Subcortical Low-Intensity Lesions on Fluid-Attenuated Inversion Recovery Images After Revascularization Surgery for Moyamoya Disease

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■ OBJECTIVE: **Although uncommon, subcortical low-intensity (SCLI) changes on fluid-attenuated inversion recovery images are observed in various diseases, including cerebral ischemia. Here, we aimed to clarify the incidence and clinical implications of SCLI changes after revascularization surgery for moyamoya disease, focusing on the correlation with postoperative transient neurologic events (TNEs).**

■ METHODS: **In this retrospective case series analysis, we included 10 hemispheres from 9 adults with moyamoya disease who underwent revascularization surgery. Subcortical signal intensity at the 5 gyri around the anastomosis point was quantitatively measured at 1 week and 3 months postoperatively. Changes in cerebral blood flow (CBF) were assessed using single-photon emission computed tomography.**

■ RESULTS: **Images taken 1 week after surgery showed widespread SCLI changes below the operative fields in all 10 cases, but these changes normalized by 3 months. In addition, the changes in signal intensity at anastomoses negatively correlated with the changes in CBF ($R^2 = 0.36$; $P = 0.039$). Postoperative TNEs occurred in 6 cases (60%) but were resolved within 17 days after surgery. Postoperative CBF increased in 9 of the 10 cases, with a median of 23%; however, these increases were not associated with the development of TNEs. The SCLI changes at the anastomosis points did not differ by the experience of TNEs.**

■ CONCLUSIONS: **Early after surgery, SCLI changes are common findings below the operative fields but negatively correlate with increases in CBF. Although no significant association was found between TNEs and the SCLI changes, the synchronized development of these phenomena may suggest a common underlying pathogenesis.**

INTRODUCTION

In patients with moyamoya disease (MMD), revascularization surgery is performed to improve hemodynamic impairments and prevent ischemic or hemorrhagic strokes.[1-4] However, despite the efficacy of this procedure, there is a relatively high incidence of postoperative complications, including infarction, hemorrhage, and transient neurologic events (TNEs).[5-8] Among these complications, TNEs are particularly common, with an overall incidence rate of 14%–77%.[6,9-11] TNEs usually develop early in the postoperative period and resolve within a few weeks of surgery without leaving a permanent neurologic deficit and are believed to be caused by local hyperperfusion after the direct bypass.[9,12,13] However, recent studies have suggested that other factors, such as transient hypoperfusion,[11] watershed shift,[10] and vasogenic edema,[6,14] are relevant causative factors. Thus, the pathogenesis of TNEs remains unclear.

Subcortical low-intensity (SCLI) lesions on T2-weighted or fluid-attenuated inversion recovery (FLAIR) images are uncommon magnetic resonance imaging (MRI) findings. However, they

Key words
- Moyamoya disease
- STA-MCA anastomosis
- Subcortical low-intensity
- Transient neurologic event

Abbreviations and Acronyms
CBF: Cerebral blood flow
EMS: Encephalomyosynangiosis
FLAIR: Fluid-attenuated inversion recovery
M4: Cortical branch of the MCA
MCA: Middle cerebral artery
MMD: Moyamoya disease
MRI: Magnetic resonance imaging
ROI: Region of interest
SCLI: Subcortical low-intensity
SPECT: Single-photon emission computed tomography
STA: Superficial temporal artery
TNE: Transient neurologic event

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are observed under various pathologic conditions, such as cerebral infarction, inflammation, neurodegenerative disease, and early ischemia in MMD.[15-19] Nonheme iron, free radicals, and degradative products of oxyhemoglobin have all been proposed to be responsible for the appearance of SCLI lesions. Recently, Tanioka et al.[20] also observed SCLI changes after revascularization surgery for MMD and proposed the presence of an association between these lesions and the development of postoperative TNEs.

In this study, we investigated the incidence and the clinical implications of SCLI lesions after revascularization surgery for MMD, focusing on their correlation with TNEs.

METHODS

Study Design and Participants

This was a retrospective case series analysis. We enrolled consecutive adults with MMD who underwent revascularization surgery in our hospital between September 2013 and October 2015. Subcortical signal intensity was quantitatively assessed at the anastomosis sites at 1 week and 3 months postoperatively. Changes in cerebral blood flow (CBF) were assessed by single-photon emission computed tomography (SPECT) using 111MBq of N-isopropyl[^{123}I]-*p*-iodoamphetamine before and the day after surgery. This study was approved by the institutional review board of our hospital.

Operative Indications, Procedures, and Management

Patients were considered candidates for revascularization if they had a symptomatic cerebral hemisphere with compromised cerebrovascular reserve capacity. Therefore, neither asymptomatic patients nor the asymptomatic hemispheres of symptomatic patients were considered for surgery. All patients underwent anastomosis of the superficial temporal artery (STA) to middle cerebral artery (MCA) with encephalomyosynangiosis (EMS), with a frontal or parietal branch of the STA anastomosed to the cortical branch of the MCA (M4) in an end-to-side manner. After the anastomosis, the brain surface was covered with the temporal muscle, which was split and halved to make it thinner to avoid compression of the brain, completing the EMS.

Preoperatively, all patients received 500 mL of crystalloid solution to prevent dehydration. Surgery was then performed under total intravenous anesthesia with propofol and fentanyl, and the arterial pressure of carbon dioxide maintained at 35–45 mm Hg. Postoperatively, all patients were returned to consciousness and were extubated in the operating room, with intravenous hydration continued until the patients could tolerate eating by mouth. Using an intravenous infusion of nicardipine hydrochloride, as appropriate, the systolic blood pressure was strictly maintained within 110 and 140 mm Hg to avoid hyperperfusion or hypoperfusion, usually until 1 week postoperatively.

Radiologic Examination

Before surgery, CBF and cerebrovascular reserve were measured quantitatively by N-isopropyl[^{123}I]-*p*-iodoamphetamine SPECT with and without a 10-mg/kg intravenous injection of acetazolamide. Postoperative CBF was also measured on the day after surgery, and local changes in CBF at the anastomosis site were assessed compared with the contralateral region (internal standard) to give the radioisotope count ratio.

All MRIs were performed with a 3-T system (Magnetom Skyra [Siemens AG, Healthcare Sector, Erlangen, Germany]). FLAIR images (spin echo; repetition time, 11,000 milliseconds; echo time, 144 milliseconds; fractional anisotropy, 150) were obtained at 1 week and 3 months postoperatively. Using the axial slice that contained the anastomosis point, we set 5 consecutive regions of interest (ROIs) in the surrounding subcortical white matter (Figure 1). The degree of SCLI per region was evaluated as the radioisotope count ratio.

Statistical Analysis

The Fisher exact and Mann-Whitney U tests, respectively, were used to analyze differences in the dichotomous and numeric data between the groups. Differences in the degree of SCLI change at the 5 gyri were analyzed by the Kruskal-Wallis test with post hoc analysis. Linear regression analysis was used to evaluate the association between the numeric data, including M4 occlusion times and the changes in CBF or SCLI lesions. Any *P* value <0.05 was considered statistically significant. Analysis was performed using the EZR software (Jichi Medical University, Shimotsuke, Japan).[21]

RESULTS

Table 1 summarizes the details of the 9 consecutive adult patients with MMD who underwent revascularization surgery and were

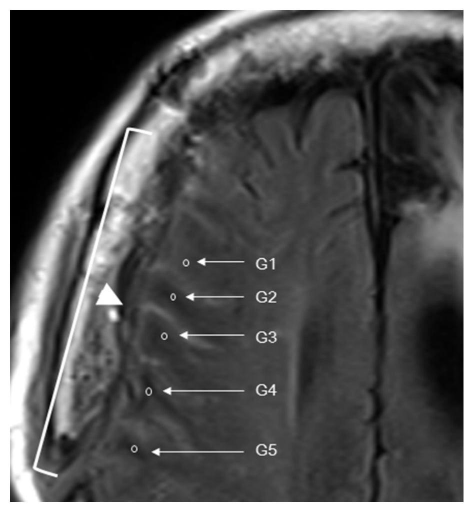

Figure 1. Quantification of signal intensity for the subcortical white matter. Regions of interest (ROIs) measuring 1 mm in diameter were set at the anastomosis point (*arrowhead*) and 2 gyri each anterior and posterior to that point (*G1–G5*, *arrows*). The bracket indicates the surgical field. The signal intensity of each ROI was measured quantitatively. Another ROI was set on the subcortical white matter contralateral to the operated hemisphere for use as an internal standard, and relative signal intensities were calculated as ratios (signal intensity of ROI/signal intensity of standard ROI).