



# Mechanical Thrombectomy with Solitaire Stent Retrieval for Acute Cardioembolic Stroke

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**Objective :** Few studies have reported the outcome of mechanical thrombectomy with Solitaire stent retrieval (MTSR) in subtypes of acute ischemic stroke. The purpose of this study was to evaluate the efficacy and result of MTSR in acute cardioembolic stroke.

**Methods :** Twenty consecutive patients with acute cardioembolic stroke were treated by MTSR. The angiographic outcome was assessed by thrombolysis in cerebral infarction (TICI) grade. TICI grade 2a, 2b, or 3 with a measurable thrombus that was retrieved was considered as a success when MTSR was performed in the site of primary vessel occlusion, and TICI grade 2b or 3 was considered as a success when final result was reported. Clinical and radiological results were compared between two groups divided on the basis of final results of MTSR. Persistent thrombus compression sign on angiogram was defined as a stenotic, tapered arterial lumen whenever temporary stenting was performed. The clinical outcomes were assessed by the modified Rankin Scale (mRS) at 3 months.

**Results :** The failure rate of MTSR was 20% (4/20) and other modalities, such as permanent stenting, were needed. Final successful recanalization (TICI grade 2b or 3) was 80% when other treatments were included. The rate of good outcome (mRS≤2) was 35% at the 3-month follow-up. Failure of MTSR was significantly correlated with persistent thrombus compression sign ( $p=0.001$ ).

**Conclusion :** Some cases of cardioembolic stroke are resistant to MTSR and may need other treatment modalities. Careful interpretation of angiogram may be helpful to the decision.

**Key Words :** Intracranial embolism · Mechanical thrombolysis.

## INTRODUCTION

Ischemic stroke is a major cause of death in developed countries. Intravenous thrombolysis with recombinant tissue plasminogen activator (IV rt-PA) has been proven to be effective for the treatment of acute ischemic stroke. However, IV rt-PA has limited ability to recanalize a large vessel occlusion (LVO)<sup>21,34</sup>. Mechanical thrombectomy with Solitaire stent re-

trieval (MTSR) is a simple procedure that has been reported to have excellent recanalization rates of LVO<sup>9,18</sup>. The efficacy of MTSR can differ according to the etiology of ischemic stroke. TOAST study has been widely used and denotes five subtypes of ischemic stroke<sup>1</sup>. Clinical features that suggest the diagnosis of cardioembolic stroke includes sudden onset to maximal neurologic deficit (<5 minutes) and altered consciousness at onset<sup>3</sup>. However, the clinical diagnosis of cardioembolic

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stroke is difficult. Several systems of classification of ischemic stroke have been devised<sup>1,13)</sup>, but they share core etiologic categorization. Clinical and radiological outcomes after MTSR of acute cardioembolic stroke have not been reported. In this study, we assessed the outcome of MTSR in cardioembolic stroke.

## MATERIALS AND METHODS

This retrospective study had institutional ethics committee approval. Two neurointerventionists participated in the treatments.

### Patient selection

A total of 46 consecutive patients with ischemic stroke due to LVO were treated using intra-arterial procedures from May 2011 to March 2015. Twenty patients were diagnosed with acute cardioembolic stroke. On admission, neurologic assessments were performed using the National Institutes of Health Stroke Scale (NIHSS). All patients underwent non-contrast brain computed tomography (CT). Eligible patients were treated with IV rt-PA and the association of multisection CT angiography (CTA), and perfusion CT (PCT) was performed to confirm immediate recanalization of the LVO 1 hour after IV rt-PA<sup>31)</sup>. Non-eligible patients for IV rt-PA received CTA and PCT, or brain magnetic resonance imaging (MRI) and magnetic resonance angiography (MRA). If large vessels were still occluded, intra-arterial procedures would be performed. Cardioembolic stroke was diagnosed on luminal status of contralateral internal carotid artery (ICA) and other major vessels, and arrhythmia such as atrial fibrillation and/or congestive heart failure and/or valvular heart disease<sup>1)</sup>. The inclusion criteria of this study were as follows : 1) baseline NIHSS score  $\geq 8$ ; 2) large vessel occlusion; and 3) confirmed atrial fibrillation and/or congestive heart failure and/or valvular heart disease at admission. Large vessels were ICA, M1 segment of middle cerebral artery (MCA), and basilar artery (BA). The exclusion criteria were as follows : 1) the Alberta Stroke Program Early CT Score (ASPECTS)  $< 5$  and 2) any grade stenosis of intracranial and/or extra-cranial arteries using NASCET criteria. After MTSR, immediate postprocedural brain CT and 24-hour brain MRI and MRA was performed.

### Interventional procedures

All procedures were performed under general anesthesia or sedation. For the anterior circulation, a guiding catheter was introduced into the cervical ICA as distal as possible. A Shuttle guide sheath (Shuttle-SL; Cook, Bloomington, IN, USA) was used to support the guiding catheter in some cases. The guiding catheter was continuously flushed with heparinized normal saline. Solitaire stent (Covidien, Irvine, CA, USA) for MTSR was selected in accordance with target vessel diameter; the stent diameter was 1 or 2 mm larger than that of the target vessel. A microcatheter (Prowler Select Plus [Cordis, Dublin, OH, USA] or Rebar<sup>TM</sup> 27 [Covidien]) was navigated distal to the point of occlusion and superselective angiography was carried out to evaluate the status of distal vasculature. The Solitaire stent was advanced and was temporarily deployed for 5 to 10 minutes to allow full expansion. After Solitaire stent deployment, cerebral angiography was performed to evaluate the status of the occluded vessel. During extraction of the thrombus, the deployed Solitaire stent and the microcatheter were pulled back as a single unit. Manual compression of cervical carotid artery was performed, if possible. In cases of posterior circulation stroke, the process of MTSR was similar to that of anterior circulation stroke.

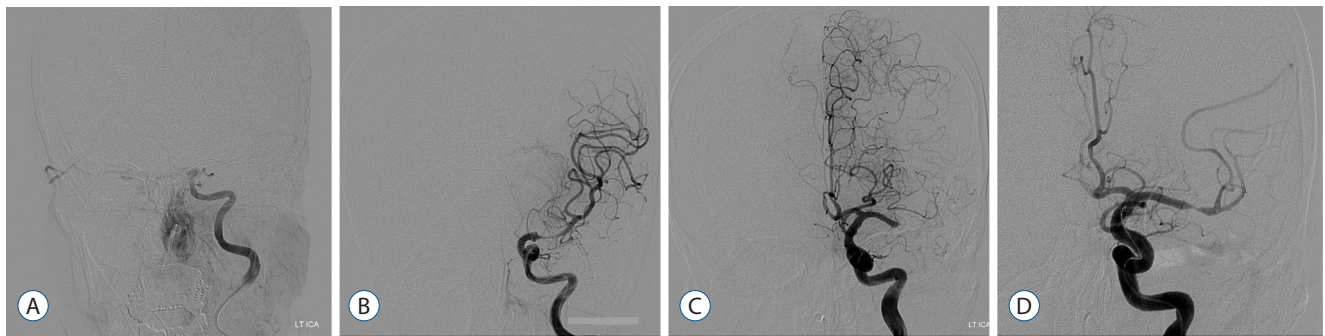
If cerebral angiography presented no effect after trials of MTSR, other treatment modalities, such as permanent stenting or balloon angioplasty, were considered. When the occluded vessel was recanalized, another angiographic run was performed to assess the status of distal vessels. If a major vessel distal to primary occlusion site was occluded, another MTSR was also performed.

### Outcome measure and analysis

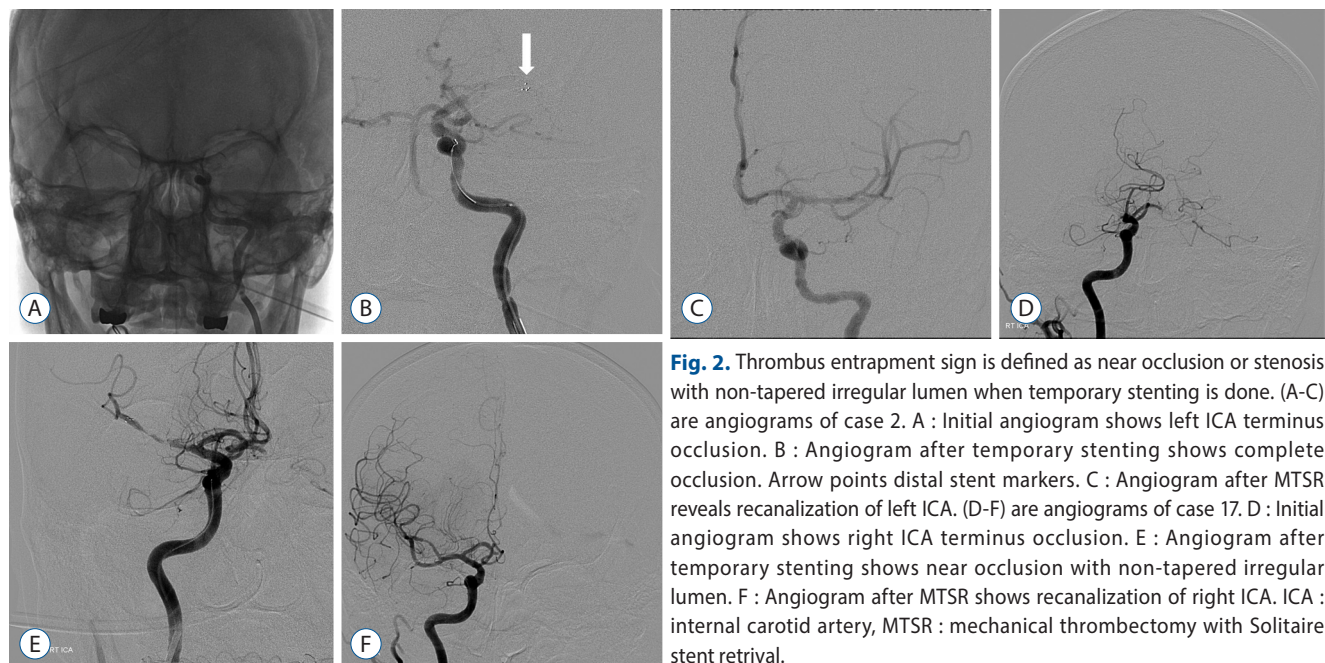
The thrombus that occluded the vessel should be located at either inside or outside of the deployed stent. Thrombus that was completely outside outlines the relatively smooth curve of the deployed stent. Thus, a cerebral angiogram reveals a tapered vascular stenosis at the point of occlusion during temporary stenting, and it is presumed that the thrombus is not entrapped inside the stent but compressed by the stent. Presently, this was designated as a thrombus compression (TC) sign (Fig. 1). Thrombus that was partially or totally inside the stent could be outlined as a bulging contour through stent struts. Cerebral angiography presents near occlusion or stenosis with non-tapered irregular lumen at the target vessel after

full deployment of the stent, and it is reasonable to assume that the thrombus are totally or partially entrapped inside the stent. This represented a thrombus entrapment (TE) sign (Fig. 2). Angiographic signs during each time of temporary stenting were analyzed. Inter-observer agreement was assessed and Kappa coefficient was measured as 0.68. It was considered to be substantial agreement (Kappa 0.61–0.80)<sup>32</sup>. Primary occlusion points were the ICA, M1, and BA. Persistent TC signs were defined as TC signs after each session. The thrombolysis in cerebral infarction (TICI) scale was used to evaluate angiographic intracranial flow. After each session, MTSR failure in the site of primary vessel occlusion was defined when cerebral

angiography revealed no improvement of TICI grade (TICI 0, 1) and no measurable clot was extracted. Successful MTSR was defined as recanalization of TICI grade 2a/b or 3 after MTSR. Distal vessel occlusion was defined as a vessel occlusion independent of the primary vessel occlusion. Final successful recanalization was defined as TICI grade 2b or 3 at the end of the whole procedure because the additional MTSR of distal vessel occlusion could be required. Clinical outcome was assessed at 3 months using the modified Rankin Scale (mRS). Good clinical outcome was defined as a mRS score 0–2. We divided the patients into two groups on the basis of the results (success or failure) of MTSR in the primary vessel



**Fig. 1.** Thrombus compression sign is defined as a tapered vascular stenosis when temporary stenting. (A and B) are angiograms of case 3. A : Initial angiogram shows left ICA terminus occlusion. B : Angiogram after temporary stenting shows a tapered stenosis which mimics true stenosis of left MCA. (C and D) are angiograms of case 13. C : Initial angiogram shows left M1 occlusion. D : Angiogram after temporary stenting reveals a pseudostenosis of left MCA. ICA : internal carotid artery, MCA : middle cerebral artery.



**Fig. 2.** Thrombus entrapment sign is defined as near occlusion or stenosis with non-tapered irregular lumen when temporary stenting is done. (A-C) are angiograms of case 2. A : Initial angiogram shows left ICA terminus occlusion. B : Angiogram after temporary stenting shows complete occlusion. Arrow points distal stent markers. C : Angiogram after MTSR reveals recanalization of left ICA. (D-F) are angiograms of case 17. D : Initial angiogram shows right ICA terminus occlusion. E : Angiogram after temporary stenting shows near occlusion with non-tapered irregular lumen. F : Angiogram after MTSR shows recanalization of right ICA. ICA : internal carotid artery, MTSR : mechanical thrombectomy with Solitaire stent retrieval.

**Table 1.** Summary of patients' characteristics and results

Case	Age /sex	Antithrombotic Tx	IV t-PA	Occlusion	Angiographic sign per session	Baseline TICI	TICI after MTSR	MTSR of distal occlusion	Final TICI (other Tx)	Baseline NIHSS	24 hr F/U NIHSS	mRS (3 mos)
1	53/F	ASA cilostazol	(+)	Rt. ICA-T	CCEC	0	2a	Yes	2b	15	11	4
2	44/F	No	(+)	Lt. ICA-T	EEE	0	2a	Yes	2a	20	20	5
3	69/F	WFR	(+)	Lt. ICA-T	CCCC	0	0	No	3 (stenting)	23	7	0
4	77/M	No	(+)	Lt. M1	C	0	3	No	3	21	14	4
5	83/F	No	(-)	BA	E	0	3	No	3	13	13	6
6	76/F	No	(+)	Lt. M1	EEE	0	3	Yes	3	22	10	1
7	58/M	ASA	(+)	Rt. ICA-T	EEE	0	2b	No	2b	9	7	0
8	84/F	WFR	(-)	BA	C	0	3	No	3	NA	NA	5
9	77/M	ASA	(-)	BA	CCCC	0	0	No	3 (balloon)	13	13	5
10	77/M	No	(-)	Rt. ICA	CCCE	1	2b	Yes	2b	11	4	2
11	71/M	No	(+)	Rt. ICA-T	CE	0	2a	Yes	2a	16	16	4
12	71/M	ASA	(+)	Lt. M1	CE	0	3	No	3	20	32	6
13	79/F	No	(-)	Lt. M1	CCCC	0	0	No	0	15	20	5
14	62/M	ASA	(-)	BA	E	0	3	No	3	NA	NA	4
15	66/F	No	(+)	Rt. M1	CCCE	0	2a	Yes	2a	15	13	5
16	75/F	No	(-)	BA	E	0	3	No	3	NA	NA	2
17	66/M	ASA	(+)	Rt. ICA-T	EE	0	2b	No	2b	9	8	3
18	78/M	WFR	(+)	Rt. M1	CCCE	0	3	No	3	14	17	5
19	66/M	ASA	(-)	Lt. M1	CE	0	3	No	3	18	4	2
20	81/F	ASA	(+)	Lt. ICA-T	CCCC	0	0	No	3 (stenting)	18	3	0

Tx : therapy, IV t-PA : intravenous tissue plasminogen activator, TICI : thrombolysis in cerebral infarction scale, MTSR : mechanical thrombectomy with Solitaire® stent retrieval, NIHSS : National Institutes of Health Stroke Scale, F/U : follow up, mRS : modified Rankin scale, mos : months, F : female, ASA : acetyl salicylic acid, Rt. : right, ICA-T : internal carotid artery terminus, C : thrombus compression sign, E : thrombus entrapment sign, Lt. : left, WFR : warfarin, M : male, BA : basilar artery, NA : not available



occlusion and compared factors between two groups (Table 1). Statistical analysis was conducted by using the Statistical Package for the Social Sciences, version 12 (SPSS Inc., Chicago, IL, USA). The Fisher exact test and the Mann-Whitney U test were used to evaluate the relationship between factors and the results of MTSR. Statistical significance was accepted for  $p < 0.05$ .

## RESULTS

Twenty consecutive patients (10 men and 10 women) who suffered acute cardioembolic stroke were treated with MTSR. Eleven patients (55%) had taken prophylactic antithrombotic medications (aspirin [n=7]; aspirin+cilostazol [n=1]; warfarin [n=3]) before acute stroke. The mean age of the patients was 71 years (range, 44–84 years). The median baseline NIHSS score was 15 (range, 9–23). IV rt-PA was performed in 12 (60%) patients. Sites of primary vessel occlusion were ICA in 8, MCA (M1) in 7, and BA in 5 cases. The average time from femoral puncture to the end of the procedure was 84 minutes (range, 30–180 minutes). Recanalization (TICI 2b, 3) was successful in 80% (16/20) of the patients at the end of the whole procedure that included other treatment modalities. The rate of reperfusion hemorrhage was 10% (2/20). At the 3 months follow-up, 35% (7/20) of patients had a good clinical outcome (mRS 0–2).

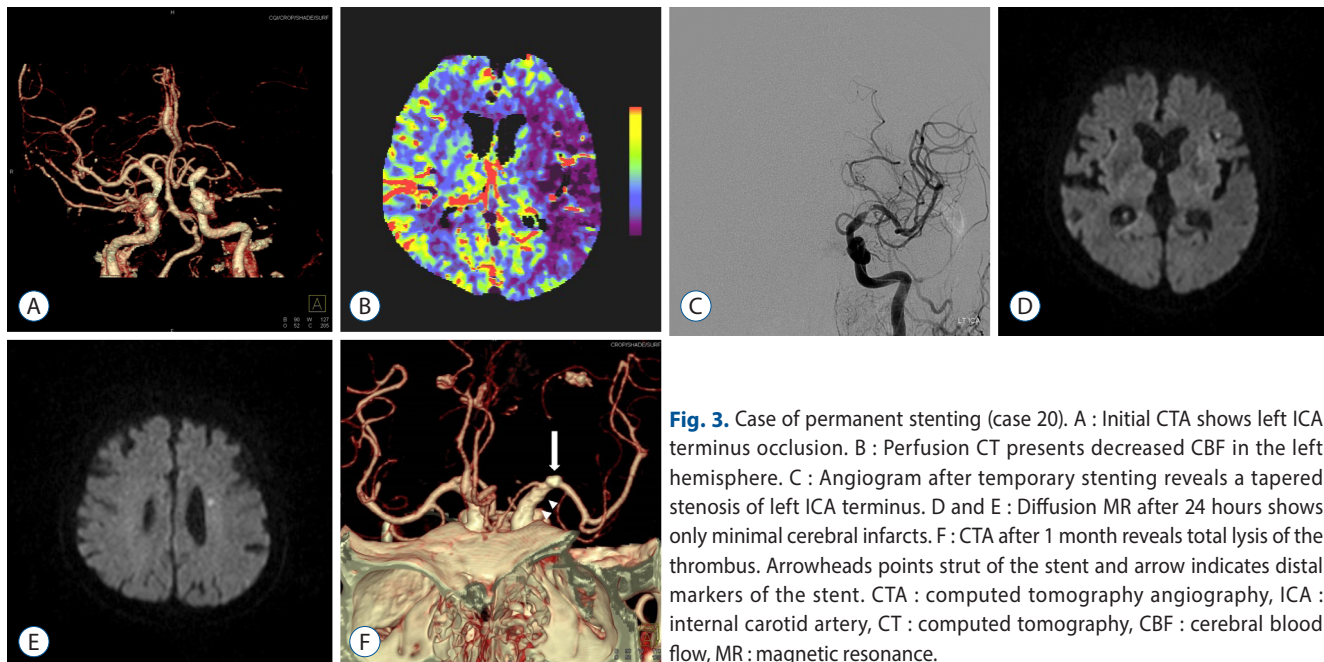
The failure rate of MTSR in the primary vessel occlusion was 20% (4/20). IV rt-PA, prophylactic antithrombotic medication, complications, and good clinical outcome were not significantly associated with failure of MTSR. The presence of angiographic TE sign was significantly correlated with success of MTSR ( $p=0.003$ ). The failure of MTSR was significantly associated with persistent TC signs ( $p=0.001$ ). The rate of secondary MTSR of distal vessel occlusion was 30% (6/20).

## DISCUSSION

IV rt-PA for acute ischemic stroke is effective, but the recanalization rates of LVO in previous studies ranged from 21% to 56%, which were not satisfactory<sup>6,34</sup>. MTSR is an effective method for recanalization of LVO<sup>9,18</sup>. MTSR is simple, but rates of successful recanalization were variable from 26%

to 89%<sup>9,15,18</sup>. The effectiveness of MTSR can be commonsensically summarized into the following steps after stent deployment. First, the thrombus is cut through with struts of deployed Solitaire stent and is partially or totally entrapped in the stent lumen. Second, the entrapped thrombus is stuck or attached to the struts and is removed with the stent. Both steps can be strongly influenced by variations in mechanical properties of the thrombus, which provides hardness and an adhesive force against the vessel wall. Embolized thrombi can have different chronological ages<sup>11,21</sup>. Hardness is positively correlated with chronological aging, which is determined by the organizing stages<sup>8,11,14</sup>. Therefore, thrombi could have variable hardness and elasticity<sup>8,11,14,17,19,20,22,23</sup>. Thrombi also have internal heterogeneity of stages, but may be categorized in two distinct patterns: a hard, organized thrombus in which all elements are densely integrated, and a soft, fresh thrombus in which various elements are loosely cross-linked<sup>11,14,20,23,24</sup>. The variable hardness of thrombi against radial force of Solitaire stent can lead to different radiologic signs, which may be divided into dichotomous patterns. The radiological TC sign means a failure of the first step while MTSR is performed. Most cases of successful MTSR presented only TE signs or combination of TC and TE signs on serial sessions. This reflected the heterogeneity of the organizing stages within the thrombus. Presently, we included LVO due to non-atherosclerotic, cardio-embolic origin, because it is possible for MTSR to dissect the atherosclerotic vessel<sup>2</sup> and the stenotic lesion of the vessel can be mistaken as persistent TC signs. The presence of TE sign during MTSR was significantly correlated with success of MTSR ( $p=0.003$ ) and failure of MTSR was associated with persistent TC signs ( $p=0.001$ ).

Failure of the second step during MTSR can be influenced by the adhesion force between the thrombus and the vessel wall. The embolized thrombus adheres to the vessel wall in accordance with platelet adhesion and the transition from temporary adhesion to stable adhesion occurs within minutes<sup>5,10,26-28</sup>. The adhesion force of the thrombus can vary in accordance with platelet adhesion force, which is determined by thrombus burden and platelet adhesion stability<sup>7,25,29,33</sup>. Two cases presented single TC sign but the thrombi were easily removed with a session of MTSR. The thrombus can be dragged, if the adhesion force of the thrombus is too weak to resist; this distinguished the results between persistent TC signs and single TC sign. No distal thromboembolization oc-



**Fig. 3.** Case of permanent stenting (case 20). A : Initial CTA shows left ICA terminus occlusion. B : Perfusion CT presents decreased CBF in the left hemisphere. C : Angiogram after temporary stenting reveals a tapered stenosis of left ICA terminus. D and E : Diffusion MR after 24 hours shows only minimal cerebral infarcts. F : CTA after 1 month reveals total lysis of the thrombus. Arrowheads points strut of the stent and arrow indicates distal markers of the stent. CTA : computed tomography angiography, ICA : internal carotid artery, CT : computed tomography, CBF : cerebral blood flow, MR : magnetic resonance.

curred in patients with persistent TC signs, which was treated by permanent stenting. Distal thromboembolization could occur in the thrombus which was fresh, friable, and easily entrapped in the deployed Solitaire stent. Permanent stenting after failure of MTSR would be a paradox, which had good results in our series. The thrombus, which is solid and strongly adhered to the vessel, can be easily treated by permanent stenting.

If neuro-interventionists could predict characteristics of the thrombus during MTSR, the dilemma of whether to perform MTSR or permanent stenting could be solved. In our study, all cases of failed MTSR presented persistent TC signs and demanded other treatment modalities. Cases of persistent TC signs lasting over 25 minutes could be treated with permanent stenting. Some studies reported the good result of permanent stenting after IV thrombolysis and/or mechanical thrombectomy; recanalization rates ranged from 79% to 100%<sup>12,16,30</sup>. Recently, Baek et al.<sup>4)</sup> achieved good clinical outcomes of permanent stenting for failed MTSR in anterior circulation (mRS 0–2 of stenting vs. non-stenting : 35% vs. 7%). In our study, half (2/4) of patients with failed MTSR received permanent stenting; both had excellent outcomes (Fig. 3). In the other two patients, in whom occlusion occurred at bifurcation (MCA, BA), another modality was not performed in one case (MCA bifurcation occlusion) and balloon angioplasty was

used in the other case (BA bifurcation occlusion). In our early experience, we doubted the efficacy of permanent stenting at bifurcation sites (MCA, BA) and did not try to perform permanent stenting. After permanent stenting, glycoprotein IIb/IIIa Inhibitor, which is bolus injected intra-arterially and maintains for at least 24 hours is effective for prevention of acute in-stent thrombosis<sup>4,30</sup>. In our cases of stenting, anti-thrombotic medication was administered before stroke occurrence and IV rt-PA was used at Emergency room. Postprocedural medication with aspirin and clopidogrel was initiated after 24 hours.

This study has some limitations. The number of the patients is small; further evaluation of a larger cohort will be necessary. The efficacy of MTSR or permanent stenting at arterial bifurcations, such as MCA bifurcation, should be studied. Relationship between angiographic sign and distal thromboembolization should also be evaluated.

## CONCLUSION

MTSR is an efficient method for recanalization of LVO in cardioembolic stroke, but some resistant cases do occur. Persistent TC signs may predict failure of MTSR and another modality, such as permanent stenting, may be needed.

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