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Assessment of Single-Barrel Superficial Temporal Artery-Middle Cerebral Artery Bypass in Treatment for Adult Patients with Ischemic-Type Moyamoya Disease

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Data Collection B
Statistical Analysis C
Data Interpretation D
Manuscript Preparation E
Literature Search F
Funds Collection G

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Background: Moyamoya disease (MMD) is an idiopathic disease caused by progressive steno-occlusion of the distal internal carotid artery. Ideal surgical treatment for adult patients with ischemic-type MMD has not been achieved. The aim of this study was to evaluate the efficacy of single-barrel superficial temporal artery-middle cerebral artery (STA-MCA) bypass in treatment for adult patients with ischemic-type MMD by analyzing clinical and radiological data retrospectively.

Material/Methods: The present study included 37 patients with non-hemorrhagic MMD, including 21 women and 16 men (21~55 years old, mean age 38.1 years). The bypass surgery was performed on 56 sides in the 37 patients. The clinical charts, angiographic revascularization, and hemodynamic changes were reviewed at 6–60 months after surgery.

Results: Among the 37 patients, the clinical symptoms and signs of 32 patients were improved or stabilized. Five patients had complications, including 2 cases of acute cerebral infarction, 1 case of epidural hematoma, and 1 case of transient speech disturbance, and 1 patient died. Follow-up computed tomography perfusion (CTP) revealed that cerebral blood flow (CBF) was markedly improved after surgery ($P<0.05$). Time to peek (TTP) and mean transit time (MTT) were significantly decreased after surgery ($P<0.05$). No significant change in cerebral blood volume (CBV) was found after surgery ($P>0.05$). Postoperative patency was clearly verified in 52 bypasses (92.8%) of 56 bypasses on follow-up DSA imaging.

Conclusions: Single-barrel STA-MCA bypass can be considered as an effective surgical treatment, which exhibits satisfactory clinical efficacy in ischemic-type MMD patients.

MeSH Keywords: Cerebral Revascularization • Moyamoya Disease • Neurosurgery • Postoperative Complications

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Background

Moyamoya disease (MMD) is an idiopathic disease caused by progressive steno-occlusion of the distal internal carotid artery, resulting in compensatory development of collateral vessels [1]. Patients with symptomatic MMD have a chronic decrease in blood flow [2]. Generally, classification of MMD can be split into ischemic-type and hemorrhagic type based on etiology [1,3]. Clinical manifestations of brain ischemia are quite specific in children, while intracranial hemorrhage and permanent or transient rain infarction often occur in adults [4].

Superficial temporal artery (STA)-middle cerebral artery (MCA) bypass is a surgery that causes low blood flow supply from the extracranial carotid to the distal MCA. STA-MCA bypass has been used clinically for cerebrovascular occlusive disease and as an adjuvant therapy for complex intracranial aneurysms [5]. Characteristics of patients clearly show that STA-MCA bypass revascularization provides good clinical outcomes in ischemic-type patients [6], but few studies on surgical type of hemorrhagic MMD have been reported. Indirect revascularization surgeries, such as extracranial-intracranial arterial bypass (EIAB) and modified encephaloduroarteriosynangiosis (mEDAS), are generally accepted as the treatment of choice in pediatric patients [7]. However, it is unclear which type of surgical technique is most effective in treating adult patients with ischemic-type MMD, although some retrospective studies have been conducted with the limitations of age ranges, numbers of patients, and short-term follow-up [3,8].

The primary purpose of the present study was to investigate the efficacy of single-barrel STA-MCA bypass surgery in treatment for adult patients with ischemic-type MMD by retrospectively analyzing clinical and radiological data.

Material and Methods

Patient population and inclusion criteria

Between June 2013 and June 2017, a total of 37 single-barrel STA-MCA bypass procedures in 56 surgical sessions were performed in 37 adult patients for treatment of ischemic-type MMD. Medical data were collected with permission of the Ethics Committee of Suzhou Municipal Hospital affiliated to Nanjing Medical University. Written information consent to participate was obtained from all patients. The inclusion criteria were: 1) All patients presented with ischemic symptoms, including motor, sensory, cognition, and vision impairment, who were treated by single-barrel STA-MCA bypass, aged ≥20 years; 2) MMD was diagnosed via digital subtraction angiography (DSA); 3) Symptomatic hemispheres were considered for the procedure if they displayed decreased perfusion and/or a lack of vascularity when analyzed on 6-vessel DSA, magnetic resonance (MR), and/or Diamox single-photon emission computed tomography (SPECT) or computed tomography perfusion (CTP) preoperatively. Characteristics of patients are shown in Table 1.

Table 1. Characteristics of patients.

Characteristics	N=37
Age	38.1±11.9
Gender	
Male	16
Female	21
Bilateral moyamoya	
Yes	23
No	14
Initial presentations	
TIA	7
ACI	30
Suzuki angiographic stage	
3	9
4	17
5	7
6	4
Bilateral bypass	
Yes	19
No	18

TIA – transient ischemic attack; ACI – acute cerebral infarction.

Surgical technique

All patients underwent direct bypass only on the affected side after confirmation of hemodynamic impairment by SPECT and CTP. All bypass surgeries were performed by the same neurosurgeon. Bypass surgery was performed in the 37 patients presenting with ischemic symptoms at between 3 weeks and 3 months after a TIA or stroke (mean, 8.4 weeks). All patients who required bypass surgery treatments to both hemispheres were managed with staged operations, with an interval of 10–12 weeks between the 2 surgeries. Bypass surgery was implemented on the more symptomatic hemisphere first in bilateral bypass procedures. Nineteen patients received bilateral bypass procedures with 1 surgical session per side. Specific surgical methods were the following. The parietal or frontal branch of the STA was carefully dissected for approximately 6 cm following a curvilinear or linear skin incision of the temporalis

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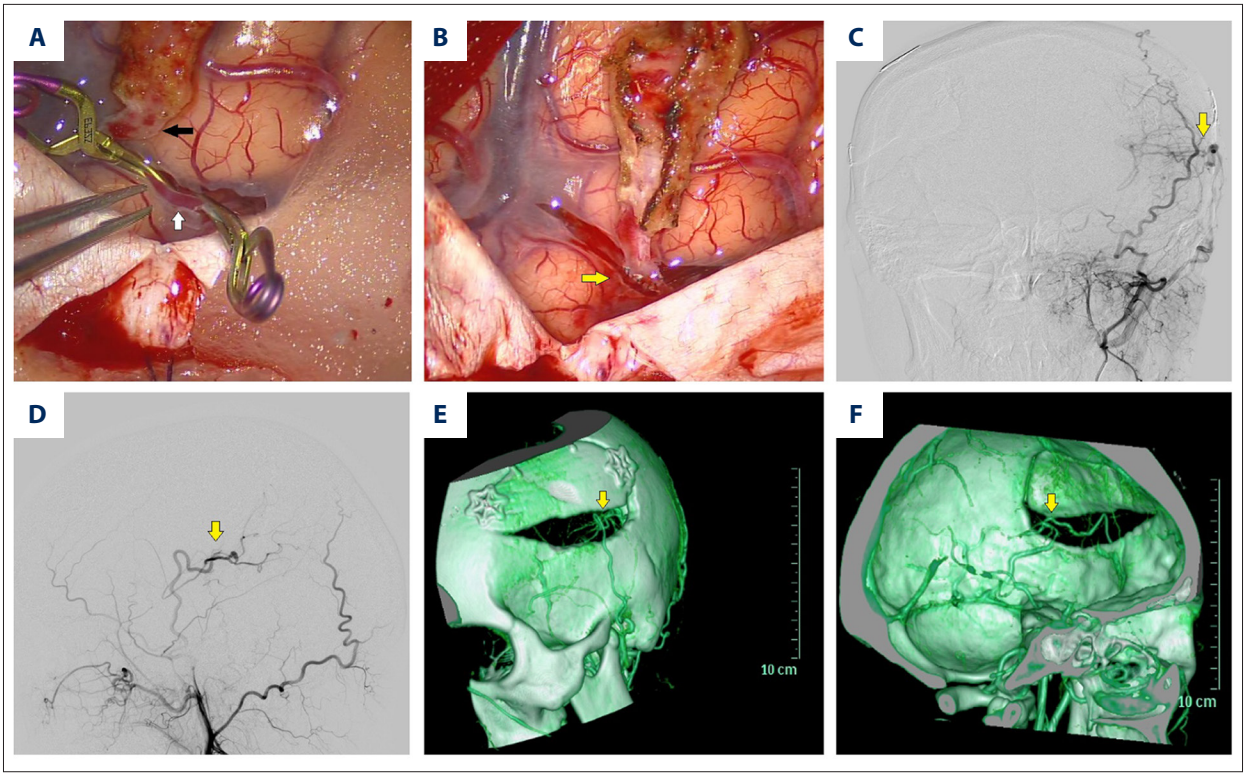

Figure 1. The operation schematic diagram of a 39-year-old male is shown in **A** and **B**. Intraoperative photograph showing the anastomosis between the STA (black arrow) and the cortical branch of the MCA (white arrow), and the anastomosis (yellow arrow) can be clearly observed. Frontal (**C**) and lateral (**D**) views of the left external carotid artery angiogram after surgery. (**E, F**) Three-dimensional (3D) reconstruction of the left hemisphere after surgery. STA – superficial temporal artery; MCA – middle cerebral artery.

muscle. After suspensory dura, a large craniotomy was performed more than 6 cm in diameter for wide dural opening. The arachnoid membrane was minimally dissected to expose suitable-sized cortical branches of the MCA as the recipient artery. Then, the blood flow of STA and MCA were blocked by use of an artery clamp. End-to-side anastomosis of donor and recipient arteries used interrupted 10-0 sutures under an operating microscope. The artery clamp was then removed and we checked for anastomotic bleeding and patency. All patients received 350 mg of acetylsalicylic acid as anticoagulant once per day postoperatively. The schematic diagram of the operation is shown in Figure 1A and 1B.

Evaluation of curative effect

A previous study [9] divided the clinical efficacy into 4 grades: Excellent indicated that preoperative clinical symptoms disappeared and without neurological dysfunction, Good indicated that preoperative clinical symptoms disappeared but with some nerve dysfunction, Secondary indicated that preoperative clinical symptoms were slightly relieved, and Poor indicated that preoperative clinical symptoms were aggravated (including death).

Revascularization treatment can be evaluated by reviewing CTP or DSA and the efficacy can be divided into 2 grades: Good: 1/3 of middle cerebral artery supplying area was supplied by STA; Poor: only a small numbers of blood supply or even no blood supply from STA.

Statistical analysis

We used SPSS 20.0 software (IBM SPSS, Armonk, NY, USA) for statistical analyses. Measurement data are presented by mean ± standard deviation. The Wilcoxon signed-rank test was used to assess the difference between preoperative and follow-up results within groups. *P*-value <0.05 was considered statistically significant.

Results

Clinical outcomes after STA-MCA bypass surgery

A total of 37 single-barrel STA-MCA bypass procedures in 56 surgical sessions were performed in 37 adult patients for treatment of ischemic-type MMD. Single-barrel STA-MCA

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Table 2. Surgical complications.

Number of patients	Ages/sex	Symptom onset post-operative (days)	Symptoms	Radiologic findings	Results
1	38/Male	12	Dysarthria	Acute cerebral infarction	Partial recovered
2	57/Female	7	Dysarthria	Acute cerebral infarction	Full recovered
3	29/Male	4	Seizure	Epidural hematoma	Full recovered
4	31/Female	9	Motor aphasia	Transient speech disturbance	Full recovered
5	49/Female	5	Severe sepsis and respiratory failure	Acute cerebral infarction	Dead

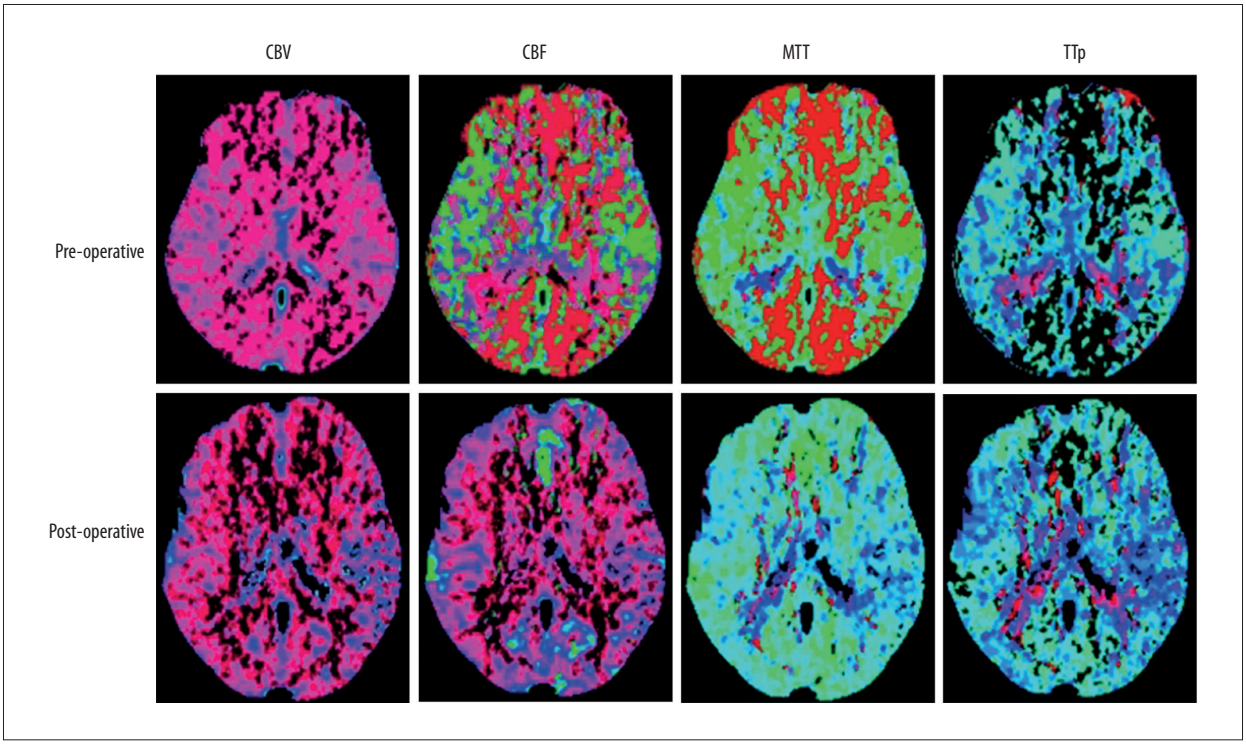

Figure 2. CTP scans with CBV, CBF, TTP, and MTT obtained before and after surgery. CTP – computed tomography perfusion; CBV – cerebral blood volume; CBF – cerebral blood flow; MTT – mean transit time; TTP – time to peek.

anastomosis was technically successful in all 56 hemispheres. Among the 37 patients, the symptoms and signs of 32 patients were improved or stabilized. Five patients had complications, including 2 cases of acute cerebral infarction. It was worth mentioning that a 38-year-old man had an infarct in the MCA area 12 days after bypass surgery, after which his neurological status worsened. No definite reason for acute infarction was found in subsequent next evaluations. The patient partially recovered language function in 2 months post-operatively, although he was left with dysarthria. Among the 37 patients, 1 suffered from epidural hematoma and 1 had a transient speech disturbance. Although these patients with complications were symptomatic initially, they recovered without neurologic symptoms over time. However, among these patients, 1 died due to severe sepsis and respiratory failure. Complications are summarized in Table 2. According to clinical criteria, prognosis was excellent in 27 cases, good in 5 cases, secondary in 4 cases, and poor in 1 case. Follow-up imaging was performed in all 56 revascularized hemispheres to assess patency of the bypass. These studies were performed at 6–60 months after surgery. Fifty-two bypasses (92.8%) of 56 bypasses revealed the patency of the craniofacial vessels and

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Table 3. Changes of CTP parameters after STA-MCA bypass in 52 revascularized hemispheres.

CTP parameters	Preoperation	Postoperation	P value
CBV	3.19±1.47	3.22±1.56	0.649
CBF	47.66±8.16	54.12±9.91	**0.013**
MTT	5.27±1.08	4.36±0.97	**0.007**
TTP	13.16±3.54	11.08±2.88	**0.003**

Value was presented as mean ± standard deviation. CTP – computed tomography perfusion; CBV – cerebral blood volume; CBF – cerebral blood flow; MTT – mean transit time; TTP – time to peek. *P*-value <0.05 was showed in bold fonts.

the anastomotic stoma was good. Four bypasses (7.2%) of 56 bypasses demonstrated vascular obstruction or decreased of blood flow, which were evaluated as poor via imaging evaluation following STA-MCA bypass.

Changes of CTP parameters after STA-MCA bypass surgery

The overall clinical outcomes were followed up at 6–62 months (mean, 28.3 months) after surgery. Complete sets of CTP results were obtained for 37 patients with 56 revascularized hemispheres in order to assess changes in CBF, CBV, MTT, and TTP. Follow-up computed CTP revealed that the cerebral hemodynamics in the revascularized hemispheres was noticeably improved after STA-MCA bypass (Figure 2). Cerebral blood flow (CBF) was markedly improved after surgery ($P<0.05$). Time to peek (TTP) and mean transit time (MTT) were significantly decreased after surgery ($P<0.05$). No significant change of cerebral blood volume (CBV) was detected after the operation ($P>0.05$) (Table 3). Postoperative patency was clearly verified via follow-up DSA imaging or three-dimensional (3D) reconstruction (Figure 1C–1F).

Discussion

MMD is a rare cerebrovascular disorder characterized by progressive stenosis and occlusion of the internal carotid (ICA) and the anterior (ACA) and middle cerebral arteries (MCA). It can be diagnosed by confirming the cerebrovascular occlusion of the distal internal ICA, ACA, and the MCA through DSA and CTP [10]. Nevertheless, brain perfusion SPECT or MRI perfusion with/without acetazolamide can be performed to assess the hemodynamic status of the brain due to chronic hypoperfusion from diminished vascularity [11]. Generally speaking, MMD is diagnosed after a transient ischemic attack (TIA) in children and after a cerebral stroke in adults. Hence, it is necessary to intensively study use of revascularization surgery for treatment of MMD.

Previous studies reported that the combination of direct and indirect bypass is the optimal treatment in adult MMD [7,12]. It was reported that the annual risks of symptomatic infarction and hemorrhage were 0.2% and 0.4%, respectively, after analyzing 77 combined revascularization surgeries of 60 adult MMD patients and reported that the combined revascularization surgery resulted in satisfactory long-term improvement in clinical application, hemodynamic states, angiography, and prevention of recurrent stroke or TIA [13,14]. A potential mechanism is that direct revascularization could be effective at the early stage after surgery, maintaining its dominant role in collateralization, and these distal cerebral vessels progressively become partly or entirely occluded [15]. Thereafter, the indirect revascularization might replace these areas where blood flow could not reach through direct revascularization. To a certain extent, combined surgery might be more effective. Although combined revascularization surgery can immediately increase CBF and decrease the risk of ischemic attack, and combined revascularization surgery requires more time and is more complex [16]. The combined surgical procedure can lead to high risk of postoperative neurological morbidity, with hemodynamic compromises and bleeding-prone vasculopathy [17]. Hyperperfusion can also occur after combined revascularization surgery [18,19].

In the present study, we performed single-barrel STA-MCA direct bypass only, without the addition of an indirect revascularization procedure. A total of 56 surgeries in 37 adult MMD patients with hemodynamic impairment were analyzed, demonstrating the effectiveness of surgical treatment in adult ischemic-type MMD patients. Results revealed that among the 37 patients, the symptoms and signs of 32 patients were improved or stabilized; 5 patients had complications, including 2 cases of acute cerebral infarction, 1 case of epidural hematoma, and 1 case of transient speech disturbance, and 1 patient died due to severe sepsis and respiratory failure. To determine optimal targets for STA-MCA revascularization surgery, cerebral perfusion imaging is used to provide information about the severity and extent of the ischemic area. MTT and TTP values were observed to be significantly reduced and CBF was found to be markedly improved after direct revascularization treatment, but CBV was not significantly changed in these operated hemispheres. The results indicated that the corresponding cerebral

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hemodynamics improved after STA-MCA bypass at the surgical site. TTP and MTT maps can be quite sensitive to the presence of altered brain perfusion. During this specific phase of hemodynamic improvement, increased cerebral perfusion pressure can result in reduced MTT and TTP with or without vasodilatation. Nevertheless, in the absence of cerebral autoregulation induced by chronic cerebral hypoperfusion, CBV may remain within the previous range [20]. We hypothesize that CBF, as a subordinate sensitive parameter to changed brain perfusion, might have a better correlation with patency of the bypass artery [21]. However, CBF increasing markedly after surgery can directly reflect the graft patency to some extent. We did not find a statistically significant change in CBV in all surgical sessions, perhaps because CBV is a complex physiological parameter [22] composed of arterial, capillary, and venous compartments, as well as parenchymal and pial components, and the reduced perfusion pressure is variable due to the vasodilatory response of these different compartments [23].

Conclusions

The results of our preliminary study suggest that the direct revascularization of single-barrel STA-MCA bypass is a safe and durable method of cerebral revascularization in adult patients with ischemic-type MMD and can be considered as a potential treatment option for adult patients with ischemic-type MMD. Our promising results warrant further larger-scale clinical studies to determine the effect of STA-MCA bypass on the long-term outcome of MMD patients.

Conflict of interest

None.

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