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History and Progression of Endovascular Recanalization for the Acute Ischemic Stroke in Japan

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Percutaneous transluminal recanalization for acute large vessel occlusion stroke has been performed more than 30 years and progressing along with development of endovascular device. The treatment started with local injection of urokinese through simple microcatheter and guiding catheter system. In those days, single lumen balloon catheter was developed and it allowed us to navigate balloon catheter to the intracranial large arteries and the thrombus was crashed with balloon to reanalyze. In Japan, mechanical thrombectomy device approved in 2010 and the occlusion has been effectively reanalyzed. Furthermore, aspiration of thrombus using larger lumen catheter combination with vacuum system was introduced in 2011. Stent retriever has been available from 2014, and making the procedure more straightforward and successful. Romanized control studies proved the effects of mechanical thrombectomy and the treatment is becoming standard treatments for acute ischemic stroke.

Keywords: percutaneous transluminal recanalization, acute ischemic stroke, history, review

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INTRODUCTION

Percutaneous transluminal recanalization (PTR) for acute large vessel occlusion has been performed more than 30 years and progressing with development of new devices [1, 2] (Fig. 1). Here, we review a history of PTR with personal experience of the treatment and discuss the current status of the treatment. Author took an ethical course of Shimane University and this article was written following the guideline.

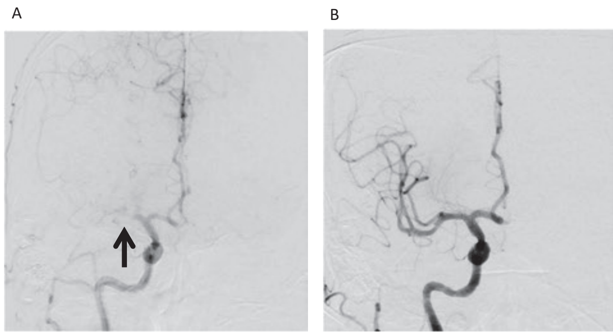

Fig. 1. Endovascular recanalization
A: Right carotid angiography shows occlusion at the M1 portion of the middle cerebral artery (arrow).
B: Right carotid angiography following thrombectomy with stent-retriever shows recanalization of the occlusion.

HISTORY

Local thrombolysis and balloon angioplasty

Cerebral angiography is a principal diagnostic tool for cerebrovascular disease. In the modern radiological study, MR angiography or CT angiography is replacing conventional cerebral angiography because of the less invasiveness. However, cerebral angiography still gives us most accurate and detail information of cerebrovascular disease. Neuroendovascular treatment is developed from cerebral angiography and the author started learning the treatment with local thrombolysis for acute ischemic stroke in 1996. The system was simple, navigating microcatheter using microguidwire to the occlusion site and inject urokinase locally [3] (Fig. 2). It was so impressive since neurological deficit such as hemiparesis or aphasia improved dramatically if recanalization was achieved. CT perfusion study, namely dynamic CT, was employed for the proper patients selection. The amount of urokinase depended on the recanalization, usually 420,000 unit. It should be injected slowly (10,000 unit/min.) for effective reaction to the thrombus. Disadvantage of the urokinase injection was hemorrhagic complication [4]. Larger amount of urokinase treatment resulted in hemorrhagic infarction even if the vessel occlusion was recanalized [5, 6].

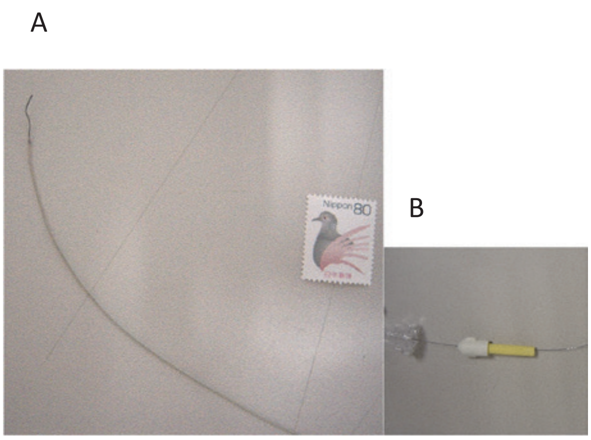

Fig. 2. Photographs of basic neuroendovascular system
A: A tip of the microcatheter
B: A handling part of the microguidewire

Another tool for PTR was balloon angioplasty, crushing thrombus to recanalize [7]. STEALTH single lumen balloon catheter (Boston Scientific Co, Natick, MA, USA) was navigated with microguidwire into the occlusion and the wire was replaced to the bulb-wire for inflation of the balloon (Fig. 3). The system sometimes did not work because of leakage from the bulb. Post-procedural hemorrhagic infarction was less than local thrombolysis.

Since the evidence of the local thrombolysis was limited [8], Japanese neurosurgeons designed randomized control trial (RCT) of intra-arterial infusion of urokinase within 6 hours of middle cerebral artery (MCA) stroke: the middle cerebral artery embolism local fibrinolytic intervention trial (MELT) Japan [9]. The result of the study was not so favorable than we expected and stopped because of introduction of tissue plasminogen activator (tPA).

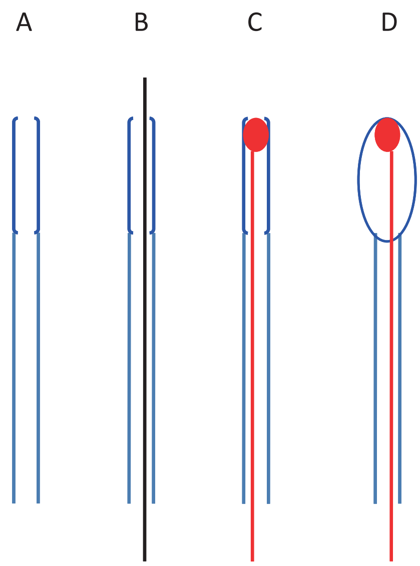

Fig. 3. Schematic illustration of single lumen balloon catheter
A: A single lumen balloon catheter
B: A balloon catheter with microguidewire for the navigation
C: A balloon catheter with bulb-wire
D: Inflation of balloon with bulb-wire

Tissue plasminogen activator

Permission of intravenous administration of tPA in 2005 gave great impact on Japanese stroke treatment. The most important factor for the tPA treatment is time window (within 3 hours at the beginning and extended to 4.5 hours in 2012) and the emergency transfer as well as clinical diagnosis became more speedy. Japanese stroke association run stroke campaign 'Time is brain' and contributed for awareness of stroke symptom and immediate admission. However, the effect of intravenous tPA for the occlusion of large vessels such as internal carotid artery (ICA) or proximal portion of MCA was limited [10, 11]. Endovascular treatment was required again and mechanical thrombectomy have been developed.

Mechanical thrombectomy

MERCI mechanical thrombectomy devise (Stryker Neurovascular, Mountain View, CA, USA) is composed of spiral wire and balloon guiding catheter

(Fig. 4A). Firstly microcatheter was navigated to the occlusion site and spiral-shape wire was released from microcatheter to capture the thrombus. Under fixation of guiding catheter inflating balloon, the wire was removed with thrombus (Fig. 4B). The effect of the device was reported in 2005 [12], but it was introduced to Japan in 2010 because of device lag, import and permission delay. Watching the removed thrombus, we convinced the effect of the device. Although the size of spiral wire was selected to fit the vascular diameter, mechanical stress for the vascular wall or stretching perforating artery was not ignored. Post-procedural hemorrhagic complication occurred occasionally (Fig. 4C, D).

In 2011, PENUMBRA aspiration catheter and vacuum pomp system (Penumbra, Alameda, CA, USA) was developed (Fig. 5A). That system enables us to retrieve the whole thrombus from occlusion site and is effective especially in ICA occlusion caused by larger emboli or secondary coagulation [13]. Lager catheter is more effective to remove thrombus, however, it is not easy to navigate lager catheter into tortuous cerebral arteries (Fig. 5B). Recently, more flexible aspiration catheters have been provided.

In 2013 international stroke conference organized in Honolulu, RCTs failed to show the effective of mechanical thrombectomy against tPA treatment, so called 'Honolulu shock' [14, 15, 16]. Improper indication of the endovascular treatment was a main cause of the failure.

Subarachnoid hemorrhage is the most fatal stroke and one of the main themes for neurosurgeon. We saw revolution of the treatment from surgical clipping to endovascular embolization with electrical detachable coils [17]. Intracranial fine stent was developed for embolization of wide neck aneurysm. SOLITAIRE stent (Covidien, Dublin, Ireland) was originally designed for embolization for the cerebral aneurysm. Coincidentally, it was found effective for capturing emboli and used for recanalization for acute ischemic stroke (Fig. 6A). It was introduced to Japan in 2014. Since the device is delivered to the occlusion site through microcatheter, technical success rate is higher than other device [18]. In 2015, RCTs proved the effectiveness of the treatment [19, 20, 21, 22, 23], so called 'Nashville hope' and it has been dramatically spreading widely. The first generation of the stent retriever was electrically detachable (Fig. 6B) and accidentally detached during retrieve (Fig. 6C). Therefore, the connection was renovated in the second generation to prevent that accident.

Recently, advantage of the aspiration catheter and stent-retriever was merged as combined technique [24] (Fig. 6D), which enables complete recanalization with one time procedure, i.e. first pass effect [25].

PERSONAL STUDY

We are running the frontline of the PTR more than two decades, and we compared the result of our personal experience between early period (1996-1998) and recent period (2012-2014) [26]. Elder patients were treated with PTR in the recent period. Main target of the PTR was M1 segment of the MCA in the early period. The ratio of the ICA and posterior circulation increased in the recent period. Regarding with methods of PTR, the mechanical retrieval devices were mainly employed in the recent period and resulted in more complete recanalization significantly. Good recovery of Glasgow outcome scale increased and death decreased significantly in the recent period [26].

HOT TOPICS AND SOCIAL ACT

An efficacy of endovascular thrombectomy in patients with more distal M2 segment MCA occlusions has been proved with meta-analysis [27]. Thus, A meta-analysis of mechanical thrombectomy for posterior circulation occlusion demonstrated that the outcomes of mechanical thrombectomy for patients with posterior circulation occlusion were poorer than with anterior circulation occlusion [28]. On the other hand, mechanical thrombectomy appears to have lower rates of symptomatic intracranial hemorrhage and to increase successful recanalization. Given the high recanalization rate, mechanical thrombectomy may serve as an adjunct to standard treatment [28]. Meyer *et al*. reported study on thrombectomy for very elderly patients aged ≥90 [29]. Despite high mortality and less frequent favorable outcome in

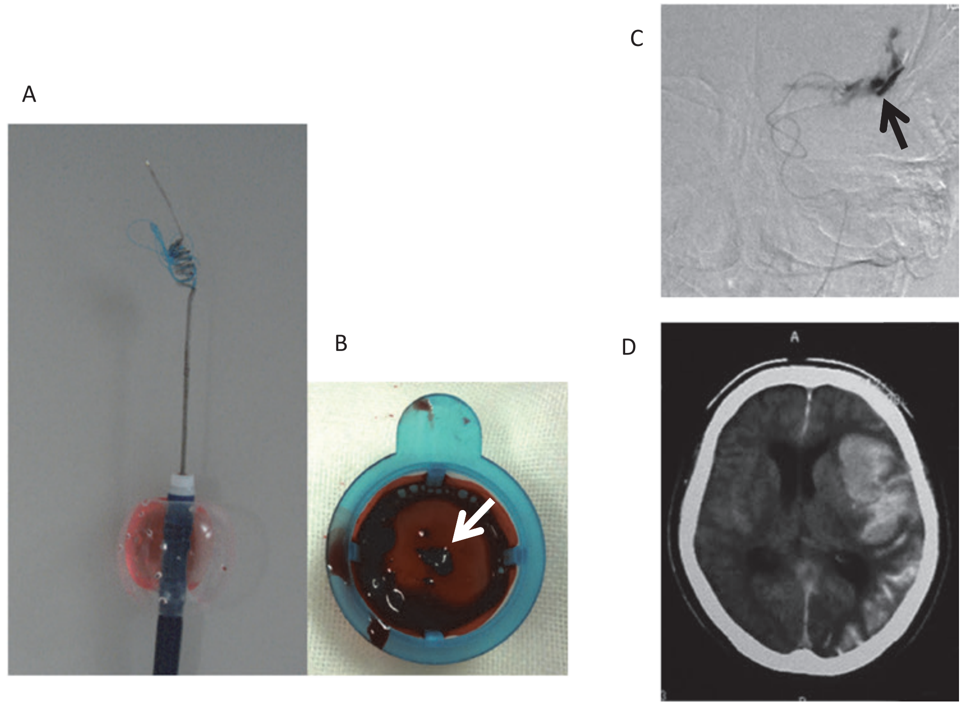

Fig. 4. Merci retriever system
A: A photograph of spiral wire and balloon guiding catheter
B: A photograph of captured thrombus (arrow)
C: Selective angiography following retrieve shows extra-versation of the contrast media along with Sylvian fissure (arrow).
D: CT shows subarachnoid hemorrhage with Sylvian hematoma.

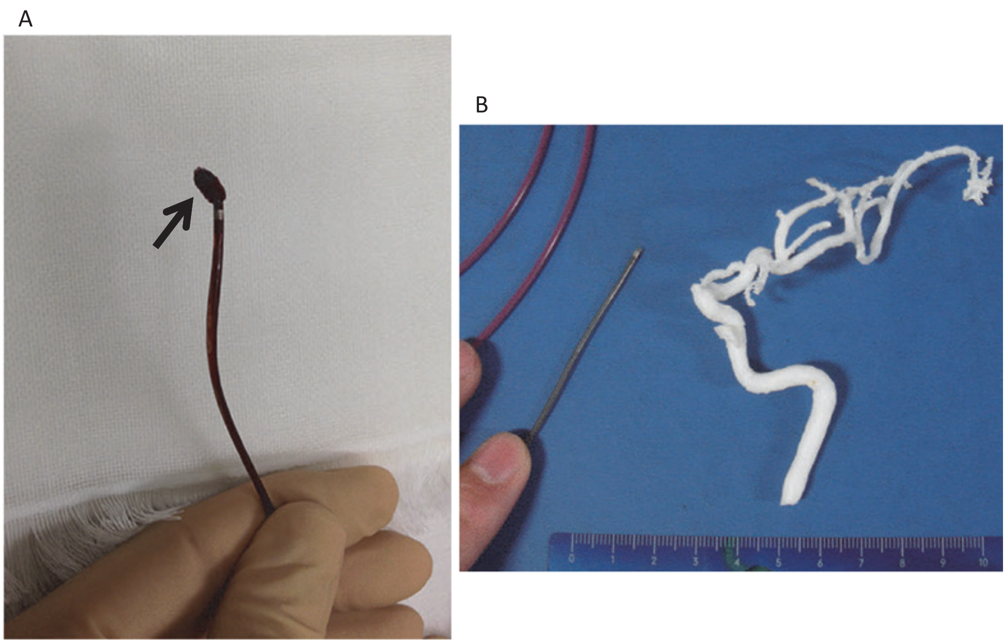

Fig. 5. Photographs of aspiration catheter
A: Aspiration catheter with captured thrombus (arrow).
B: Aspiration catheter and three demotions model of cerebral artery. It is not easy to navigate larger catheter into the tortuous cerebral artery.

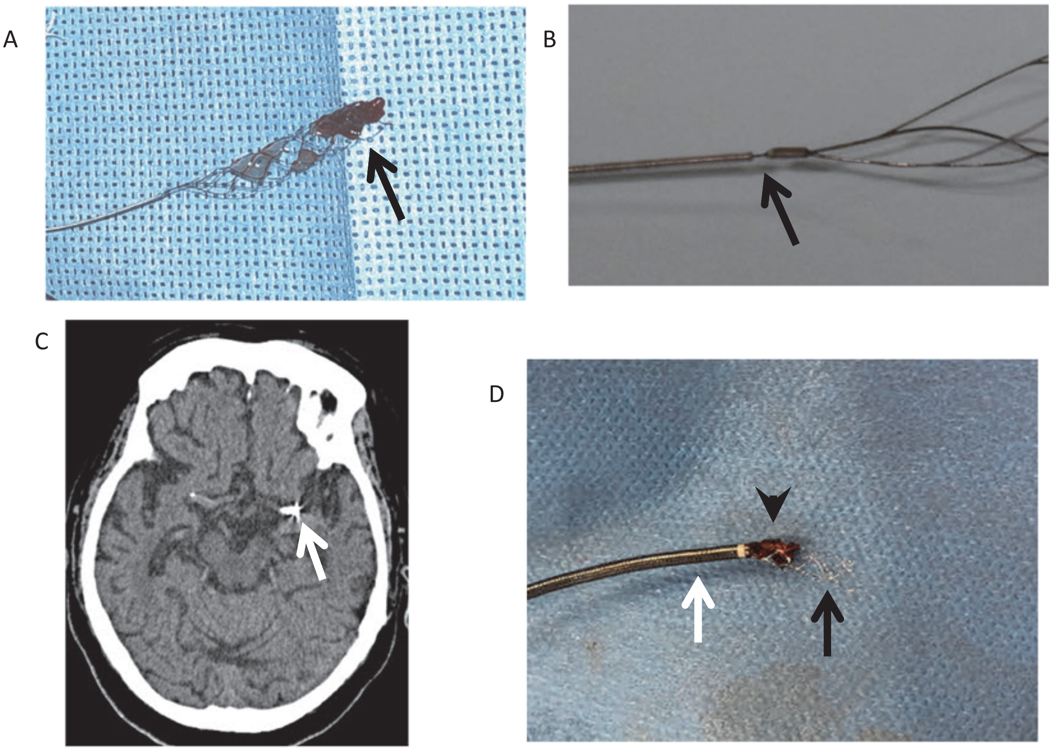

Fig. 6. Stent retriever
A: A photograph of stent retriever with captured thrombus (arrow).
B: Connection (arrow) of stent and delivery wire is fragile in the first generation.
C: CT shows accidentally detached stent remains in the left middle cerebral artery (arrow).
D: A thrombus (arrowhead) is retrieved combination with aspiration catheter (white arrow) and stent retriever (black arrow).

very elderly patients, thrombectomy is still effective and safe for nonagenarians [29]. Regarding with the time window, along with development of imaging study to detect ischemic penumbra, it will be employed up-to 24 hours or onset undetermined stroke such as wake-up stroke [30]. We are discussing on skipping intravenous tPA to perform endovascular treatment immediately [31].

Japanese society for neuroendovascular therapy organized RESCUE Japan project to provide PTR for rural area as well as urbane area [32]. Thus, Japanese government established national plan for promotion of measures against cerebrovascular and cardiovascular disease in 2019 and the hospitals are ranked for stroke treatment cooperation with the Japan stroke society [33].

CONCLUSION

The history and progress of the PTR were reviewed and discussed with personal experience. Together with development of the endovascular devices, the result of PTR has been improving day by day. RCTs proved the effects of mechanical thrombectomy and the treatment is becoming standard treatments for acute large vessel occlusion ischemic stroke.

Conflict of interest

The authors declare no conflict of interest.

REFERENCES

1) Goyal M, Menon BK, van Zwam WH, *et al*. Endovascular thrombectomy after large-vessel ischaemic stroke: a meta-analysis of individual patient data from five randomised trials. *Lancet* 2016;387:1723-31. doi: 10.1016/S0140-6736(16)00163-X.
2) Saver JL, Goyal M, van der Lugt A, *et al*.

Time to Treatment with endovascular thrombectomy and outcomes from ischemic stroke: a meta-analysis. *JAMA* 2016;316:1279-88. doi: 10.1001/jama.2016.13647.

3) Ueda T, Sakaki S, Kumon Y, Ohta S. Multivariable analysis of predictive factors related to outcome at 6 months after intra-arterial thrombolysis for acute ischemic stroke. *Stroke* 1999;30:2360-5. doi: 10.1161/01.str.30.11.2360.

4) Lisboa RC, Jovanovic BD, Alberts MJ. Analysis of the safety and efficacy of intra-arterial thrombolytic therapy in ischemic stroke. *Stroke* 2002;33:2866-71. doi: 10.1161/01.str.0000038987.62325.14.

5) Brekenfeld C, Remonda L, Nedeltchev K, *et al*. Symptomatic intracranial haemorrhage after intra-arterial thrombolysis in acute ischaemic stroke: assessment of 294 patients treated with urokinase. *J Neurol Neurosurg Psychiatry* 2007;78:280-5. doi: 10.1136/jnnp.2005.078840.

6) Fields JD, Khatri P, Nesbit GM, *et al*. Meta-analysis of randomized intra-arterial thrombolytic trials for the treatment of acute stroke due to middle cerebral artery occlusion. *J Neurointerv Surg* 2011;3:151–5. doi: 10.1136/jnis.2010.002766.

7) Nakayama T, Tanaka K, Kaneko M, Yokoyama T, Uemura K. Thrombolysis and angioplasty for acute occlusion of intracranial vertebrobasilar arteries. Report of three cases. *J Neurosurg* 1998;88:919-22. doi: 10.3171/jns.1998.88.5.0919.

8) Furlan A, Higashida R, Wechsler L *et al*. Intra-arterial prourokinase for acute ischemic stroke. The PROACT II study: a randomized controlled trial. *JAMA* 1999;282:2003-11. doi: 10.1001/jama.282.21.2003.

9) Ogawa A, Mori E, Minematsu K, *et al*. Randomized trial of intraarterial infusion of urokinase within 6 hours of middle cerebral artery stroke: the middle cerebral artery embolism local fibrinolytic intervention trial (MELT) Japan. *Stroke* 2007;38:2633-9. doi: 10.1161/STROKEAHA.107.488551.

10) De Silva DA, Brekenfeld C, Ebinger M, *et al*. The benefits of intravenous thrombolysis relate to the site of baseline arterial occlusion in the Echoplanar Imaging Thrombolytic Evaluation Trial (EPITHET). *Stroke* 2010;41:295-9. doi: 10.1161/STROKEAHA.109.562827.

11) Hirano T, Sasaki M, Mori E, *et al*. Residual vessel length on magnetic resonance angiography identifies poor responders to alteplase in acute middle cerebral artery occlusion patients: exploratory analysis of the Japan Alteplase Clinical Trial II. *Stroke* 2010;41:2828-33. doi: 10.1161/STROKEAHA.110.594333.

12) Smith WS, Sung G, Starkman S, *et al*. Safety and efficacy of mechanical embolectomy in acute ischemic stroke: results of the MERCI trial. *Stroke* 2005;36:1432-8. doi: 10.1161/01.STR.0000171066.25248.1d.

13) Kang DH, Hwang YH, Kim YS, Park J, Kwon O, Jung C. Direct thrombus retrieval using the reperfusion catheter of penumbra system: forced-suction thrombectomy in acute ischemic stroke. *AJNR Am J Neuroradiol* 2011;32:283-7. doi: 10.3174/ajnr.A2299.

14) Broderick JP, Palesch YY, Demchuk AM *et al*. Endovascular therapy after intravenous t-PA versus t-PA alone for stroke. *N Engl J Med* 2013;368:893-903. doi: 10.1056/NEJMoa1214300.

15) Ciccone A, Valvassori L, Nichelatti M, *et al*. Endovascular treatment for acute ischemic stroke. *N Engl J Med* 2013;368:904-13. doi: 10.1056/NEJMoa1213701.

16) Kidwell CS , Jahan R, Gornbein J, *et al*. A trial of imaging selection and endovascular treatment for ischemic stroke. *N Engl J Med* 2013;368:914-23. doi: 10.1056/NEJMoa1212793.

17) Molyneux A, Kerr R, Stratton I, *et al*. International Subarachnoid Aneurysm Trial (ISAT) of neurosurgical clipping versus endovascular coiling in 2143 patients with ruptured intracranial aneurysms: a randomized trial. *Lancet* 2002;360:1267-74. doi: 10.1016/s0140-6736 (02) 11314-6.

18) Saver JL, Jahan R, Levy EI, *et al*. Solitaire flow restoration device versus the Merci Retriever in patients with acute ischeamic stoke (SWIFT): a randomized, parallel group, non-inferiority trial. *Lancet* 2012;380:1241-49. doi: 10.1016/S0140-6736 (12) 61384-1.

19) Berkhemer OA, Fransen PSS, Beumer D, *et al*. A Randomized trial of Intraarterial Treatment for Acute Ischemic Stroke. *N Engl J Med* 2015;

372:11-20. doi: 10.1056/NEJMoa1411587.

20) Campbell BC, Mitchell PJ, Kleinig TJ, *et al*. Endovascular therapy for ischemic stroke with perfusion-imaging selection. *N Engl J Med* 2015;372:1009-18. doi: 10.1056/NEJMoa1414792.

21) Goyal M, Demchuk AM, Bijoy K. Menon BK, *et al*. Randomized assessment of rapid endovascular treatment of ischemic stroke. *N Engl J Med* 2015;372:1019-30. doi: 10.1056/NEJMoa1414905.

22) Saver JL, Goyal M, Bonafe A, *et al*. Stent-retriever thrombectomy after intravenous t-PA vs. t-PA alone in stroke. *N Engl J Med* 2015;372:2285-95. doi: 10.1056/NEJMoa1415061.

23) Jovin TG, Chamorro A, Cobo E, *et al*. Thrombectomy within 8 hours after symptom onset in ischemic stroke. *N Engl J Med* 2015;372:2296-306. doi: 10.1056/NEJMoa1503780.

24) McTaggart RA, Tung EL, Yaghi S, *et al*. Continuous aspiration prior to intracranial vascular embolectomy (CAPTIVE): a technique which improves outcomes. *J Neurointerv Surg* 2017;9:1154-9. doi: 10.1136/neurintsurg-2016-012838.

25) Colby GP, Baharvahdat H, Mowla A, *et al*. Increased success of single-pass large vessel recanalization using a combined stentriever and aspiration technique: a single institution study. *World Neurosurg* 2019;123:e747-e752. doi: 10.1016/j.wneu.2018.12.023.

26) Hayashi K, Morofuji Y, Horie N, Izumo T, Matsuo T. Progression of endovascular treatment for acute ischemic stroke. *No Shinkei Geka* 2019;47:761-7. doi: 10.11477/mf.1436204020. (Eng Abstr)

27) Menon BK, Hill MD, Davalos A, *et al*. Efficacy of endovascular thrombectomy in patients with M2 segment middle cerebral artery occlusions: meta-analysis of data from the HERMES Collaboration. *J Neurointerv Surg* 2019 ;11:1065-9.

28) Wang F, Wang J, He Q, *et al*. Mechanical thrombectomy for posterior circulation occlusion: a comparison of outcomes with the anterior circulation occlusion – a meta-analysis. *J Atheroscler Thromb* 2020;27:1325-39. doi: 10.5551/jat.54221.

29) Meyer L, Alexandrou M, Flottmann F, *et al*. Endovascular treatment of very elderly patients aged ≥90 with acute ischemic stroke. *J Am Heart Assoc* 2020;9:e014447. doi: 10.1161/JAHA.119.014447.

30) Nogueira RG, Jadhav AP, Haussen DC, *et al*. Thrombectomy 6 to 24 hours after stroke with a mismatch between deficit and infarct. *N Engl J Med* 2018;378:11-21. doi: 10.1056/NEJMoa1706442.

31) Suzuki K, Matsumaru Y, Takeuchi M, *et al*. Effect of mechanical thrombectomy without vs with intravenous thrombolysis on functional outcome among patients with acute ischemic stroke: the SKIP randomized clinical trial. *JAMA* 2021;325:244-53. doi: 10.1001/jama.2020.23522.

32) Takagi T, Yoshimura S, Sakai N, *et al*. After KOBE declarantion: regional activities to spread endovascular therapy for acute ischemic stroke. Result of national survey of acute thrombectomy in Japan: RESCUE-Japan Project 2016. *No Kekkannai Chiryo* 2019;4:2-6. (Eng Abstr)

33) Kuwabara M, Mori M, Komoto S. Japanese national plan for promotion of measures against cerebrovascular and cardiovascular disease. *Circulation* 2021;143:1929–31. doi: 10.1161/CIRCULATIONAHA.120.052737.