

Preprocedural Basal Ganglionic Infarction Increases the Risk of Hemorrhagic Transformation but Not Worse Outcome Following Successful Recanalization of Acute Middle Cerebral Artery Occlusions

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Key words

- Basal ganglia
- Endovascular
- Hemorrhage
- Recanalization
- Thrombectomy

Abbreviations and Acronyms

AOL: Arterial occlusive lesion
CT: Computed tomography
HT: Hemorrhagic transformation
ICA: Internal carotid artery
MCA: Middle cerebral artery
MRI: Magnetic resonance imaging
mRS: Modified Rankin score
NIHSS: National Institutes of Health Stroke Scale
tPA: tissue plasminogen activator



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OBJECTIVE

Endoluminal revascularization is increasingly being used to reopen large arterial occlusions. Many techniques are used, including emergent carotid angioplasty and stenting, intraarterial thrombolysis (intraarterial tissue plasminogen activator [tPA]), and mechanical thrombectomy using devices such as the Merci Retrieval System (Concentric Medical, Inc, Mountain View, California, USA). Defining the preintervention clinical and imaging parameters

■ **OBJECTIVE:** We recently demonstrated that the preprocedural magnetic resonance imaging (MRI) pattern of deep middle cerebral artery (MCA) territory injury predicts poor prognosis. We postulate that the structures of the deep MCA field are particularly vulnerable to hemorrhagic transformation (HT) following reperfusion.

■ **METHODS:** We reviewed all cases of acute occlusions involving the M1 segment of the MCA with diffusion restriction of at least 50% of the deep MCA field on MRI (M1a pattern) that underwent endovascular therapy. We compared those with and without recanalization in regards to HT and disability on discharge.

■ **RESULTS:** Thirty-five patients met inclusion criteria. The recanalized M1a group ($n = 27$) had higher rates of HT (67% vs. 25%, $P = 0.05$) and a trend toward more parenchymal HT (37% vs. 0%, $P = 0.07$) and symptomatic HT (22% vs. 0%, $P = 0.12$) than those M1a patients who failed to recanalize ($n = 8$). Clinical improvement in the National Institutes of Health Stroke Scale by discharge was better in the survivors of the recanalized group.

■ **CONCLUSIONS:** Among patients with the preintervention M1a MRI pattern of advanced basal ganglionic injury, successful recanalization predicts a higher risk of HT but better outcome.

in order to select patients for revascularization will likely be an important aspect of acute stroke therapy and related research (8, 9).

We recently described the worse outcome at discharge predicted by the distinct preintervention magnetic resonance imaging (MRI) pattern of extensive injury of the deep middle cerebral artery (MCA) territory (M1a pattern), to include the lenticular nucleus, the caudate, and internal and external capsules versus distal M1 MCA occlusions (M1b) (10). This is the result of sufficiently prolonged occlusion of the prebifurcation, horizontal M1 segment of the MCA, which includes the origins of the lenticulostriate arteries, which are not collateralized as the distal MCA cortical branches are.

Although worse death and disability followed all patients with the M1a pattern in our prior analysis, we sought to establish

whether this is a result of a more complex relationship between successful recanalization and hemorrhagic transformation (HT), particularly because blood-brain barrier failure is more prevalent in the deep MCA field following ischemia (1). We also sought to determine whether the recanalized M1a subset of patients who subsequently experience HT would have worse outcomes than the natural history of the M1a patient with persistent M1 occlusion.

METHODS

We prospectively registered all consecutive patients undergoing endovascular therapy for large intracranial arterial occlusions from August 2002 to December 2007 according to protocol approved by our university institutional review board. We reviewed all patients presenting with acute occlusion

of the internal carotid artery (ICA) terminus or the M1 segment of the MCA, or tandem occlusions if at least one of the lesions involved the terminal ICA or M1.

Patients were selected for thrombectomy if they failed to meet intravenous thrombolytic indications or failed to improve following thrombolysis. Although preintervention diffusion–perfusion mismatch was not a requirement for inclusion in this analysis, a clinical criterion required for consideration of endovascular therapy at our institution is the presence of perfusion–diffusion mismatch. Patients were not treated if there was already a large volume of infarction or if the stroke neurologist felt that the premonitory condition of the patient made revascularization a futile effort. In cases where the patient's last known well time was not known or, in cases of wake-up strokes, calculated to be in excess of 8 hours, the stroke neurologist based the decision to proceed with recanalization if the admission MRI or computed tomographic (CT) scan showed a limited infarct volume in the presence of perfusion mismatch. The exact method(s) of revascularization was left to the discretion of the operator. However, primary or adjunctive therapy with intraarterial thrombolytics was only performed if the patient was clearly within 6 hours of symptom onset and did not have a subjectively large infarct volume.

All patients were required to have undergone preintervention MRI demonstrating the M1a pattern, defined as a subjective volumetric diffusion abnormality in at least 50% of the deep MCA field, to include the basal ganglia and immediately adjacent white matter, and postintervention cranial imaging at 72 hours. Imaging earlier than 72 hours was acceptable if definite HT was demonstrated.

We recorded the final revascularization of the primary arterial occlusive lesion (AOL) from the angiogram according to the previously described scale (7). We grouped patients according to failed (AOL 0 or 1) and partially or completely successful recanalization (AOL 2 or 3).

We compared M1a patients with and without M1 recanalization in regards to demographic data; the presence of prestroke comorbidities and suspected or demonstrated cardioembolic source for stroke; time from symptom onset to intervention; concomitant use of intraarterial thrombo-

lytic or preintervention administration of intravenous thrombolytic; and intra- or postprocedural administration of antiplatelets, anticoagulants, or vasoactive agents.

The primary outcome measure was any HT or parenchymal hematoma hemorrhage on imaging 48–72 hours postintervention according to the European Cooperative Acute Stroke Study scale (3, 5). All patients underwent immediate postprocedural head CT and serial imaging using head CT and/or MRI both per institutional protocol as well as in cases of clinical deterioration. At our institution, multimodal MRI includes diffusion-weighted imaging, perfusion-weighted imaging, gradient-recall echo, and susceptibility-weighted imaging sequences.

A neuroradiologist not involved in the stroke therapy independently assessed the noncontrast CT and/or MR images within 72 hours postintervention to adjudicate the presence and degree of HT. HT was defined as hypointense signal on the gradient-recall echo or susceptibility-weighted images within the brain parenchyma. In patients who only underwent CT examinations without postprocedural MR images, any parenchymal hyperdensity seen on the immediate postprocedural CT examination that partially or completely cleared within 24 hours was considered contrast enhancement or staining, whereas a hyperdensity on the immediate postprocedural CT persistently present 24 hours after endovascular therapy was considered HT (6, 13).

We assessed whether the HT was symptomatic, defined as a decline in NIHSS score by 4 or more points, or prompting intervention, if the decline was clinically attributed to the HT. We compared clinical outcomes including the modified Rankin score (mRS) and improvement in NIHSS score by discharge in survivors. We then analyzed the proportion of patients within each group with death or dependency at discharge.

Statistical analyses for categorical variables included Fisher's exact test and odds ratios for selected comparisons. We examined continuous variables using an analysis of variance and the Mann-Whitney test for unevenly distributed variables.

RESULTS

A total of 35 patients were included in the analysis. The average age was 63 years and

46% were male. Twenty-seven patients had successful endovascular recanalization of the initial M1 occlusion and 8 did not, resulting in an overall recanalization rate of 77%. Baseline demographics, prestroke comorbidities, distribution of cardioembolic strokes, serum glucose level at admission, and aspects of the intervention were similar between groups (Table 1). There were two patients with tandem ICA-M1 occlusions, both of whom underwent carotid angioplasty and stenting for the cervical ICA lesion. Both of these patients subsequently achieved successful recanalization of the M1 occlusions as well, and one had HT. There were no cases of recanalization with the Penumbra suction device (Penumbra, Inc., Alameda, California, USA) in this cohort.

The overall rate of HT in this cohort was 57% (20/35). In the primary comparison, M1a patients who were successfully recanalized had more HT than those who failed recanalization (67% [18/27] vs. 25% [2/8], $P = 0.05$) and there was a trend toward more parenchymal hematoma HT (37% [10/27] vs. 0%, $P = 0.07$) and symptomatic HT (22% [6/27] vs. 0%, $P = 0.12$). Hemorrhagic transformation was only symptomatic in the parenchymal hematoma type, which only occurred in the recanalized group. Of the six patients with symptomatic HT, three received ventriculostomies only, one underwent craniotomy and hematoma evacuation, whereas two did not undergo any surgical intervention.

In clinical outcomes, the mRS by discharge was similar between groups. Likewise, the rate of death or dependency at discharge was no different between those with successful and failed recanalization. Only six patients had a good clinical outcome (mRS <3) at discharge, and all were successfully recanalized (22%). Four of these recanalized patients experienced HT and two did not. Of survivors, those who achieved successful recanalization had more improvement in NIHSS by discharge (10 ± 8 vs. 1 ± 5 , $P < 0.01$).

The preprocedural administration of intravenous thrombolytic or the adjuvant use of intraarterial thrombolytic was not related to HT. Of the patients failing to recanalize, one received full-dose intravenous tPA without subsequent HT. Of the patients who were successfully recanalized, three of four receiving full-dose intravenous tPA

Table 1. Demographics and Clinical Outcomes of M1a Patients With and Without Recanalization

Characteristic	Recanalization		P
	Successful (n = 27)	Failed (n = 8)	
Age (year)	63.4 ± 22.7	60.4 ± 19.0	0.7
Male sex	11 (41)	5 (63)	0.4
Premorbid history of:			
Hypertension	16 (59)	4 (50)	0.7
Diabetes	6 (22)	0	0.3
Prior stroke	1 (4)	0	1
Cardiac history	11 (41)	4 (50)	0.7
Hyperlipidemia	10 (37)	3 (37)	1
Peripheral vascular disease	2 (7)	0	1
Cardioembolic source	13 (48)	5 (63)	0.7
Time to intervention (hours)	6:17 ± 2:46	5:35 ± 1:43	0.5
Concomitant thrombolytic	7 (26)	1 (13)	0.6
Antiplatelet use†	7 (26)	4 (50)	0.2
Anticoagulant use†	2 (7)	0	1
Vasoactive agent use†	5 (19)	3 (37)	0.3
Admission glucose (mmol/L)	143 ± 48	131 ± 13	0.5
Clinical measure			
NIHSS improvement*	10 ± 8	1 ± 5	0.01
Discharge mRS, median (IQR)	4 (4–6)	5 (5–6)	0.4
Discharge mRS <3	6 (22)	0	0.3
Any HT	18 (67)	2 (25)	0.05
Parenchymal hematoma–type HT	10 (37)	0	0.07
Symptomatic HT	6 (22)	0	0.3

Note: Values are n (%) unless otherwise mentioned. Boldface indicates significance.
HT, hemorrhagic transformation; IQR, interquartile range; NIHSS, National Institutes of Health Stroke Scale.
*Patients who died were not analyzed in this comparison.
†Administration of any amount within the first 72 hours of admission.

had HT, whereas another two received two-thirds dose and both had HT. One of these latter two also received 5 mg intraarterial tPA. One patient did not receive intravenous tPA but received 15 mg intraarterial tPA in adjunct with Merci thrombectomy. The administration of antiplatelet medications during or after the intervention was evenly distributed between groups, as was the use of vasoactive agents and anticoagulants within the first 72 hours.

DISCUSSION

Patients with advanced, deep MCA diffusion restriction prior to intervention experi-

ence more HT, substantially worse neurologic function, and higher rates of death or disability when compared to other preintervention MRI patterns. We were able to prove our initial hypothesis that among M1a patients, there is a positive relationship between recanalization and HT. Despite this higher rate of HT, however, we further demonstrate that overall clinical outcomes may still be better in those who have successful recanalization than in those who do not. In other words, the natural history of the M1a cohort is worse than the clinical course following successful reperfusion, despite the increased risk of HT.

HT in successfully recanalized M1a pa-

tients is the likely consequence of reperfusing the injured deep MCA field, which is excessively permeable because of the particular susceptibility of the region to ischemia (1). However, we demonstrate that HT and even parenchymal HT do not necessarily imply a worse outcome in the M1a patient. Almost one quarter of recanalized M1a patients (6/27) had a good functional outcome by discharge, four of whom had HT, as opposed to none of those failing recanalization. By discharge, patients with successful recanalization improved by an average of 9 more NIHSS points than those failing recanalization.

By our definition, all patients with the M1a MR pattern already have established injury in large portions of the deep gray nuclei prior to any intervention (Figure 1). Although successful revascularization may not avert the loss of function that ensues from these injuries, preservation of the penumbral cortex may still have a measurable beneficial effect on the clinical outcome and thus mitigate any additional morbidity that hemorrhage contributes to the group's collective disability. Alternatively, HT resulting from reperfusion of a profoundly infarcted deep MCA field may not truly decrease the already poor functional outcome to any demonstrable extent, as evidenced by the equally poor median mRS scores seen in both groups.

These data represent our single-center experience with endovascular acute stroke treatment, and our numbers are limited. Because many patients cannot undergo MR imaging and only about half of all these patients have the M1a pattern, we were only able to collect a modest sample. As a result, we combined all subtypes of the M1a group (7) and analyzed them collectively.

Longer-term clinical outcome and several imaging markers with prognostic significance were admittedly not assessed in our study. Angiographic collateral grade, postintervention infarct core volume, and final infarct volume 30 days after stroke are correlated with tissue fate and long-term neurologic function (2, 4, 11, 12). Our study was not powered to detect uneven distributions of any of these markers, which may have helped identify a subgroup of patients with better outcomes.

We felt the cohort failing endovascular therapy to best represent the “natural” history of the M1a patient, which is a study

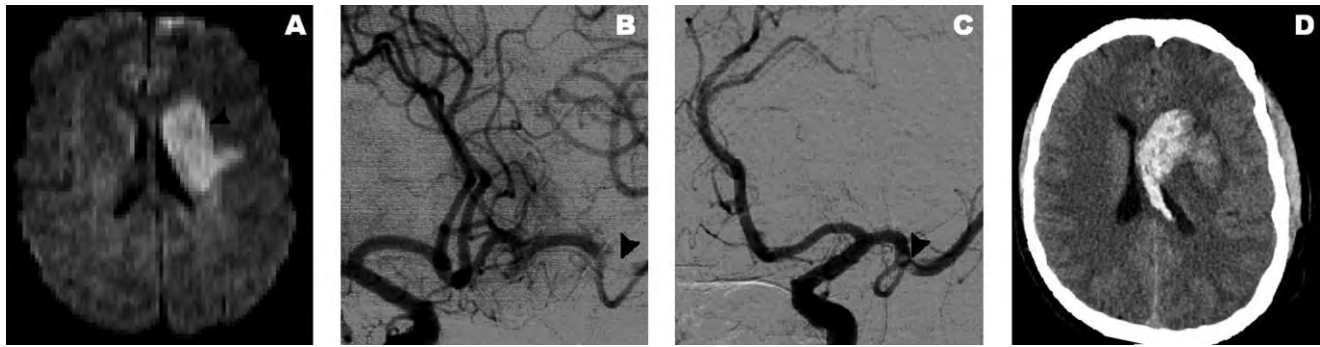


Figure 1. Illustration of hemorrhage into the basal ganglia following recanalization. **(A)** Diffusion-weighted MRI demonstrates infarction of the left caudate body (arrowhead). **(B)** Right ICA angiogram in the right anterior oblique view demonstrates a subtotal occlusion of the right M1 segment of the MCA (arrowhead) with occlusion of the left cervical carotid artery

(not shown). **(C)** Slightly different projection of a left ICA angiogram after stenting of the left cervical carotid artery and partial (AOL 2) recanalization of the MCA thrombus (arrowhead). **(D)** Immediate postprocedural CT demonstrating hemorrhage of the left caudate with intraventricular extension.

design limitation. The natural history would have been more accurately represented by the M1a patient randomized to no therapy. We await the results of the MR Rescue study, which we expect to be the first randomized trial data of thrombectomy (with mandatory preintervention MRI) to further clarify the true natural history of the M1a patient.

Our study suggests that although HT is more common among recanalized M1a patients, the M1a MRI pattern predicts poor outcome overall, regardless of HT and recanalization success. Despite HT, the functional outcome of the recanalized M1a patient may be better than the natural history of the M1a patient as represented by the nonrecanalized cohort. The only M1a patients in this study who had good outcomes were those with successful recanalization. Because this was a retrospective cohort analysis, a larger, randomized cohort is required to substantiate these findings.

CONCLUSIONS

Deranged permeability is present in the basal ganglia and white matter of the deep MCA territory following ischemia, which increases the susceptibility to hemorrhage following reperfusion. Patients with acute stroke and preintervention MRI evidence of deep MCA field diffusion restriction have higher rates of HT following recanalization, but an improved clinical outcome when compared to those who do not recanalize. Although HT should be a concern, the physician should be aware that recana-

lization is the only means of achieving a good clinical outcome in patients with the M1a MRI pattern. This also suggests that alternate endovascular therapies, such as intracranial angioplasty and/or stenting, by leaving thrombus in the lenticulostriate ostia, may be safer than clot extraction in this acute stroke population subset.

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honoraria from Ferrer and Boehringer Ingelheim; received support for clinical trials from Concentric Medical; and is a site investigator in multicenter trials sponsored by AGA Medical and the NIH for which the UC Regents received payments based on the number of subjects enrolled.

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Abnormal White Matter Changes After Cerebral Aneurysm Treatment with Polyglycolic-Polylactic Acid Coils

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Key words

- Aneurysm
- Endovascular coiling
- White matter changes

Abbreviations and Acronyms

CSF: Cerebrospinal fluid


FLAIR: Fluid-attenuated inversion recovery

MRI: Magnetic resonance imaging

PGLA: Polyglycolic-polylactic acid

PRES: Posterior reversible encephalopathy syndrome

SAH: Subarachnoid hemorrhage

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INTRODUCTION

Endovascular coil and stent technology has become an integral treatment modality for cerebral aneurysms (1, 8). Efficacy and safety of this minimally invasive technology was confirmed in the International Subarachnoid Aneurysm Trial; however, durability of this modality remains uncertain (7). In one series, angiographic follow-up revealed that over 20% of coiled aneurysms recanalized, resulting in the potential for subarachnoid hemorrhage (SAH) (9). To

■ **BACKGROUND:** Polyglycolic-polylactic acid (PGLA) coils induce inflammation within a cerebral aneurysm, which in turn is hypothesized to decrease aneurysm recurrence. We present 2 patients, who after aneurysm coiling with PGLA coils, developed mild symptoms and extensive magnetic resonance imaging (MRI) white matter changes.

■ **METHODS:** The first patient was a 46-year-old woman who underwent coiling of a 6.8 × 6.8 × 7.0-mm incidentally discovered basilar apex aneurysm. Approximately 1 month after her aneurysm coiling, she developed scintillating scotoma, and an MRI of her brain revealed bilateral white matter changes with punctate enhancement. The second patient, a 56-year-old woman, developed paresthesias and gait instability 1 month after retreatment of a ruptured 12 × 8-mm basilar tip aneurysm with stent assisted coiling. MRI of the brain also revealed bilateral white matter changes with punctate enhancement as well as an area of restricted diffusion in her pons.

■ **RESULTS:** Both patients underwent aneurysm coiling with PGLA coils. An extensive clinical evaluation revealed no specific etiology. The patients' symptoms and MRI abnormalities improved spontaneously over a period of weeks.

■ **CONCLUSIONS:** Conclusions: After extensive evaluation for alternate causes of disease, we hypothesize that the patients' symptoms and MRI findings, which were not all within the territory supplied by the coiled vessel, were due to an overexuberant inflammatory response related to the PGLA coils. These cases highlight the importance of heightened clinical suspicion of neurologic complaints in the subacute period after aneurysm coiling. We recommend a low threshold for neuroimaging of these patients.

reduce aneurysm recurrence and related complications, bioactive coils, of which polyglycolic-polylactic acid (PGLA) coils are the most common, have been designed to allow inflammation-induced scarring within aneurysms. Although inflammation within the aneurysm wall and the perianeu-

rysmal cerebrum is recognized, extensive cerebral inflammatory changes have not been documented postcoiling. We report two patients who experienced postprocedure neurologic symptoms with extensive white matter changes on brain imaging after aneurysm treatment with PGLA coils.