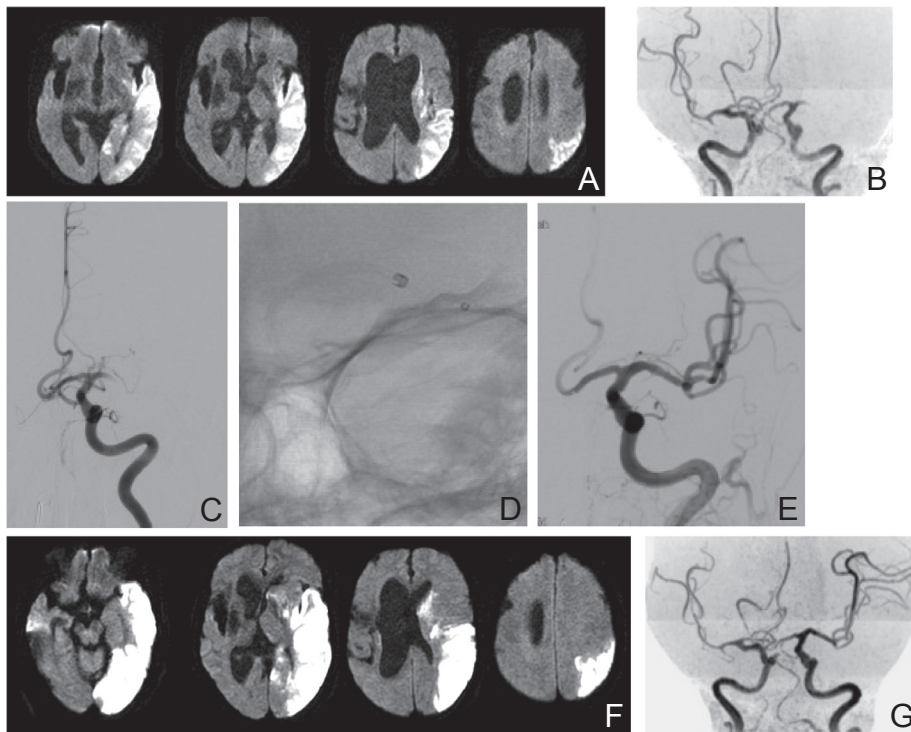


Fig. 2 A: The DWI on admission showed high signal intensity in the area of the left middle cerebral artery. B: Occlusion of the M1 segment of the left middle cerebral artery was shown on MRA. C: Cerebral angiography showed occlusion of the M1 segment of the left middle cerebral artery. D: The Penumbra reperfusion catheters 054 and 032 were guided to the left M1 segment. E: Recanalization of the left middle cerebral artery was achieved. F: The DWI performed on the following day of recanalization showed a slight increase in infarction volume in the basal ganglia, but revealed no new cerebral infarction in the area supplied by the superior trunk of the middle cerebral artery. G: The MRA performed on the following day of recanalization therapy demonstrated no reocclusion of the recanalized vessels. DWI: diffusion-weighted imaging, MRA: magnetic resonance angiography.

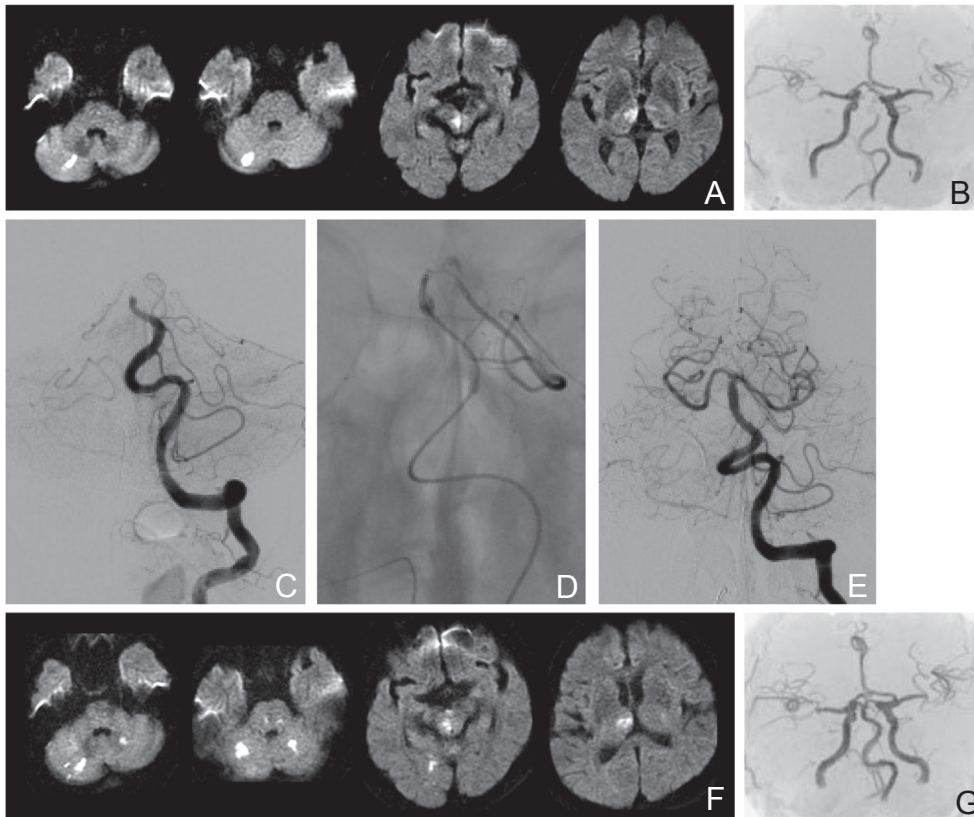


Fig. 3 A: The DWI on admission showed a high signal intensity area in part of the brainstem, thalamus, and cerebellum. B: Occlusion of the end of the basilar artery was shown on MRA. C: Cerebral angiography showed occlusion at the end of the basilar artery. D: The Penumbra reperfusion catheter 054 was guided to the basilar artery. The left superior cerebellar artery was visualized on the imaging performed before the start of aspiration. E: Recanalization of the basilar artery was achieved. F: The DWI performed on the following day of recanalization showed an increase in infarction volume in the cerebellum and brainstem, but revealed no new extensive cerebral infarction. G: The MRA performed on the following day of recanalization therapy demonstrated no reocclusion of the recanalized vessels. DWI: diffusion-weighted imaging, MRA: magnetic resonance angiography.

The Penumbra 054 was advanced just before the thrombus in the M1 segment with the Penumbra 032 arranged coaxially, and aspiration through the Penumbra 054 was initiated using a separator. The thrombus was located at the M1–M2 bifurcation. When aspiration was continued patiently, the M1–M2 bifurcation appeared gradually and the M2 segment was actually trifurcated. When the Penumbra 032 coaxially inside the Penumbra 054 was guided near the M1–M2 bifurcation and the separator was moved within the safe range, three branches of the M2 segment were eventually recanalized. The TIC1 score was 2b, and no hemorrhagic complications were noted in brain CT after the treatment. The time from puncture to the start of aspiration was 55 min, and the time from the start of aspiration to recanalization was 50 min (the actual aspiration time was 6 min). The volume of blood aspirated was 100 mL. The DWI performed on the following

day showed a slight increase in infarction volume (ASPECTS+W of 4), but MRA revealed no reocclusion of the middle cerebral artery. At 30 days after the onset, NIHSS score was 28, and mRS score was 5. The patient was transferred to rehabilitation hospital 29 days after the onset. mRS score remained 5 at 180 days after the onset.

III. Case 7: A 64-year-old man (Fig. 3)

The time of onset was unclear. On admission, the patient was semicomatose and showed left hemiplegia with a GCS score of 7 (E1V1M5) and NIHSS score of 35. Occlusion at the end of the basilar artery was revealed on MRA, and a high signal intensity area was shown on DWI in part of the right brainstem, thalamus, and cerebellum. After general anesthesia, cerebral angiography showed an occlusion of the end of the basilar artery with thrombus and bilateral posterior cerebral arteries that were

supplied by the posterior communicating artery. A 7-Fr guiding sheath was placed in the left vertebral artery and a micro guide wire was introduced to the left posterior cerebral artery. Then, the Penumbra reperfusion catheter 054 was guided to the basilar artery with the Penumbra 032 inserted coaxially, and aspiration was initiated. Although we could introduce the Penumbra 054 at an ideal location just before the thrombus, we could not move the separator in the full range because the separator was advancing in the perforating branch instead of passing through the thrombus in the direction of the posterior cerebral artery. Therefore, we continued aspiration by carefully putting the separator into and out of the catheter, then the thrombus was aspirated gradually and recanalization of the end of the basilar artery was finally achieved. The cerebral angiography showed occlusion of the P3 segment of the right posterior cerebral artery, but we discontinued the manipulation because it seemed to be difficult to achieve mechanical recanalization of this area. The TICI score was 2b, and no hemorrhagic complications were observed in brain CT after the treatment. The time from puncture to the start of aspiration was 70 min, and the time from the start of aspiration to recanalization was 30 min (the actual aspiration time was 15 min). The volume of blood aspirated was 250 mL. The DWI performed on the following day showed a slight increase in infarction volume, and MRA showed no reocclusion of the basilar artery. At 30 days after the onset, NIHSS score was 6 and mRS score was 4. The patient was clear at that time but still had left hemiplegia, and transferred to rehabilitation hospital 38 days after the onset. mRS score was 4 at 180 days after the onset.

Discussion

As of May 2013, the Merci retrieval system (Concentric Medical Inc., Mountain View, California, USA) and the Penumbra system are available as two mechanical clot retrievers in Japan. The Penumbra system has been reported to offer higher recanalization rates in a short period of time as compared to the Merci retrieval system.^{2-5,8-11)} The reperfusion catheter of the Penumbra system is produced in sizes 054, 041, 032, and 026 with a dedicated separator attached to each catheter. In Japan, the reperfusion catheter is available in 054, 041, and 032. The reperfusion catheter is guided to the exact proximal portion of the thrombus, and the thrombus is aspirated by putting the separator into and out of the reperfusion catheter.^{2,4,5,8,11)} The reperfusion catheter with the largest diameter is Penumbra 054,

which is frequently used for the thrombus located in the internal carotid artery to the proximal middle cerebral artery M1, and for the vertebral artery to the basilar artery.¹¹⁾ We had concerns about guiding the catheter to the M1 segment, but the catheter was flexible and easily passed through the internal carotid artery siphon by using a coaxially mounted Penumbra 032.¹¹⁾ If a common 18 size microcatheter is inserted coaxially during this procedure, the tip of the Penumbra 054 may damage the vessel wall when the catheter is advanced through the flexion point because of the difference in the diameters of the microcatheter and the Penumbra 054.¹¹⁾ Furthermore, because steam shaping of the reperfusion catheter is possible to some extent, slightly bending the tip of the catheter before the procedure may facilitate the catheter passing through the internal carotid artery siphon. The catheter is very flexible and the inner lumen of the catheter can be narrowed or distorted by merely tightening the Y-connector of the guiding catheter.

The reperfusion catheter must be precisely guided to the proximal portion of the thrombus and the separator must be out by approximately 4 mm from the tip of the catheter to successfully aspirate the thrombus. However, one cannot put the separator into and out of the catheter with confidence because the distal vascular structure cannot usually be identified based on the thrombus.¹¹⁾ When guiding the reperfusion catheter, one should first guide a typical microcatheter to the distal part of the thrombus, and inject a small amount of contrast agent from the microcatheter to ensure that the catheter is advanced in the true vessel lumen, and then guide the reperfusion catheter using the exchange method.¹¹⁾ During this procedure, the course of the visualized distal vessels should be carefully observed. If the separator is advancing in the direction of the expected distal vessels, the separator can be used relatively safe. However, when the thrombus is located at the M1–M2 bifurcation or the end of the basilar artery, the separator is likely to come out of the catheter and move straight ahead, and sometimes advances to the vessel walls or perforating branches. In this case, the separator should not be forcefully pushed forward. In principle, we perform this manipulation under general anesthesia or deep sedation because patient's movement can prevent us from performing the procedure safely.

During thrombus aspiration, it is necessary to select a catheter with a diameter that is similar to that of the occluded vessel. If a reperfusion catheter with a clearly smaller diameter than that of the occluded vessel is used, then restored blood flow may cause peripheral dispersion of the disrupted

thrombus that could not be completely aspirated.^{3,6)} Partial occlusion of the peripheral blood vessels was observed after recanalization of the occluded segment in Cases 4 and 7 in our study. We used catheters of the largest available size in these cases. Despite this, the disrupted thrombus was considered to disperse the peripheral vessels after restoring the blood flow.

After the reperfusion catheter was guided to the thrombus, the mean time from puncture to recanalization was 75.9 min, the mean time from the start of thrombus aspiration to recanalization was 26.1 min, and the mean actual aspiration time was 11.1 min. All patients achieved significant recanalization of TICI grade 2a or greater. For effective thrombus aspiration, fine location adjustment of a reperfusion catheter is necessary. If the catheter is located in an unstable position and advanced too far by mere chance, or the catheter does not reach the thrombus, the thrombus cannot be effectively aspirated. When the thrombus is effectively aspirated, a high recanalization rate can be achieved in a very short period of time. Aspiration is typically accomplished using a pump, but some researchers have reported that better recanalization was achieved by manual aspiration using a syringe.¹⁾ The mean volume of blood aspirated until recanalization was 134.3 mL, and no patients required blood transfusion after the surgery. Although there is little need to care about total blood loss due to aspiration during the procedure, the possibility of requiring blood transfusion after the surgery cannot be excluded.

In the Penumbra Pivotal Stroke Trial, 81.6% of the patients were successfully treated with the post-treatment thrombolysis in myocardial infarction (TIMI) grades of 2 or more. Moreover, 24% of the patients achieved good clinical outcome at 30 days as defined by a composite to the discharge NIHSS score of 0–1 or improvement of over 10 points, as well as a 30-day mRS score of less than 2.⁴⁾ Although recanalization of TICI grades 2a or more was achieved in all 7 patients in our study, mRS scores after 30 days were 0 in 1 patient, 4 in 5 patients, and 5 in 1 patient, and mRS scores after 180 days were 0 in 1 patient, 3 in 1 patient, 4 in 4 patients, and 5 in 1 patient. The unfavorable outcome in our patients compared to the Penumbra Pivotal Stroke Trial is probably due to the age and severity of the disease. Many of our patients were old with a mean age of 71.7 years (63.5 years in the Penumbra Pivotal Stroke Trial) and had severe neurological status with a mean NIHSS score on admission of 24.9 (17.6 in the Penumbra Pivotal Stroke Trial). Although our patients had poor 30-day mRS scores compared to the Penumbra Pivotal

Stroke Trial, NIHSS score was improved more than 10 points in 4 of the 7 patients (57.1%), and these patients were considered to achieve a good clinical outcome according to the definition used in the Penumbra Pivotal Stroke Trial. The mean NIHSS score was considerably improved from 24.9 before the treatment to 12.4 at 30 days after the treatment, which may have led to favorable results, such as an increased participation in available rehabilitation program and an alleviation of the burden of care. Moreover, 12.8% of the patients in the Penumbra Pivotal Stroke trial had procedural events including vasospasm, reocclusion of the target vessel, dissection, and perforation, and 2.7% had events that were considered serious. On the other hand, no patients experienced complications including intracranial hemorrhage in association with the procedure. It is necessary for surgeons to gain more experience and master the skills of manipulating catheters and separators of the Penumbra system.

Recently, two studies on the usefulness of endovascular therapy for acute ischemic stroke have been published.^{12,13)} In the MR RESCUE study, patients within 8 hours after the onset of large-vessel, anterior circulation strokes were randomly assigned into mechanical embolectomy (Merci retriever or Penumbra system) or standard care.¹³⁾ The mean score of 90-day mRS did not differ significantly between these two groups, and embolectomy was not superior to the standard care even in patients showing a favorable penumbra pattern (substantial salvageable tissue with small infarct core) on CT or MR perfusion images. Recanalization rate (TICI score of 2 to 3) in the embolectomy group was low and achieved in 67% of the patients. The International Management of Stroke (IMS) III study also showed no significant difference in functional independence rate (mRS of 2 or less) with endovascular therapy after the intravenous rt-PA as compared to intravenous rt-PA alone.¹²⁾ However, among patients with an NIHSS score of 20 or more, there was a tendency for higher functional independence rate in patients treated by endovascular therapy after the intravenous rt-PA ($P = 0.06$). Various endovascular devices were used in this study, and the recanalization rates (TICI score of 2 to 3) varied and were low; e.g., 71% for the MicroSonic SV (EKOS Corporation, Bothell, Washington, USA) infusion with intra-arterial rt-PA, 73% for the Merci retriever, 85% for the Penumbra system, and 75% for the Solitaire FR revascularization device (ev3 Neurovascular, Irvine, California, USA).

Mechanical clot retrievers other than the Penumbra system include Solitaire FR, a stent-based clot retriever.^{3,6,8,9,14,15)} In particular, stent-based clot retrievers have been reported to provide high recanalization

rates. Furthermore, since reperfusion can be expected at the moment when the stent is expanded, the time from occlusion to reperfusion may be shortened as compared with other clot retrievers.¹⁴ If stent-based clot retriever becomes available in Japan, we will have more options for endovascular treatment, especially those who cannot undergo rt-PA treatment.^{6,8,14} The development of new revascularization devices has improved recanalization rates and time but not clinical outcome. Recently, direct aspiration of thrombus with a large caliber aspiration catheter (ADAPT technique) has reported 100% recanalization rate in a short time from puncture to at least TICI 2b recanalization (28.1 min) with excellent clinical outcome.¹⁰ In order to obtain a high recanalization rate, it is necessary not only to introduce new devices but also to devise an effective use of these devices and techniques. The benefit of the endovascular therapy in stroke patients with acute large vessel occlusion should be examined further under a condition with a high recanalization rate using modern revascularization devices.

In conclusion, our findings suggest that the Penumbra system might be effective for treatment in elderly patients or patients with high NIHSS score wherein rt-PA therapy is inadvisable or ineffective in ischemic stroke secondary to large vessel occlusion. These patients may result in bed-ridden or dead without an effective treatment. Recanalization can improve their quality of life on condition that the procedure is performed effectively without serious complications. We need to accumulate more cases and further examine the efficacy of endovascular therapy by not only evaluating the rate of mRS score of 0–2 but also evaluating the rate of mRS score of 3–4 or the improvement of NIHSS score in these clinically poor patients.

Conflicts of Interest Disclosure

The authors have no personal, financial, or institutional interest in any of the drugs, materials, or devices in the article. All authors who are members of The Japan Neurosurgical Society (JNS) have registered online Self-reported COI Disclosure Statement Forms through the website for JNS members.

References

- 1) Jankowitz B, Aghaebrahim A, Zirra A, Spataru O, Zaidi S, Jumaa M, Ruiz-Ares G, Horowitz M, Jovin TG: Manual aspiration thrombectomy: adjunctive endovascular recanalization technique in acute stroke interventions. *Stroke* 43: 1408–1411, 2012
- 2) Tenser MS, Amar AP, Mack WJ: Mechanical thrombectomy for acute ischemic stroke using the MERCI retriever and Penumbra aspiration systems. *World Neurosurg* 76(6 Suppl): S16–S23, 2011
- 3) Turk AS 3rd, Campbell JM, Spiotta A, Vargas J, Turner RD, Chaudry MI, Battenhouse H, Holmstedt CA, Jauch E: An investigation of the cost and benefit of mechanical thrombectomy for endovascular treatment of acute ischemic stroke. *J Neurointerv Surg* 6: 77–80, 2014
- 4) Penumbra Pivotal Stroke Trial Investigators: The penumbra pivotal stroke trial: safety and effectiveness of a new generation of mechanical devices for clot removal in intracranial large vessel occlusive disease. *Stroke* 40: 2761–2768, 2009
- 5) Taschner CA, Treier M, Schumacher M, Berlis A, Weber J, Niesen W: Mechanical thrombectomy with the Penumbra recanalization device in acute ischemic stroke. *J Neuroradiol* 38: 47–52, 2011
- 6) Tateshima S, Sakai N: Endovascular treatment for acute stroke: appropriate treatment strategy using multi modal device. *JNET* 5: 3–14, 2011
- 7) Sacks D, Black CM, Cognard C, Connors JJ 3rd, Frei D, Gupta R, Jovin TG, Kluck B, Meyers PM, Murphy KJ, Ramee S, Rüfenacht DA, Stallmeyer MJ, Vorwerk D: Multisociety Consensus Quality Improvement Guidelines for Intraarterial Catheter-directed Treatment of Acute Ischemic Stroke, from the American Society of Neuroradiology, Canadian Interventional Radiology Association, Cardiovascular and Interventional Radiological Society of Europe, Society for Cardiovascular Angiography and Interventions, Society of Interventional Radiology, Society of NeuroInterventional Surgery, European Society of Minimally Invasive Neurological Therapy, and Society of Vascular and Interventional Neurology. *Am J Neuroradiol* 34: E0, 2013
- 8) Almekhlafi MA, Menon BK, Freiheit EA, Demchuk AM, Goyal M: A meta-analysis of observational intra-arterial stroke therapy studies using the Merci device, Penumbra system, and retrievable stents. *AJNR Am J Neuroradiol* 34: 140–145, 2013
- 9) Smith WS, Sung G, Saver J, Budzik R, Duckwiler G, Liebeskind DS, Lutsep HL, Rymer MM, Higashida RT, Starkman S, Gobin YP; Multi MERCI Investigators, Frei D, Grobelny T, Hellinger F, Huddle D, Kidwell C, Koroshetz W, Marks M, Nesbit G, Silverman IE: Mechanical thrombectomy for acute ischemic stroke: final results of the Multi MERCI trial. *Stroke* 39: 1205–1212, 2008
- 10) Turk AS, Spiotta A, Frei D, Mocco J, Baxter B, Fiorella D, Siddiqui A, Mokin M, Dewan M, Woo H, Turner R, Hawk H, Miranpuri A, Chaudry I: Initial clinical experience with the ADAPT technique: a direct aspiration first pass technique for stroke thrombectomy. *J Neurointerv Surg* 6: 231–237, 2014
- 11) Yoo AJ, Frei D, Tateshima S, Turk AS, Hui FK, Brook AL, Heck DV, Hirsch JA: The Penumbra Stroke System: a technical review. *J Neurointerv*

- Surg* 4: 199–205, 2012
- 12) Broderick JP, Palesch YY, Demchuk AM, Yeatts SD, Khatri P, Hill MD, Jauch EC, Jovin TG, Yan B, Silver FL, von Kummer R, Molina CA, Demaerschalk BM, Budzik R, Clark WM, Zaidat OO, Malisch TW, Goyal M, Schonewille WJ, Mazighi M, Engelter ST, Anderson C, Spilker J, Carrozzella J, Ryckborst KJ, Janis LS, Martin RH, Foster LD, Tomsick TA; Interventional Management of Stroke (IMS) III Investigators: Endovascular therapy after intravenous t-PA versus t-PA alone for stroke. *N Engl J Med* 368: 893–903, 2013
 - 13) Kidwell CS, Jahan R, Gornbein J, Alger JR, Nenov V, Ajani Z, Feng L, Meyer BC, Olson S, Schwamm LH, Yoo AJ, Marshall RS, Meyers PM, Yavagal DR, Wintermark M, Guzy J, Starkman S, Saver JL; MR RESCUE Investigators: A trial of imaging selection and endovascular treatment for ischemic stroke. *N Engl J Med* 368: 914–923, 2013
 - 14) Dorn F, Stehle S, Lockau H, Zimmer C, Liebig T: Endovascular treatment of acute intracerebral artery occlusions with the solitaire stent: single-centre experience with 108 recanalization procedures. *Cerebrovasc Dis* 34: 70–77, 2012
 - 15) Roth C, Papanagiotou P, Behnke S, Walter S, Haass A, Becker C, Fassbender K, Politi M, Körner H, Romann MS, Reith W: Stent-assisted mechanical recanalization for treatment of acute intracerebral artery occlusions. *Stroke* 41: 2559–2567, 2010

Address reprint requests to: Atsushi Shindo, MD, Department of Neurological Surgery, Kagawa University Faculty of Medicine, 1750-1 Ikenobe, Miki-cho, Kita-gun, Kagawa 761-0793, Japan.
e-mail: ashindo@kms.ac.jp