ANALYZING THE EARLY CLINICAL AND IMAGING OUTCOMES OF STA-MCA BYPASS SURGERY VIA THREE-DIMENSIONAL VOLUMETRIC MEASUREMENT IN PATIENTS WITH INTRACRANIAL ATHEROSCLEROSIS

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Abstract

Background: Intracranial atherosclerotic disease (ICAD) is a leading cause of ischemic stroke and remains associated with high morbidity and mortality. Although recent studies suggest that superficial temporal artery to middle cerebral artery (STA–MCA) bypass may benefit patients with hemodynamic compromise, its clinical efficacy remains a matter of controversy.

Objective: We aimed to evaluate the effectiveness of STA-MCA bypass surgery in patients with ICAD, focusing on both clinical outcomes and cerebral hemodynamic imaging using 3D volumetric analysis.

Methods: Six patients with ICAD who underwent STA-MCA bypass surgery were selected using pre-defined criteria. Clinical outcomes were retrospectively reviewed using the National Institutes of Health Stroke Scale (NIHSS) and the Modified Rankin Scale (mRS). Imaging outcomes were examined by analyzing the brain lesion area and perfusion using computed tomography perfusion (CTP). Statistical significance was analyzed using paired rank-sum and Friedman tests.

Results: In all cases, the primary diagnosis was ischemic stroke with significant stenosis of the internal carotid or middle cerebral artery. All patients demonstrated patent grafts, and no ischemic events occurred within 30 days after surgery. However, one patient had a postoperative asymptomatic acute subdural hematoma. All patients showed stable or improved neurological and functional outcomes after 30 days. Median NIHSS scores remained stable (pre-op 1.50 [0.00–7.50] vs. 30 days 1.50 [0.00–5.25], $p = 0.368$), while median mRS scores showed a non-significant trend toward improvement (pre-op 1.50 [0.75–3.50] vs. 30 days 1.00 [0.00–3.00], $p = 0.082$). Volumetric perfusion analysis demonstrated reductions in lesion volumes for CBF (66.40 [43.35-145.70] → 28.55 [19.85-111.28] mL), MTT (220.75 [101.60-337.05] → 143.00 [39.93-242.35] mL), and Tmax (265.45 [145.53-333.63] → 212.40 [101.08-260.20] mL) on CT perfusion immediately postoperatively and at short-term follow-up, although these changes did not reach statistical significance ($p = 0.068$ for all). CBV lesion volume also decreased slightly (1.15 [0.25–5.51] → 0.00 [0.00–2.54] mL, $p = 0.109$).

Conclusion: Our results suggest that STA-MCA bypass surgery may offer clinical and hemodynamic benefits for ICAD patients who are unresponsive to medical and endovascular treatments. In this study, improved NIHSS and mRS scores, as well as hemodynamic parameters, were observed using CTP. Performing volumetric measurements may support the assessment of imaging outcomes. Given the small sample size and short follow-up period, these findings should be interpreted with caution. Large-scale and long-term studies are warranted to validate our findings and optimize ICAD treatment strategies.

Keywords: recurrent stroke, cerebral revascularization, STA-MCA bypass, intracranial atherosclerosis, 3D volumetric measurement, case series

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Introduction

Intracranial atherosclerotic disease (ICAD) is a significant cause of ischemic stroke.[1–5] Despite advances in best medical therapy (BMT) and endovascular treatment (EVT), ICAD remains associated with high morbidity and mortality.[6] Surgical revascularization, particularly superficial temporal artery to middle cerebral artery (STA–MCA) bypass, has been explored as an option to restore perfusion in selected patients.[7–11]

The benefit of extracranial–intracranial (EC–IC) bypass has long been debated. Early randomized trials failed to demonstrate the superiority of bypass over BMT, primarily due to the high perioperative risks.[9,12,13] More recently, the CMOSS trial reported no reduction in its primary composite outcome,[14] although post-hoc analyses suggested fewer late ipsilateral strokes beyond 30 days, emphasizing the importance of careful hemodynamic selection.[15] Similarly, Japanese series, such as JET and JET-2, demonstrated lower recurrence rates when bypass was limited to patients with impaired cerebral blood flow or cerebrovascular reserve.[8,16] Subsequent observational studies have highlighted the potential benefits of this approach, including a reduced risk of transient ischemic attacks (TIAs) and improved functional outcomes.[17–20]

Given this ongoing controversy, we aimed to determine the efficacy of STA–MCA bypass in enhancing cerebral perfusion and improving prognosis in patients with ICAD who presented with recurrent ischemic events and confirmed cerebral hypoperfusion despite BMT. Therefore, we retrospectively analyzed early clinical and imaging outcomes at Chulabhorn Hospital. Clinical outcomes were measured using the National Institutes of Health Stroke Scale (NIHSS) and the Modified Rankin Scale (mRS). In contrast, imaging outcomes were determined by assessing the pathological areas of the brain using CTP data and three-dimensional (3D) volumetric data.

Methods

This study was conducted in accordance with the Declaration of Helsinki. The research protocol was reviewed and approved by the Human Research Ethics Committee of Chulabhorn Royal Academy (project code: EC 029/2567). The approval was granted on May 9, 2024, with a 12-month approval period. Informed consent was obtained from all individual participants included in the study. Consent for publication of the study findings, including relevant images and data, was obtained from all individual participants.

Patient selection

This study included patients who underwent STA-MCA bypass surgery at Chulabhorn Hospital, Thailand, between January 2022 and December 2024. Eligible patients were adults (≥18 years) with ischemic stroke or TIA due to ICAD, confirmed by >70% stenosis or occlusion of the MCA or ICA, who experienced recurrent ischemic events despite best medical therapy (dual antiplatelet therapy). Preoperative CTP confirmed hypoperfusion in the corresponding vascular territory. Patients with minimal neurological deficits (NIHSS = 0) were included if they had recurrent ischemic symptoms and documented hypoperfusion. Exclusion criteria included prior intracranial hemorrhage, active systemic disease, infection, severe cognitive impairment, or comorbidities conferring high surgical risk or limited life expectancy. Full details of the inclusion and exclusion criteria are presented in the Supplement.

Surgical technique

Each STA-MCA bypass procedure was performed under general anesthesia. Preoperatively, a CTA was performed to assess the STA and select the donor branch, either the frontal or parietal branch. Single-barrel bypass was the default approach; however, if intraoperative assessment during harvesting and dissection revealed an inadequate donor vessel (e.g., insufficient length, caliber, or flow), a double-barrel bypass was performed at the surgeon's discretion.

A craniotomy was performed over the Sylvian fissure to provide optimal access to the MCA, and the dura was incised to expose the underlying brain tissue. Under an operating microscope, an appropriate cortical branch of the MCA was identified. An arteriotomy was performed on the MCA branch, and the incision was just large enough to accommodate the STA. Then, the STA was brought into the operative field. An end-to-side anastomosis was performed between the STA and the MCA branch using fine microsutures (10-0 nylon).

The patency of the bypass was confirmed intraoperatively using Doppler ultrasound or indocyanine green to verify that blood flow was successfully established through the bypass without any obstruction. After confirming the success of the anastomosis, the dura was closed, the bone flap was replaced and secured with plates and screws, and the skin was sutured back in place. A drain was placed subcutaneously to prevent hematoma formation.

Postoperative management and follow-up

All patients were admitted to the neurosurgical intensive care unit after their surgery. A postoperative CTP scan was performed within the first 24 hours, and the NIHSS and mRS scores of each patient were recorded by a neurologist. All patients were prescribed a regimen of both perioperative and lifelong aspirin (81 mg per day).

The patients attended outpatient follow-up appointments one and four weeks after discharge. During these visits, CTA and CTP were performed to assess graft patency and evaluate the success of the procedure. Subsequent follow-up intervals were set based on the patient's individual progress. The postoperative follow-up appointments were scheduled at 3 months, 6 months, and annually thereafter.

Imaging data processing and analysis

Imaging data were collected, processed, and analyzed using a systematic approach to ensure precision and consistency across all cases—a Philips Spectral CT 7500 scanner was utilized to acquire raw data and images. The computed tomography (CT) data were processed using Syngo via software version VB80D, Siemens Healthineers AG, Forchheim, Germany. The data were exported to the Picture Archiving and Communication System (PACS) of Chulabhorn Hospital. Further analysis was performed using the Brainlab software viewer version 4.0, image fusion version 4.0, and Brainlab Elements SmartBrush version 3.0 (Brainlab AG, Munich, Germany).

Preoperative and postoperative images were selected for analysis. Images prepared in the axial plane at the levels of the ganglionic and supraganglionic regions were used in this analysis.

Measurement of lesion area

Lesion area measurements were performed at the ganglionic and supraganglionic levels according to the Alberta Stroke Program Early CT Score (ASPECTS) anatomical divisions. Areas of interest were selected based on visual identification of color changes on the perfusion parameter maps, compared with the contralateral (normal) hemisphere. Once a region with abnormal color differentiation was identified, a freehand line was manually drawn to outline the area of interest. The image analysis software then automatically calculated the enclosed area in square millimeters (mm^2), which was subsequently converted to square centimeters (cm^2) for consistency in data presentation. This approach was intended to provide quantitative area measurements for each ASPECTS-defined region, in contrast to the traditional ASPECTS method, which assigns a binary score (0 or 1) to each region. **(Figures 1 and 2).**

Measurement of perfusion parameters and lesion volume

CTP datasets were imported into the Brainlab 3D viewer and processed with the SmartBrush tool for segmentation of perfusion deficits. Regions of interest were manually delineated, and the software automatically refined boundaries based on intensity patterns. Segmentation was verified in axial, coronal, and sagittal planes before generating 3D models for volumetric analysis. Lesion areas were initially measured in mm^2 and converted to cm^2 for consistency **(Figures 1 and 2).** Perfusion deficits were visualized using color maps (orange for CBF, light blue for CBV, red for MTT, and pink for Tmax) **(Figure 3).**

Imaging interpretation

To minimize operator bias, all imaging analyses were independently performed by three blinded raters, consisting of two experienced neurosurgeons and one neurosurgical resident. Imaging datasets were exported in Digital Imaging and Communications in Medicine (DICOM) format with all patient identifiers (e.g., name, date of acquisition) removed to ensure blinding. Each operator conducted volumetric measurements separately following predefined and standardized protocols.

Interobserver variability was assessed by calculating the intraclass correlation coefficient (ICC), with values ≥ 0.75 considered indicative of acceptable reliability. In cases where discrepancies were identified, a consensus meeting was held among the three raters to review the segmentation and volumetric data in detail. The final imaging outcomes reported in this study represent the consensus values derived from this adjudication process. This systematic approach was undertaken to strengthen the reproducibility and validity of the imaging measurements.

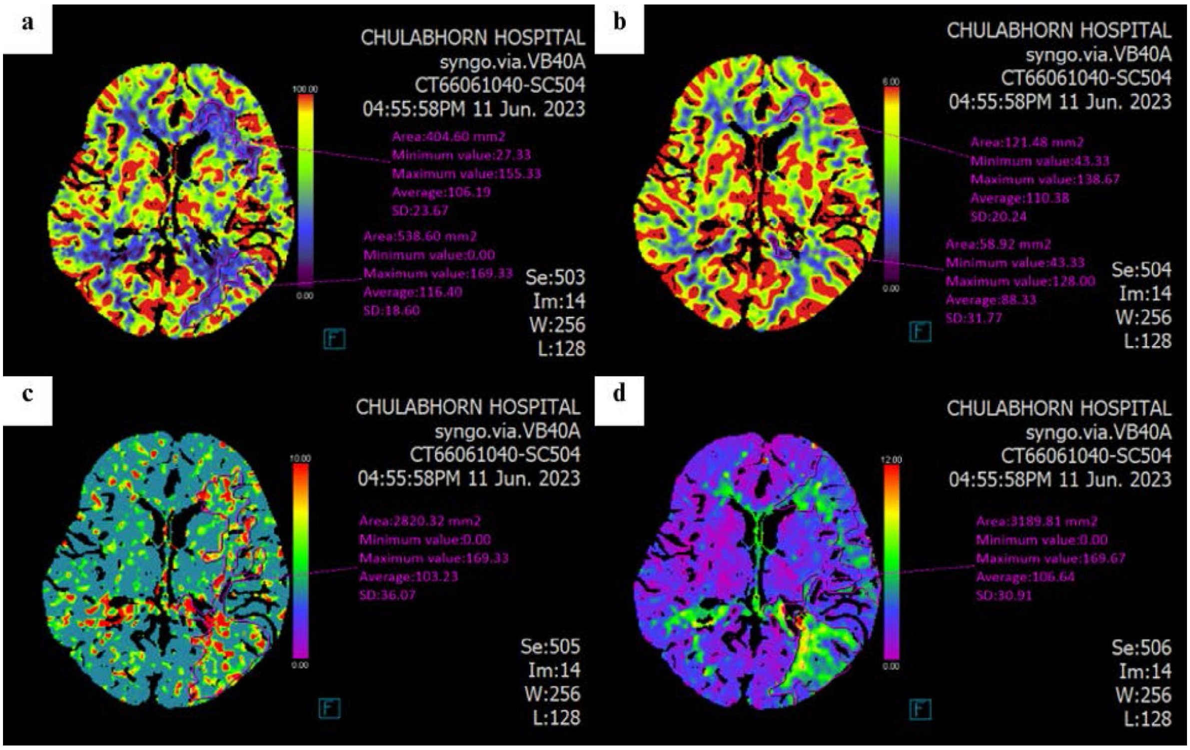

Figure 1. Representative computed tomography perfusion images (axial plane) at the ganglionic level. **(a)** A cerebral blood flow map showing variations in blood flow across regions of 404.60 mm^2 and 538.60 mm^2; **(b)** a cerebral blood volume map showing areas of 121.48 mm^2 and 58.92 mm^2; **(c)** a mean transit time map showing a larger region (2,820.32 mm^2); and **(d)** a time-to-maximum map showing an area of 3,189.81 mm^2

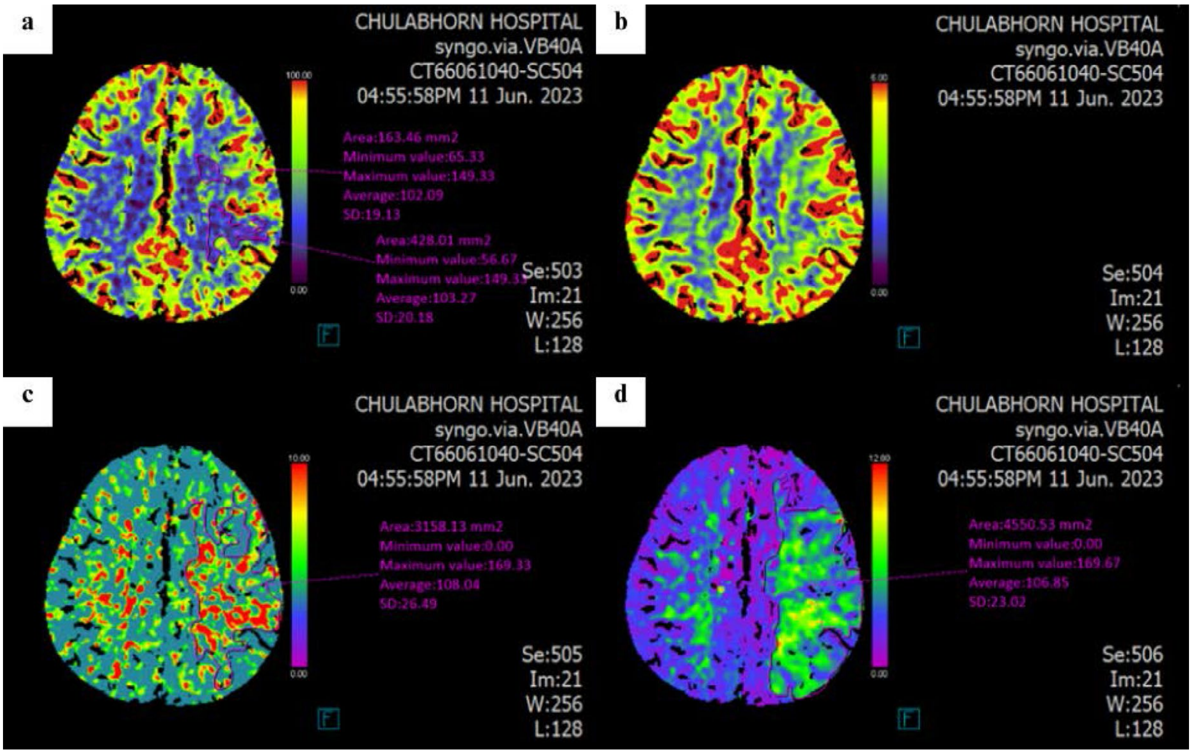

Figure 2 Representative computed tomography perfusion images (axial plane) at the supraganglionic level. **(a)** A cerebral blood flow (CBF) map showing variations in blood perfusion across areas measuring 163.46 mm² and 428.01 mm². **(b)** A cerebral blood volume map; no abnormality was detected despite a CBF deficit; this indicated the presence of a penumbra (i.e., hypoperfused but salvageable brain tissue), which are targeted in therapeutic interventions designed to restore adequate blood flow and prevent infarction. **(c)** A mean transit time map showing a larger region of 3,158.13 mm². **(d)** A time-to-maximum map showing an area of 4,550.53 mm²

Statistical analysis

We employed the paired rank-sum test to compare the preoperative and postoperative values of cerebral perfusion parameters (CBF, CBV, MTT, and Tmax), and the Friedman test to compare the preoperative, immediate postoperative, and 30-day postoperative values. Nonparametric tests were selected because of the small sample size (n = 6) and the non-normal distribution of the data. The results are presented as medians with interquartile ranges (25th to 75th percentile) to account for variability in the dataset. A *p*-value of < .05 was considered statistically significant for all comparisons.

Results

The patients' demographic and clinical information is presented in **Table 1.** Among the six patients, four were male, and two were female. The median patient age was 66 years (range: 28–71 years). All patients had multiple underlying conditions, and these were predominantly related to the cardiovascular system. Hypertension and dyslipidemia were the most common comorbidities. Clinically, two cases presented with isolated hemiparesis, two cases had dysarthria, one case had transient dysphasia, and one case had both hemiparesis and dysarthria. The patients' diagnoses primarily involved significant stenosis (> 70%) of the ICA and/or MCA. When the level of neurological impairment was assessed, it was found that three patients showed no impairment (NIHSS score = 0) and that one had a severe impairment (NIHSS score = 15). The patients' mRS scores varied from 0 to 5.

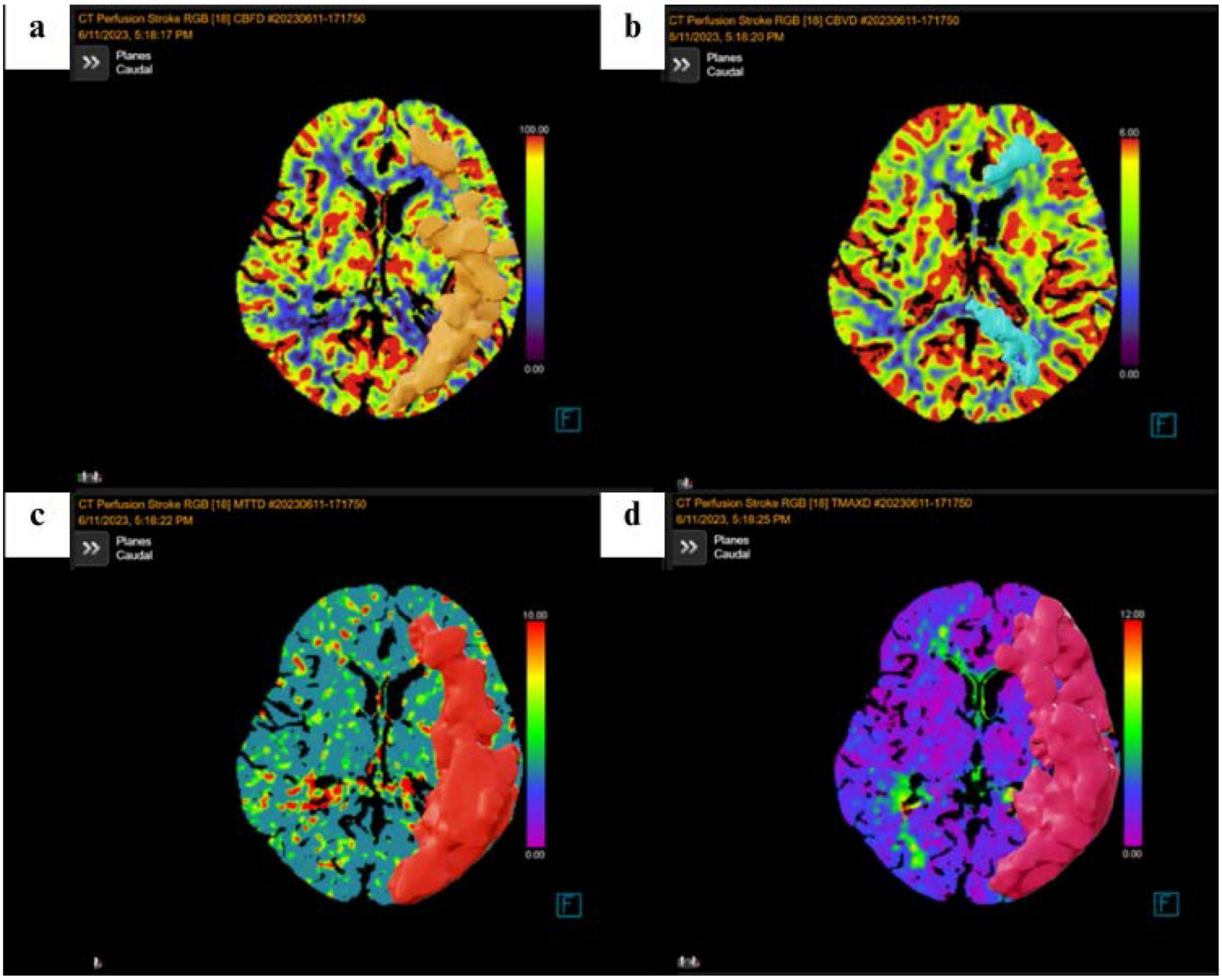

Figure 3. Axial computed tomography perfusion images (ganglionic level) illustrating the cerebral perfusion parameters. **(a)** A cerebral blood flow map with the regions with reduced blood flow (representing perfusion deficit) colored orange. **(b)** A cerebral blood volume map, with regions of decreased blood volume colored light blue. **(c)** A mean transit time map with the regions with a prolonged transit time colored red. **(d)** The area with an increased Tmax value is colored pink, indicating delayed perfusion.

For those with NIHSS = 0 at the time of surgery, all had a documented history of recurrent ischemic symptoms (e.g., TIAs) and demonstrated preoperative hypoperfusion on CTP despite best medical therapy. Therefore, the bypass procedures in these cases were therapeutic rather than prophylactic, aimed at reducing the risk of subsequent stroke.

During the follow-up period, patent grafts were observed, and no ischemic events occurred, except in one patient, who developed a postoperative asymptomatic acute subdural hematoma that was managed conservatively. At 30 days, most patients showed stable or improved neurological and functional outcomes; however, these changes did not reach statistical significance. Median NIHSS scores remained stable (pre-op 1.50 [0.00–7.50] vs. 30 days 1.50 [0.00–5.25], $p = 0.368$), while median mRS scores showed a non-significant trend toward improvement (pre-op 1.50 [0.75–3.50] vs. 30 days 1.00 [0.00–3.00], $p = 0.082$) **(Table 2, Supplement 1).**

When we analyzed the volumetric data from the lesions (Supplement 2), we observed that the values of three of the parameters were reduced: CBF, MTT, and Tmax. The exception was CBV, which underwent minimal changes. Tmax showed the most significant reduction. The individual patients' perfusion parameter values are shown and compared in **Figure 4.**

The statistical analysis showed that the reductions recorded at the immediate postoperative follow-up time point were not statistically significant. The p-values for CBF and Tmax were both 0.068, indicating a trend toward reduction, while CBV and MTT had p-values of 0.465 and 0.144, respectively (Supplement 3). At 30 days, lesion volumes demonstrated reductions in CBF (66.40 [43.35–145.70] → 28.55 [19.85–111.28] mL), MTT (220.75 [101.60–337.05] → 143.00 [39.93–242.35] mL), and Tmax (265.45 [145.53–333.63] → 212.40 [101.08–260.20] mL), although these did not reach statistical significance (p = 0.0+68 for all). CBV lesion volume also decreased slightly (1.15 [0.25–5.51] → 0.00 [0.00–2.54] mL, $p = 0.109$) **(Table 3, Supplement 3).**

Additionally, in each case, the lesion area was calculated using the CTP data (in the axial plane, at both ganglionic and supraganglionic levels) and the PACS (EV Insite application), despite all the parametric data indicating lesion area reductions, no statistically significant differences were observed, as shown in **Supplements 4 and 5.**

Discussion

In this study, we retrospectively analyzed both clinical and imaging outcomes in patients with ICAD who underwent STA-MCA bypass surgery. We assessed clinical outcomes using the NIHSS and mRS scores, and determined imaging outcomes by evaluating pathological areas of the brain at the ganglionic and supraganglionic levels. Our findings align with those of previous studies that have shown STA-MCA bypass surgery to be a viable option for patients with ICAD refractory to medical therapy and EVT. [11,17–19,21–23]

Table 1. The patients' demographic characteristics and clinical information

Pt. No.	Sex/age (years)	Underlying disease (s)	Symptom(s)	Location/ affected vessel	Side of bypass/ barrel type	NIHSS score	mRS score
1	F/67	SVD	Dysphasia	Left/ICA	Left/Single	0	0
2	M/66	DM, HTN, DLP, AF	Left hemiparesis	Right/ICA and MCA	Right/Double	5	3
3	M/61	HTN, DLP, CKD, IFG	Right hemiparesis	Left/MCA	Left/Single	0	1
4	M/71	DM, HTN, DLP	Dysarthria	Left/MCA	Left/Single	0	1
5	F/69	TVD, HTN, DLP	Dysarthria	Right/ICA and MCA	Right/Double	15	5
6	M/28	HTN	Right hemiparesis and dysarthria	Left/ICA and MCA	Left/Single	3	2

Pt. No., patient number; F, female; M, male; SVD, small vessel disease; DM, diabetes mellitus; HTN, hypertension; DLP, dyslipidemia; AF, atrial fibrillation; CKD, chronic kidney disease; IFG, impaired fasting glucose; TVD, triple vessel disease; ICA, internal carotid artery; MCA, middle cerebral artery; NIHSS, National Institutes of Health Stroke Scale; mRS, Modified Rankin Scale

Table 2. Postoperative follow-up and clinical outcomes of the patients

Pt. No.	Compli-cation	Ischemic events (< 30 days)	Ischemic events (> 30 days)	Graft patency	NIHSS score (immediate postoperative)	NIHSS score (30 days)	mRS score (immediate postoperative)	mRS score (30 days)
1	None	None	None	Yes	0	0	0	0
2	None	None	None	Yes	5	5	3	3
3	None	None	None	Yes	0	0	0	0
4	None	None	None	Yes	0	0	1	1
5	None	None	None	Yes	15	6	4	3
6	Acute SDH	None	None	Yes	3	3	2	1

Pt. No., patient number; SDH, subdural hematoma; NIHSS, National Institutes of Health Stroke Scale; mRS, Modified Rankin Scale

Table 3. Comparative analysis (paired rank-sum test) of the cerebral perfusion parameters before and after (30-day postoperative) surgery

Parameter	Preoperative median (interquartile range) lesion volume (mL)	30-Days postoperative median (interquartile range) lesion volume (mL)	*p-value*
CBF	66.40 (43.35–145.70)	28.55 (19.85–111.28)	0.068
CBV	1.15 (0.25–5.51)	0.00 (0.00–2.54)	0.109
MTT	220.75 (101.60–337.05)	143.00 (39.93–242.35)	0.068
Tmax	265.45 (145.53–333.63)	212.40 (101.08–260.20)	0.068

CBF, cerebral blood flow; CBV, cerebral blood volume; MTT, mean transit time; Tmax, time to maximum

Extracranial–intracranial (EC-IC) bypass procedures, such as the STA-MCA bypass, are alternative treatments for large vessel occlusion due to ICAD, particularly when EVT or medical therapy is unsuccessful. Prior research has shown that undergoing STA-MCA bypass can reduce the risk of recurrent TIA and stroke, as well as improve functional outcomes, as evidenced by decreased NIHSS scores and favorable mRS scores postoperatively.(16,24–26) In other studies, the risk of TIA after STA-MCA bypass surgery was found to be reduced during a 180-day post-operative follow-up period compared to that at the time of diagnosis,(6) and postoperative mRS scores were found to be lower.(18) In a cohort of 75 patients who underwent either a unilateral or bilateral STA-MCA bypass, no instances of TIA were observed during a 10-year follow-up period.(19) It has also been reported that 13% of patients who underwent an STA-MCA bypass experienced a stroke, compared to 32% of patients who underwent medical therapy over 34 months, and that the annual incidence of ischemic events in patients who underwent bypass surgery was 8%, compared to 18% in those awaiting surgery.(21, 22) Furthermore, the clinical outcomes in patients who underwent STA-MCA bypass surgery were found to be better than those in patients who did not undergo surgery. Additionally, the surgical patients showed significant improvements in their NIHSS and mRS scores compared to the patients who received BMT.(23) The findings of a systematic review showed that urgent STA-MCA bypass surgery is a viable treatment option for younger patients (< 60 years) with MCA territory strokes who are unresponsive to medical therapy.(11)

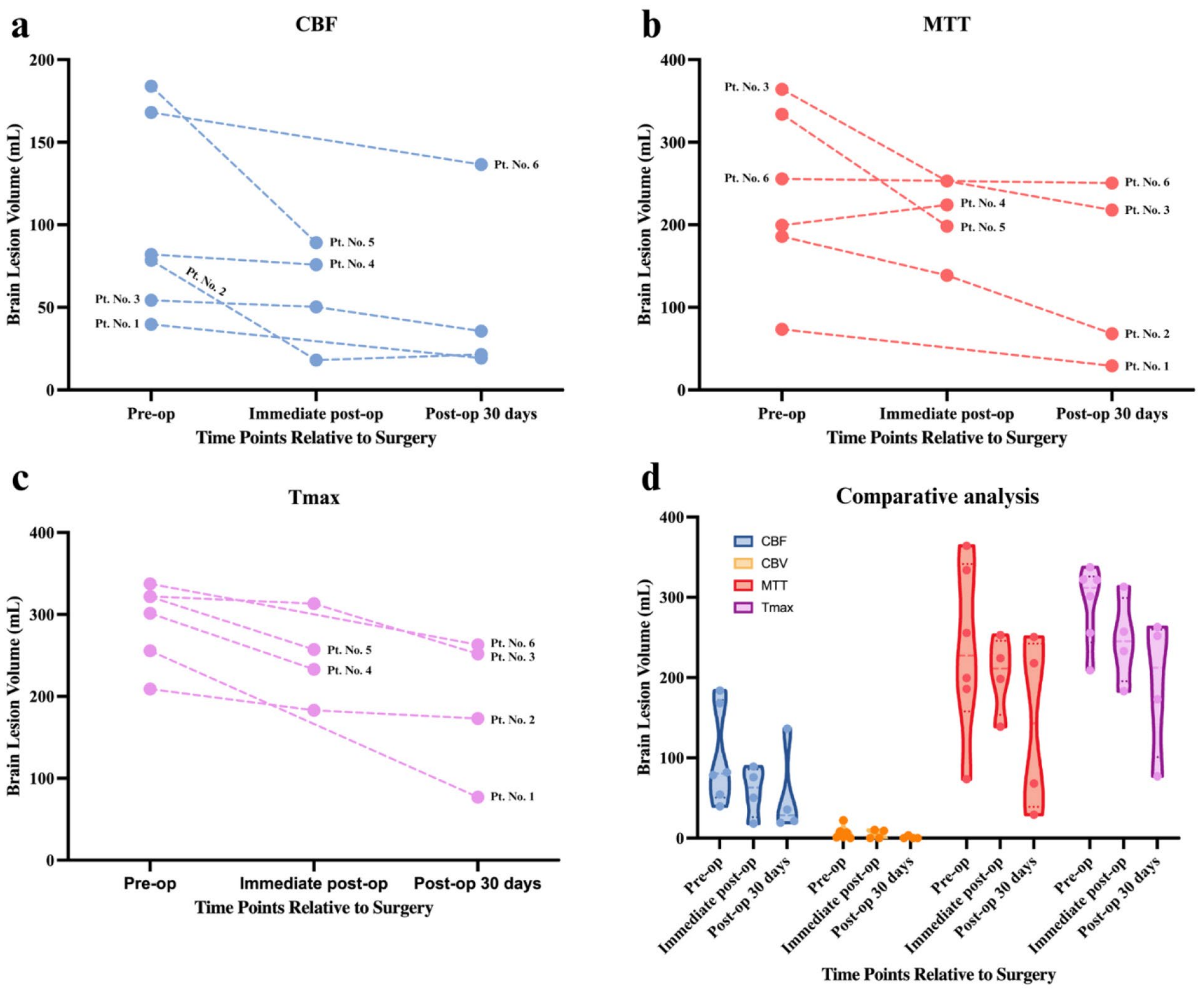

Figure 4. The lesion volume (mL) based on the individual patients' perfusion parameters: **(a)** cerebral blood flow (CBF), **(b)** mean transit time (MTT), and **(c)** time-to-maximum (Tmax). Lesion volume is shown at three time points: preoperative, immediate postoperative, and 30 dayspostoperative. **(d)** A comparative analysis performed using three-dimensional visualization and measurement software showed that the lesion volume was reduced when each parameter was used to calculate the volume. Means ± standard deviations are shown. Note: This figure was created using Prism 10 version 10.4.1.

However, the results of some studies have raised doubts about the effectiveness of the STA-MCA bypass procedure. A meta-analysis of 2,419 patients with symptomatic ICA occlusion found no significant difference in the incidence of ischemic events between patients who underwent an STA-MCA bypass and those who received medical treatment during an average follow-up period of 29 months.[7] In addition, it has been reported that STA-MCA bypass surgery does not improve the long-term prognosis of patients with major vessel occlusion, particularly those with high NIHSS scores,[7–10] and that it is not superior to BMT for the treatment of ICAD.[8,9,12,13] The possible explanations for these discrepancies may include differences in patient selection criteria, timing of intervention, surgical expertise, and the use of varying outcome measures or follow-up durations.

CTP is a functional imaging technique used to acquire cerebral hemodynamic information (e.g., CBF, CBV, and MTT data) necessary for optimal evaluation of the effects of acute stroke and distinguishing reversibly infarcted tissue from potentially salvageable tissue (penumbra).[27, 28] It can also be used to determine the outcomes of STA-MCA bypass procedures, which are designed to increase CBF and CBV and reduce MTT in ischemic regions.[11, 29] Hence, we selected CTP as the primary technique for acquiring the cerebral hemodynamic data required for this study.

The Alberta Stroke Program Early CT Score (ASPECTS) is a standardized tool used to assess early ischemic changes in patients with acute ischemic stroke, specifically in the MCA territory, using non-contrast CT imaging.(30) ASPECTS is determined by dividing the MCA territory into 10 regions and assessing data obtained at the ganglionic and supraganglionic levels. Each region is evaluated for signs of early ischemia, and one point is deducted for each affected area, resulting in a score ranging from 0 to 10. Higher scores(7–10) indicate minimal ischemic involvement and a better prognosis, while lower scores (< reflect more extensive damage and correlate with poorer outcomes.(27,28,30,31) Zhao et al. utilized dynamic susceptibility contrast-enhanced perfusion-weighted magnetic resonance imaging (DSC-PWI) to generate parameter maps to assess cerebral perfusion and then evaluated the ASPECTS data.(17) They demonstrated that CBF improved after surgery, particularly in patients with low preoperative PWI-ASPECTS values. However, there was no significant change in CBV postoperatively. In another study, CTP data were retrospectively analyzed quantitatively, and the results revealed a significant reduction in Tmax six months postoperatively, but no significant difference in CBF (<30%) was observed before and after surgery. (32) In this study, we determined the imaging outcomes by evaluating the cerebral lesions at the ganglionic and supraganglionic levels. These levels were chosen because they correspond to the regions assessed using the ASPECTS in acute stroke studies.

Our imaging results demonstrated overall improvement in CBF, MTT, and Tmax, while CBV remained stable after surgery. These changes suggest partial restoration of perfusion, likely reflecting correction of chronic hypoperfusion in penumbral tissue.(33) Improved CBF is consistent with enhanced oxygen delivery, and shorter MTT/Tmax values indicate more efficient hemodynamics following revascularization.(11, 29)

Although these changes did not reach statistical significance ($p = 0.068$ for CBF and Tmax), the results suggest a possible trend toward improved cerebral perfusion, which should be interpreted cautiously given the small sample size.

The lack of statistical significance could be attributable to several factors, including the limited sample size, which may have constrained the study's power to detect meaningful differences. Nevertheless, our results suggest that undergoing an STA-MCA bypass may confer beneficial effects on cerebral hemodynamics in patients with ICAD. One patient developed an asymptomatic postoperative subdural hematoma, highlighting that STA–MCA bypass carries a small but relevant surgical risk that must be considered in patient counseling.

A notable strength of this study is the use of 3D volume measurements to quantify lesion volumes rather than relying solely on ASPECTS. Although ASPECTS has proven utility in acute ischemic stroke assessment and is widely used due to its simplicity and reproducibility,(30, 31) it inherently evaluates only predefined cerebral territories and relies on categorical scoring. In contrast, the 3D volumetric approach offers a more nuanced and continuous measure of the lesion size. The combined use of ASPECTS for standardized scoring and volumetric analysis provides quantitative precision, there by enhancing both clinical applicability and research interpretability.

By quantifying lesion volumes, this study achieves a more comprehensive evaluation of cerebral hemodynamics and tissue perfusion, potentially facilitating improved patient stratification, treatment decision-making, and the monitoring of revascularization effects after STA-MCA bypass procedures. Moreover, integrating both ASPECTS-based assessments and 3D volumetric measurements enhances the interpretability and translational potential of the findings, as it allows researchers and clinicians to understand better the interplay between standardized scoring tools and precise volumetric quantification.

This study encountered several limitations. The small sample size ($n = 6$) significantly limited the statistical power and generalizability of the findings. The short follow-up period (30 days for most patients) precluded the assessment of long-term outcomes, including the durability of graft patency and the risk of recurrent ischemic events. Longer-term follow-up imaging at 3–6 months would be particularly valuable for assessing the durability of perfusion changes and lesion evolution after bypass surgery. In addition, the absence of a control group (e.g., patients treated with best medical therapy alone) limited the ability to compare outcomes and attribute changes solely to bypass surgery directly. Although imaging interpretation was conducted independently by three blinded raters and inter-rater reliability was assessed using ICC, some degree of inter-operator variability remains possible. The absence of a fully blinded, multi-rater external validation represents another limitation of this study. Furthermore, the lack of predefined numerical thresholds for perfusion parameters meant that lesion delineation relied on visual interpretation. While this approach is clinically pragmatic, it introduces potential variability and limits reproducibility across studies.

Additionally, the use of processed CTP data rather than raw data may have introduced artifacts that could have impacted the accuracy of the lesion volume calculations. Future research with larger, prospectively enrolled cohorts is essential. Blinded multi-rater volumetric analysis would strengthen the reliability of imaging findings. Long-term follow-up (3–6–12 months) is necessary to evaluate graft durability and functional recovery. The inclusion of a comparison group (e.g., patients treated with best medical therapy alone) can provide a more transparent benchmark for assessing the added value of STA–MCA bypass.

Conclusion

STA-MCA bypass surgery may offer clinical and hemodynamic benefit in select cases of ICAD that are unresponsive to medical therapy or EVT. In this study, STA-MCA bypass surgery was associated with favorable short-term trends in NIHSS and mRS scores. Additionally, analysis of CTP data demonstrated potential improvements in perfusion parameters (particularly CBF and Tmax), and volumetric lesion measurement may provide valuable insights for outcome assessment. Given the small sample size and lack of statistical significance, these findings should be interpreted cautiously. Larger, long-term studies are warranted to validate these observations and refine treatment strategies for ICAD.

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Competing interests

The authors declare that they have no competing interests.

Author contributions

Nattakitta Mektripop: Conceptualization, study design, imaging analysis (3D volumetric measurements), data collection, manuscript drafting, and revision. **Payothorn Decharin:** Conceptualization, study design, data interpretation, project supervision, and final manuscript approval (corresponding author). **Hattapark Dejakaisaya:** Study leadership, ethics oversight, supervision of research direction, and manuscript review. **Pongsakorn Pongsapas:** Surgical procedures, perioperative patient management, data interpretation, and manuscript drafting. **Wiriya Mahikul:** Statistical analysis, data interpretation, manuscript drafting, and revision. **Pichamon Sirilar:** Literature review, clinical data collection, and manuscript drafting. **Dollapak Sakulpanich:** Literature review, imaging data collection, and manuscript drafting. **Phoomphisit Dejchaiyasak:** Literature review, data collection, and manuscript drafting. **Pimpitcha Lertkiatdamrong:** Literature review, data collection, and manuscript drafting.

Supplementary Material

The Supplementary Material for this article can be found online at: https://jseamed.org/index.php/jseamed/article/view/241

Supplementary Criteria: Detailed Inclusion and Exclusion Criteria

Supplement 1: Statistical Analysis of NIHSS and mRS Scores Pre-Operation and Post-Operation (Immediate and 30 days)

Supplement 2: 3D Brain Lesion Volume Metric Measurement (mL)

Supplement 3: The brain lesion volume (mL) before and after immediate post-op

Supplement 4: The brain lesion area (cm²) before and after immediate post-op

Supplement 5: The brain lesion area (cm²) before and after post-op 30 days

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