Increased Ratio of Superficial Temporal Artery Flow Rate After Superficial Temporal Artery-to-Middle Cerebral Artery Anastomosis: Can It Reflect the Extent of Collateral Flow?

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■ OBJECTIVE: **There are several ways to identify donor artery patency and success of surgery after an anastomosis of the superficial temporal artery (STA) to the middle cerebral artery (MCA). The purpose of this study was to evaluate the ratio of bilateral STA mean flow rate (MFR) with the use of color Doppler ultrasonography (CDUS) after bypass surgery and to confirm the possibility of this value as a predictor of the extent of collateral flow.**

■ METHODS: **Eleven consecutive patients who had undergone STA-MCA anastomosis were included. In every case, bilateral STA MFR, mean velocity, and cross-sectional diameter were measured preoperatively and postoperatively at 1 week, 1 month, and 2 months via CDUS. We measured the bilateral STA MFR ratio changes to compensate for systemic hemodynamic variables.**

■ RESULTS: **One month after surgery, 9 of the 11 patients who underwent STA-MCA anastomosis had good patency on DSA. In patients with good patency, there was a significant increase in the baseline STA MFR ratio compared with those at 1 week, 1 month, and 2 months postoperatively (2.88, 3.07, and 4.38, respectively, $P < 0.05$). The mean STA cross-sectional diameter ratio also was significantly increased postoperatively in the good patency group (1.35, 1.41, and 1.49, respectively, $P = 0.044$). In addition, the mean STA mean velocity ratio was increased postoperatively in the good patency group (1.48, 1.40, and 1.67, respectively, $P = 0.042$).**

■ CONCLUSIONS: **We conclude that using CDUS to measure both STA MFR ratio is a potential method to predict the extent of collateral flow through an STA-MCA anastomosis.**

INTRODUCTION

Patients with hemodynamic failure, such as those with steno-occlusive disease of the intracranial arteries, are at high risk for subsequent ischemic cerebrovascular disease.[1] Extracranial-intracranial bypass surgeries involving anastomosis of the superficial temporal artery (STA) to the middle cerebral artery (MCA) has been used widely in the treatment of ischemic cerebrovascular disease.[2]

After STA-MCA anastomosis, it is critical to ensure donor artery patency. Postoperative computed tomography angiography (CTA) and magnetic resonance angiography (MRA) can be used to demonstrate donor artery patency. In addition, postoperative digital subtraction angiography (DSA) can show the patency, as well as the intracranial feeding territory. However, these studies are both invasive and expensive.

One recent study found that there is a correlation between surgical success and STA hemodynamic changes (measured using color Doppler ultrasonography [CDUS]).[3] However, these results are interpreted with caution, as the group did not consider the blood flow changes at the time of measurement. In this study, we focused on the bilateral STA mean flow rate (MFR) changes to compensate for this variable and examined the correlation with angiographic data. In addition, we discuss whether this

Key words
- Cerebral blood flow
- Color Doppler ultrasonography
- Hemodynamics
- STA-MCA bypass
- Vascular patency

Abbreviations and Acronyms
CDUS: Color Doppler ultrasonography
CSD: Cross-sectional diameter
CTA: Computed tomography angiography
CTP: Computed tomography perfusion
DSA: Digital subtraction angiography
MCA: Middle cerebral artery
MFR: Mean flow rate
MRA: Magnetic resonance angiography
MV: Mean velocity
STA: Superficial temporal artery

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result can be considered a predictor of postoperative extent of collateral flow.

METHODS AND MATERIALS

Patients

A total of 11 consecutive patients who underwent STA-MCA anastomosis for cerebral artery steno-occlusive diseases at our institution between June 2013 and August 2015 were included in this prospective study. The average patient age (2 men, 9 women) was 41 years. The following criteria were considered indications for STA-MCA anastomosis: 1) cerebral angiography revealing stenosis or occlusion at the terminal portion of the internal carotid artery or at the proximal portion of the anterior cerebral artery, MCA, or both; 2) impaired reservoir function in the vicinity of the occlusive or stenotic lesions on computed tomography perfusion (CTP) imaging; 3) fair activities of daily life corresponding to a modified Rankin Scale score of 2 or less; and 4) no evidence of other cerebrovascular diseases, such as autoimmune disease or meningitis. We decided side to operate a hemisphere that decreased vascular reservoir function on CTP and induced the patient's symptoms.

Surgical Procedure

We performed a direct end-to-side anastomosis of a branch of the STA to a cortical branch of the MCA. Both donor and recipient vessels were approximately 1 mm in diameter. The surgery was performed through a frontotemporal scalp incision with preservation of the STA branches. The donor branch of the STA was dissected from the inner surface of the scalp flap. The anastomosis site was selected on the basis of the patient's symptoms and cerebral angiography. After the suitable recipient artery was selected, the overlying arachnoid and pia mater were opened, and the vessel was prepared for anastomosis. Under microscopic visualization, an end-to-side anastomosis was performed with interrupted 10—0 Nylon sutures. Indocyanine green and intraoperative microvascular Doppler ultrasonography were used to identify blood flow after anastomosis. The craniotomy bone flap was replaced after we removed a small edge of the bone to allow passage of the STA branch. The scalp was then closed in layers with VICRYL sutures (Ethicon, Sommerville, New Jersey, USA) and a skin stapler. All STA-MCA anastomosis were performed by the same surgeon.

Study Plan

Preoperatively, a neurosonographer who was blinded to the angiographic information performed CDUS using a color-coded duplex ultrasonographic device (ProSound F75, Hitachi Aloka Medical Ltd., Tokyo, Japan). A 5.0- to 10.0-MHz sonography beam was used. For the STA examinations, each patient was examined in the supine position with his or her head turned away from the imaged side. The transducer was placed in the temporal region before the external opening of the acoustic canal for STA color imaging. Particular care was taken to keep $\leq 60°$ between the beam and the STA. The mean velocity (MV), cross-sectional diameter (CSD), and MFR were measured in bilateral STAs and were then corrected with the incident angle. At 1 week, 1 month, and 2 months postoperatively, bilateral STAs were examined on the same site. The following imaging studies also were performed at each time point: CTA, DSA, and CTP preoperatively; CTA at 1 week postoperatively; DSA at 1 month postoperatively; and CTP at 2 months postoperatively. The study plan is summarized in Table 1.

Table 1. Study Schedules

	PRE OP	POD 1 Week	POD 1 Month	POD 2 Month
CDUS	X	X	X	X
CTA	X	X		
DSA	X		X	
CTP	X			X

PRE OP, preoperatively; POD, postoperatively; CDUS, color Doppler ultrasonography; CTA, computed tomography angiography; DSA, digital subtraction angiography; CTP, computed tomography perfusion.

Statistical Analysis

The parameters were analyzed with the Mann-Whitney U test and Wilcoxon signed rank test. P values < 0.05 were considered statistically significant. Analyses were performed with the IBM Statistical Package for the Social Sciences, version 18.0 (SPSS Inc., Chicago, Illinois, USA).

RESULTS

All patients showed good blood flow on indocyanine green and intraoperative microvascular Doppler ultrasonography immediately after anastomosis. Clinical follow-up was performed in all cases. The mean follow-up duration was 15.6 months. Among the 6 patients with ischemic stroke, 4 had improved symptoms after surgery, whereas 2 were unchanged. Five patients with transient ischemic attack had no recurrence of symptoms during the follow-up period. One month after surgery, 9 of the 11 patients were found to have good donor artery patency, whereas another 2 had poor patency on DSA. Furthermore, among these 9 patients, CTP results of every patient revealed increased cerebral blood flow and decreased mean transit time at the operated hemisphere after 2 months.

The preoperative and postoperative STA MFR data from all 11 cases are shown in Table 2. The operated side/nonoperated side STA MFR ratio, MV ratio, and CSD ratio were calculated.

In the good patency group, the STA MFR ratios at 1 week, 1 month, and 2 months postoperatively increased significantly from baseline in a time-dependent fashion (2.88, 3.07, and 4.38, respectively, $P < 0.05$, Wilcoxon signed rank test). In contrast, in the poor patency group, the mean STA MFR ratio was unchanged postoperatively (Figure 1). In particular, the STA MFR ratio at 2 months postoperatively was significantly changed from the earlier measurements ($P = 0.036$, Mann-Whitney U test). At 1 month postoperatively, the mean MFR ratio of the operated and nonoperated side was more than 3, when the extent of collateral flow was satisfactory on DSA.

Similarly, the mean STA CSD ratio at 1 week, 1 month, and 2 months increased postoperatively in the good patency group