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Research Article

Strokectomy in Malignant Middle Cerebral Artery Infarction: A 20-Year Experience from a Tertiary Center in Taiwan

Yi-Ting Liu[1], Kuo-Chuan Wang[1,2*]

[1]Department of Surgery, Division of Neurosurgery, National Taiwan University Hospital, Taipei, Taiwan

[2]College of Medicine, National Taiwan University, Taipei, Taiwan

[*]**Corresponding author:** Kuo-Chuan Wang, Department of Surgery, Division of Neurosurgery, National Taiwan University Hospital, Taipei, Taiwan; No 7, Chung-Shan S. Rd., Taipei, 100, Taiwan

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Abstract

Purpose: To determine the potential benefits of strokectomy and decompressive craniectomy (DC) for patients with malignant middle cerebral artery (MCA) infarction at a tertiary center in Taiwan over a period of 20 years.

Methods: In this institutional retrospective study, we reviewed the data of all patients with malignant MCA infarction who underwent DC with or without strokectomy between 2003 and 2022 at the Department of Surgery of National Taiwan University Hospital. We collected data on patient demographics, outcomes (modified Rankin scale [mRS]), and complications.

Results: A total of 18 patients received a combination of DC and strokectomy (DC+S group), and 9 patients received DC alone (DC alone group). Compared with the DC alone group, the DC+S group had a significantly shorter duration of ventilator use ($P = .003$). They also had a significantly higher midline shift correction rate ($P < .0001$) and a significantly shorter period of increased intracranial pressure ($P < .0001$). The mRS outcome of the DC+S group was not inferior to that of the DC alone group.

Conclusions: Strokectomy is a safe technique for malignant MCA infarctions. Combining strokectomy with DC offers several advantages compared with DC alone and yields favorable outcomes.

Keywords: Decompressive craniectomy; Increased intracranial pressure; Malignant middle cerebral artery infarction; Strokectomy; Uncal herniation

Introduction

First introduced by Werner Hacke in 1996, Malignant Middle Cerebral Artery (MCA) infarction is a term used to describe a space-occupying mass effect resulting from cerebral edema following MCA infarction. [1] Patients with malignant MCA infarction typically have a poor prognosis, high mortality rate, and poor quality of life. [2] Therefore, early diagnosis and aggressive therapy, including decompressive surgery, are essential to reduce brain herniation and subsequent brainstem compression [3].

Decompressive Craniectomy (DC) is typically performed in patients with large cerebral infarctions. Multiple large-scale, multicenter, randomized, prospective studies have indicated the benefits of DC in patients with malignant MCA infarction. [4-6] Long-term benefits have also been documented at 3-year follow-up. [7] Generally, performing decompressive surgery within 48 h of stroke onset reduces the mortality rate and improves patients' functional outcomes. [8] Ultra-early DC before neurological deterioration also improves the neurological sequelae of patients with malignant MCA infarction. For instance, in patients who underwent DC within 6 h of symptom onset, low rates of mortality, vegetative state, and severe disability were observed. [9] Strokectomy refers to the partial resection of an infarcted brain tissue. It is performed either as an adjuvant procedure to DC or as a standalone surgical alternative. Strokectomy alleviates cerebral edema and enables the immediate replacement of the cranial bone. However, the resected tissue may progressively cause subsequent edema. Therefore, the necessity of strokectomy has long been debated. In addition, strokectomy has not been frequently performed, and malignant MCA infarctions are uncommon. Therefore, few cases requiring strokectomy for malignant MCA infarction have been reported in the literature. [10] In a retrospective study, Kostov et al. [11] reported similar neurological outcomes between patients who underwent strokectomy alone and patients who underwent DC alone. Nevertheless, the benefits of strokectomy in terms of overall survival and neurological outcomes have remained controversial [12].

In this study, we investigated the potential benefits of strokectomy and DC for patients with malignant MCA infarction. We reviewed the data of 27 patients with malignant MCA infarction, of whom 9 underwent DC alone (DC alone group) and 18 underwent a combination of DC and strokectomy (DC+S group).

Materials and Methods

Study Design

This retrospective study was conducted at a single hospital in Taiwan (National Taiwan University Hospital). All patients who underwent craniectomies for malignant MCA infarction from January 2003 to December 2022 were included in the study, and their data were reviewed. The study protocol was approved by the Institutional Review Board of National Taiwan University Hospital (202011049RINC). Clinical records, imaging data, outcome scores, and neurological symptoms were analyzed. In addition, the clinical outcomes, mainly the modified Rankin scale (mRS) score at 3-month follow-up, and mortality rates of the DC+S group were compared to those of the DC only group. Patients with bilateral hemisphere infarctions were excluded from the study.

Surgical Procedure

At our institute, all patients with MCA infarction, regardless of whether they have undergone thrombolytic agent therapy, intra-arterial thrombectomy, or both, are admitted to the Neurology Intensive Care Unit. Discussion pertaining to aggressive treatment is then held by unit staff with the patient and their family. If the patient agrees to undergo aggressive treatment, their dosage of dual antiplatelet agents is reduced to enable possible surgical intervention. Other medications, such as mannitol, glycerol, and hypertonic saline, are administered in accordance with established guidelines. [3,13-20] Once malignant MCA infarction with uncal herniation is radiologically confirmed, often through emergent Computed Tomography (CT), a neurosurgeon is informed, and emergent surgery is arranged. As a standard surgical procedure, DC is performed on the ipsilateral side of the malignant MCA infarction. A reversed question-mark incision is made, starting anteriorly to the tragus, extending posteriorly and rostrally, and turning anteriorly until the frontal hairline. A large craniotomy window is used to cover the entire MCA region. The dura is then opened in either a C-shape or cruciate manner and reflected. Ischemic tissue is identified as nonviable blanched brain tissue that is swollen with no clear pulsation. [21] Subsequently, subpial resection is performed using suction and bipolar forceps. Because infarcted brain tissue exhibits marked cytotoxic edema and undergoes liquefactive necrosis, this tissue is easy to remove with suction without disturbing viable brain parenchyma. Dura augmentation is then performed using either an autologous fascia graft or dura substitutes, and an Intracranial Pressure (ICP) monitor is placed at the subdural space. A skull graft is preserved in a tissue bank at our institute. For better decompression, the temporalis muscle is often resected. After surgery, the patient is transferred to the Intensive Care Unit (ICU), and a CT scan is performed within 48 h of surgery or as clinically required. ICP data are collected using a Philips IntelliSpace Critical Care and Anesthesia critical care information system and recorded on an hourly basis. A total of 24 ICP values are collected every day. The highest value is recorded and converted into daily-based ICP data.

Figure 1 shows the case of malignant right MCA infarction in a 52-year-old man. Although emergent intra-arterial thrombectomy was performed, progressive brain swelling with a midline shift was observed. Therefore, emergent DC without strokectomy was performed 24 h after the onset of stroke. However, the patient's ICP increased, and bedside sonography revealed an increased pulsatility index with enlarged hemorrhagic transformation. Follow-up brain CT also revealed progressive brain edema with an increased midline shift (Figure 1B). Therefore, right frontotemporoparietal strokectomy was performed. Follow-up brain CT revealed complete correction of the midline shift (Figure 1C). The patient remained clearly conscious on poststrokectomy day 1 and was extubated on poststrokectomy day 12.

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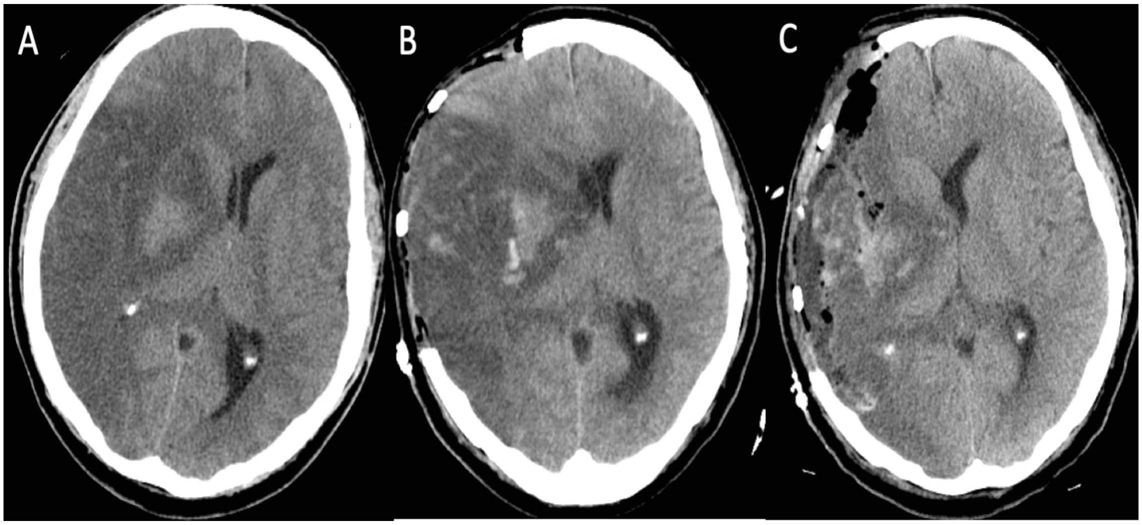

Figure 1: Malignant right MCA infarction in a 52-year-old man. (A) At initial presentation, axial CT revealed a right dense MCA sign. (B) After emergent DC without strokectomy, follow-up brain CT revealed progressive brain edema with an increased midline shift. (C) After the patient underwent a right strokectomy, follow-up brain CT revealed complete correction of the midline shift.

Outcome Measurement and Statistical Analysis

Patient outcomes were measured using the mRS both preoperatively and 3 months postoperatively. All statistical analyses were conducted using SAS software version 9.4 (SAS Institute, Cary, NC, USA). Two-tailed Student's t tests were used for metric variables, Mann-Whitney U test was used for ordinal variables, and Fisher's exact test was used for categorical variables. A P value less than .05 was considered statistically significant. Patients with missing data of 1 variable were excluded only from the corresponding statistical analysis but not from the entire study.

Results

A total of 31 patients with MCA infarction underwent DCs at National Taiwan University Hospital from 2003 to 2022. Only 1 patient with M2 territory infarction and hemorrhagic transformation did not meet the criteria for malignant MCA infarction. Specifically, this patient had a final Alberta Stroke Program Early CT Score (ASPECTS) of 6 on noncontrast brain CT and a minimal midline shift. Therefore, this patient was excluded from the study. Another 3 patients with bilateral hemisphere infarction were excluded from the study (Figure 2). A total of 27 patients were included in this study, of whom 18 underwent a combination of DC and strokectomy (DC+S group) and 9 underwent DC alone (DC alone group). Table 1 presents a summary of the patients' clinical characteristics. The mean age of the strokectomy group was significantly lower than that of the control group (58.1 vs. 68.9, P = .02). However, no difference was observed between the 2 groups in terms of gender, infarction side, initial National Institutes of Health Stroke Scale (NIHSS) score (24.6 vs. 25.4), or ASPECTS (0 vs. 0) on noncontrast CT. Compared with the control group, the number of patients who underwent thrombolytic therapy and intra-arterial thrombectomy was higher in the strokectomy group.

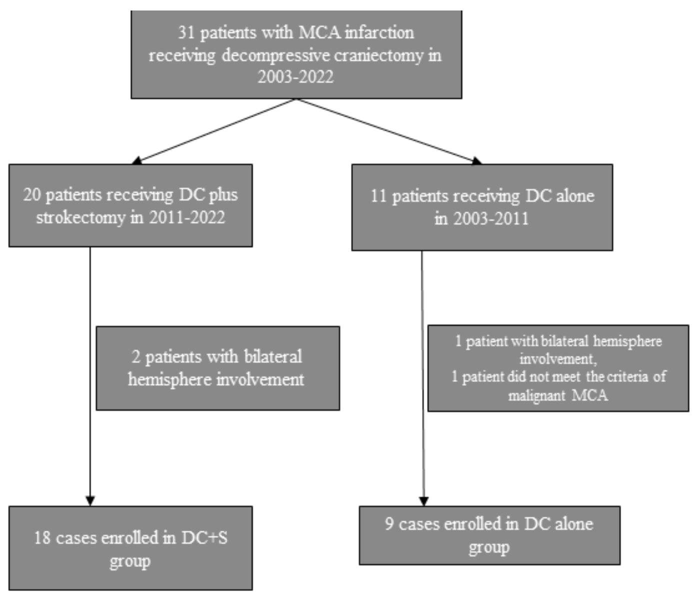

Figure 2: Flowchart of patients included in the study.

	DC+S(n=18)	DC alone(n=9)	P value
Age	58.1(13.9)	68.9(7.9)	0.0169*
Gender(M/F)	10/8	6/3	1.0000
Symptom onset to surgery	1.9(1.3)	3.7(4.9)	0.3282
Side of infarction(L/R)	5/13	4/5	0.4606
Initial NIHSS	24.6(19-33)	25.4(17-32)	0.7346
ASPECT	0(0-3)	0(0-2)	0.1005
Multiple Territory of infarction	4(22.2%)	4(44.4%)	0.3748
rtPA	9(50%)	2(22.2%)	0.2311
IA thrombectomy	3(16.7%)	0(0%)	0.5292
mRS score ≤3	3(16.7%)	0(0%)	0.5292
mRS score ≤4	11(61.1%)	3(33.3%)	0.2365
CNS infection	0(0%)	1(11.1%)	0.3333
Shunt-dependent hydrocephalus	2(11.1%)	0(0%)	0.5385
ICU stay (days)	24.1(12.5)	25.1(4.4)	0.7508
Length on ventilator (days)	15.8(10.7)	25.1(4.39)	0.0030**
Midline shift correction (%)	65.5(37)	-30.5(48.4)	<0.0001**
operation length (minutes)	218.8(32.5)	152(34.2)	0.0199*

*denoted p<0.05. **denoted p<0.01. F:female. IA:intra-arterial. L:left. M:male. mRS:modified Rankin scale. R:right. rtPA: recombinant tissue plasminogen activator.

Table 1: Characteristics and comparison between patients who underwent decompressive craniectomies alone (DC alone) and decompressive craniectomies + strokectomy (DC+S).

Figure 3 shows the primary mRS outcomes at 3 months of follow-up. In the DC+S group, 3 patients had an mRS score of 3, 8 patients had an mRS score of 4, and 7 patients had an mRS score of 5. In the DC alone group, 3 patients had an mRS score of 4, 3 patients had an mRS score of 5, and 3 patients had an mRS score of 6. Mann–Whitney U test revealed a statistically significant difference between the 2 groups (P = .0425). When the 2 groups were dichotomized into either favorable outcomes (mRS score ≤3) or unfavorable outcomes (mRS score >3), no statistical significance was observed (3/15 vs. 0/9). Similarly, when the 2 groups were dichotomized into either severe disability (mRS score >4) or moderate disability (mRS score ≤4), no significant difference was observed (7/11 vs. 6/3). In the DC alone group, 1 patient had central nervous system (CNS) infection, but the results were not significantly different. In the DC+S group, 2 patients had shunt-dependent hydrocephalus, but the results were also nonsignificant.

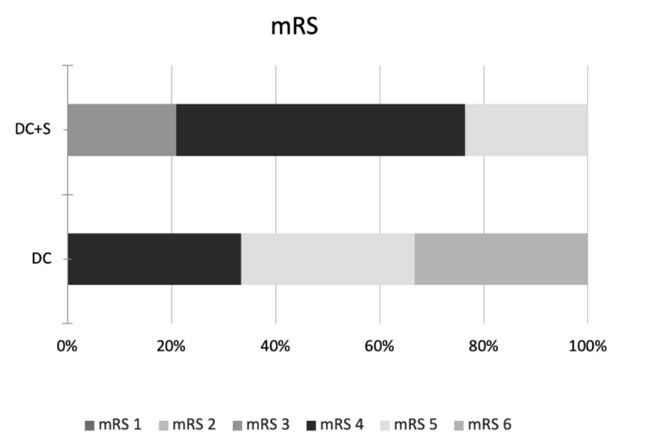

Figure 3: Outcome measurement based on the mRS between the DC alone and DC+S groups. The mRS outcome of the DC+S group was not inferior to that of the DC alone group.

According to our results, the duration of ventilator use was significantly shorter in the DC+S group than in the DC alone group (15.8 vs. 25.1, P = .003; Figure 4A). In addition, the mean ICU stay was 24 days in the DC+S group and 25 days in the DC alone group (Figure 4B). However, no statistically significant difference was observed. Midline shift correction was calculated as the difference between midline shifts on CT before surgery and immediately after surgery (within 24 h). Cases lacking essential data were excluded from the analysis. In cases with bilateral hemisphere infarction, certain limitations were expected in unilateral decompression. Therefore, these cases were excluded from the analyses of midline shift correction and ICP control. Our results indicated that the midline shift correction rate was significantly higher in the DC+S group than in the DC alone group (65.5% vs. −30.5%, P < .0001; Figure 4C). Recording ICP on a daily basis enabled the highest pressure to be recorded. By defining increased ICP (IICP) as ICP greater than 20 mmHg, we calculated the duration of IICP in the 2 groups. The results indicated that the duration of IICP was significantly shorter in the DC+S group than in the DC alone group (1 vs. 18 person-days, P < .0001). In addition, the operation time was significantly shorter in the DC alone group than in the DC+S group (152 vs. 219 min, P = .0199; Figure 4D).

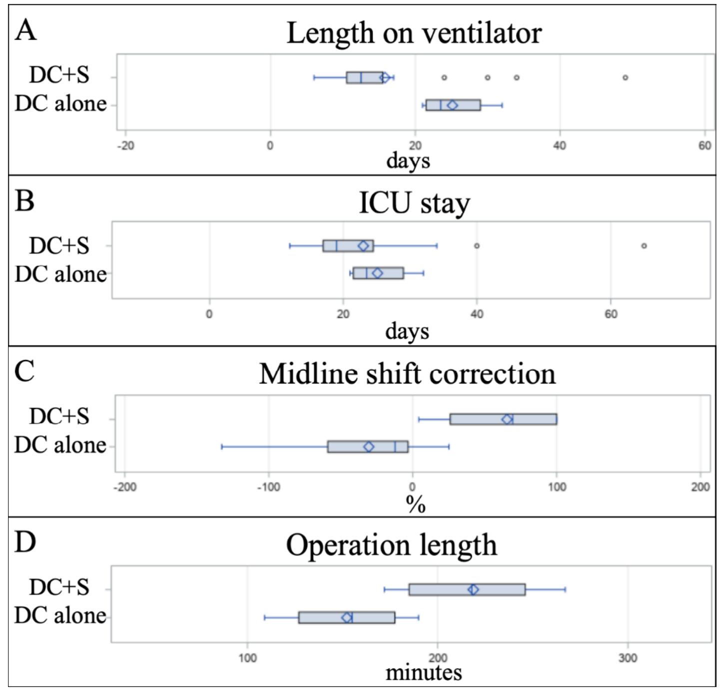

Figure 4: Comparison of the DC+S and DC alone groups. (A) Compared with the DC alone group, the DC+S group had a significantly shorter duration of ventilator use (P = .003). (B) No statistically significant difference was observed in mean ICU stay between the 2 groups. (C) The DC+S group had a significantly higher midline shift correction rate than that of the DC alone group (P < .0001). (D) The DC alone group had a significantly shorter operation duration than that of the DC+S group (P = .0199).

Discussion

According to our findings, combining DC and strokectomy may provide additional benefits for patients with supratentorial malignant stroke. This combination may provide improved decompression, reduced ventilator dependence, and potentially shorter ICU stay, with comparable neurological outcomes and adverse effects, including CNS infection and shunt-dependent hydrocephalus. Further investigation is required to determine whether the extended operation time and complex procedures involved in strokectomy are justified by the potential benefits of reduced ventilator use and ICU stay. A cost-effective analysis can also be applied to various areas and institutions to determine the most favorable treatment strategy.

Although the effectiveness of DC in patients with malignant MCA infarction aged less than 80 years is well established, some debate is still ongoing regarding the optimal timing of surgery. Some discrepancies have been observed in large-scale, randomized, controlled trials in terms of surgery timing, with some studies recommending 30 h (DECIMAL trial) and others recommending 96 h (HAMLET trial) after symptom onset. [4,5] A meta-analysis of these randomized, controlled trials recommended surgery within 48 h after onset. [8] A recent study even proposed an ultra-early surgical intervention within 6 h after the onset of stroke to improve the neurological outcomes of patients with malignant MCA infarction. [9] Achieving this goal requires accurate prediction of the future development of malignant MCA infarction. Takashi proposed the DASH score as a predictor of the development of malignant MCA infarction. [22] The widespread availability of magnetic resonance imaging in Taiwan ensures the practicality of using this score. Schwake et al.[10] proposed the Münster Stroke Score to determine whether a patient would benefit from strokectomy. This score is based on factors such as age, NIHSS score, and the vascular territory involved, making it easily applicable. With further validation, this score may assist in differentiating patients who require strokectomy from those who can benefit from DC alone.

Most of the previous studies did not include patients aged more than 80 years. Given the high comorbidity and limited physical reserve of this age group, the effectiveness of DC in this patient group has remained uncertain. Some studies have even reported poor outcomes following DC in patients aged more than 80 years. [23] In our study, patients aged more 80 years were not excluded. However, only 1 patient aged more than 80 years was included in the control group. Therefore, further investigation is required to determine whether patients aged more than 80 years benefit from DC.

The primary outcome of this study was the neurological outcomes measured on the mRS at 3 months of follow-up. Because of the low incidence of malignant MCA infarction, this study was largely limited, and we observed marginal statistical significance only in the DC+S group. In addition, we observed no statistically significant difference in the proportion of patients who survived with favorable outcomes (mRS ≤ 3). These results are consistent with those of a previous study. [11] Notably, 2 patients in the DC alone group had an mRS score of 6 (indicating death), whereas no patient in the DC+S group expired at the 3-month follow-up. Although the causality of death was not well documented, persistent brain edema with a prominent mass effect and limited midline shift correction after craniectomy alone was observed on postoperative CT. Hence, brainstem compression was highly suspected to be the cause of death. Therefore, strokectomy may not only shorten the duration of IICP and reduce ventilator dependence but may also alleviate severe brain edema, for which craniectomy alone cannot offer adequate decompression. In addition, a combination of strokectomy and craniectomy may reduce the mortality rate of patients with malignant MCA infarction. However, this presumption requires further validation in future prospective studies.

In this study, all 3 cases with shunt-dependent hydrocephalus occurred in the strokectomy group. Although no statistically significant differences were observed, a clear trend of hydrocephalus development after strokectomy was identified. This process may result from the destruction of the arachnoid villi associated with the removal of brain tissue, thus leading to the disruption of cerebrospinal fluid circulation. Further prospective studies are still required to determine the causality of hydrocephalus after strokectomy. In addition to the comparative neurological outcomes observed at 3 months of follow-up, the main difference between the strokectomy group and the control group was the much shorter durations of IICP (defined as ICP > 20 mmHg) and ventilator use, both of which presumably linked to a shorter ICU stay. However, the length of ICU stay was only 1 day shorter in the strokectomy group; thus, the finding was nonsignificant. A possible explanation would be the difference in the time frame between the 2 groups. For instance, the patients in the DC+S group underwent surgery from 2011 to 2022, whereas the patients in the DC alone group underwent surgery from 2003 to 2011. The standards of ICU care evolve with time; thus, the definitions of “standard” and “routine” care for these 2 groups of patients may have been considerably different. The degree of treatment aggressiveness and the protocol of ventilator weaning may have also been different. In summary, we cannot conclusively demonstrate the benefits of reduced IICP duration and ventilator dependence; therefore, further prospective studies are required.

The limitations of this study are its retrospective design and small sample size and the fact that malignant MCA infarction is an uncommon condition. A difference was observed between the time frames of the 2 groups. Specifically, the patients in the DC+S group underwent surgery from 2011 to 2022, and the patients in the DC alone group underwent surgery from 2003 to 2011. These time frame differences may have resulted in different background characteristics for standard care, thereby affecting postoperative outcomes. Given the lack of studies describing the detailed experiences of DC and strokectomy for patients with malignant MCA infarction, we believe that our case series provides crucial insights into the potential value of strokectomy for malignant MCA infarction.

Conclusions

In patients with malignant MCA infarction, DC can be used in combination with strokectomy to correct midline shifts and effectively control their ICP. Compared with DC alone, DC combined with strokectomy provides more favorable neurological outcomes at 3 months of follow-up. In this study, compared with the control group, the strokectomy group had significantly shorter durations of ventilator use. However, strokectomy may increase the risk of developing shunt-dependent hydrocephalus, although we observed no statistically significant differences. Further prospective studies are required to determine the potential benefits of strokectomy for patients with malignant MCA infarction.

Conflicts of interest: The authors have no conflicts of interest to declare.

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Author Contributions: All authors contributed to the conception and design of this study. Yi-Ting Liu and Kuo-Chuan Wang were responsible for material preparation, data collection, and analysis. Yi-Ting Liu wrote the first draft of the manuscript, and all authors commented on the previous versions of the manuscript. All authors read and approved the final manuscript.

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