

A3-A3 anastomosis and superficial temporal artery-radial artery graft-A3 bypass to treat bilateral ACA steno-occlusive hemodynamic ischemia with cognitive and executive dysfunction: a technical note

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Abstract

Background Executive functions are complex cognitive control functions that include cognitive flexibility, inhibition (self-control, self-regulation), and working memory. Bilateral frontal lobe ischemia is associated with cognitive impairment, especially in the context of dysexecutive syndrome. This report describes two patients who underwent bilateral anterior cerebral artery (ACA) reconstruction by A3-A3 anastomosis in conjunction with superficial temporal artery (STA)-radial artery (RA) graft-A3 bypass to treat bilateral ACA steno-occlusive hemodynamic ischemia accompanying cognitive and executive dysfunction.

Method A 74-year-old woman and a 73-year-old woman were admitted to our hospital for unilateral cerebral infarction in the frontal lobe. Magnetic resonance angiogram (MRA) demonstrated severe bilateral ACA steno-occlusive pathology in both patients. Considering the presence of impaired cognitive function with dysexecutive syndrome as well as hemodynamic compromise shown by single photon emission computed tomography (SPECT), we proceeded with A3-A3 anastomosis in conjunction with STA-RA-A3 bypass. Various neuropsychiatric tests were performed before and after the surgery.

Results We confirmed good bypass patency without periprocedural complications. One patient recovered from apallic and bedridden status and regained ambulatory condition and ability to take in an oral diet. Another patient

demonstrated improved scores in several cognitive tests with some persistent executive dysfunction.

Conclusions Bilateral ACA revascularization was technically feasible in two patients. This bypass surgery could have some positive effects in some basic cognitive function, such as memory, attention, and concentration by bilateral ACA hemodynamic improvement, although executive function, which is specific to prefrontal function, might not be reversible.

Keywords Bonnet bypass · Cerebral infarction · Cerebral revascularization · Executive function · Frontal lobe · Stroke

Introduction

Bonnet bypass was first introduced by Spetzler et al. in 1980 [1]. Thereafter, bonnet bypass has been used for skull base tumors [2], aneurysms [3, 4], and atherosclerotic diseases [5–7]. However, no study has provided a case illustration of bilateral anterior cerebral artery (ACA) revascularization for atherosclerotic ischemia. The frontal lobe, especially the prefrontal cortex, is associated with emotion, character, and execution [8, 9]. Today, some studies of moyamoya disease have also suggested that frontal lobe ischemia is associated with executive dysfunction [10, 11]. This executive dysfunction results in severe disruption of patients' premorbid activity of daily living (ADL). In this study, we report the technical detail of bilateral ACA reconstruction via combination of A3-A3 bypass and STA-RA-A3 interposition bypass for bilateral frontal lobe ischemia and discuss the potential reversibility of cognitive impairment via the current revascularization procedure.

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Materials and methods

Preoperative and postoperative examinations

Medical records of two patients who underwent surgical revascularization for a bilateral ACA steno-occlusive disease were retrospectively reviewed, including pre/post-operative computed tomography (CT), magnetic resonance imaging (MRI), digital subtraction angiography (DSA), and various neuropsychological tests according to the patients' status. Informed consent for a surgical procedure and any scientific presentation under anonymity were obtained from patients' families. Bypass patency was confirmed by DSA about 1 week postoperatively in both patients. Results of postoperative neuropsychological tests were assessed and compared with their preoperative ones.

Operation

With the patient in neutral supine position, one of the forearms was prepared for radial artery harvesting of about 17 cm after confirming the safety by Allen test. Radial artery graft (RAG) was harvested under a microscope by another neurosurgeon to meticulously coagulate/ligate small branches and thus to enhance good patency of the graft. A bicoronal skin incision was made, cutting down to the main trunk of the STA as a donor artery. After frontal craniotomy, the interhemispheric fissure was sharply dissected, preserving the bridging veins. The bilateral A3 portions of the ACA above the corpus callosum were exposed. By coagulating a small branch to the corpus callosum, sufficient length for anastomosis was prepared and secured by a rubber sheet passed under the anastomosis portion. Then, A3-A3 anastomosis was performed in a side-to-side fashion (Fig. 1a). The RAG was anastomosed to another A3 portion in a side-to-end manner, approximating to the anastomosis site of A3-A3 (Fig. 1b). In both patients, this RAG-A3 bypass was performed to another branch originating just proximal to the A3-A3 bypass site. A suitable groove in the cranium was made (via drilling) to pass the RAG, which was proximally anastomosed to the frontal branch of the STA in an end-to-end fashion (Fig. 1c). We chose the frontal branch because the frontal branch was more robust compared to the parietal branch of the STA. The entire interposition bypass is illustrated in Fig. 2, showing the concept of the surgery. An intraoperative microvascular Doppler flowmeter confirmed good bypass flow (Video 1, 1 min and 11 s, 37.0 MB, and Video 2, 1 min and 7 s, 40.7 MB.)

Results

Both patients presented with bilateral frontal lobe ischemia and cognitive impairment, which were confirmed by

radiological and neuropsychiatric studies. There was no complication related to surgery and good bypass patency was confirmed by postoperative DSA. Improved performances in the postoperative cognitive tests as compared to preoperative ones were obtained in each case.

Case illustration

Case 1

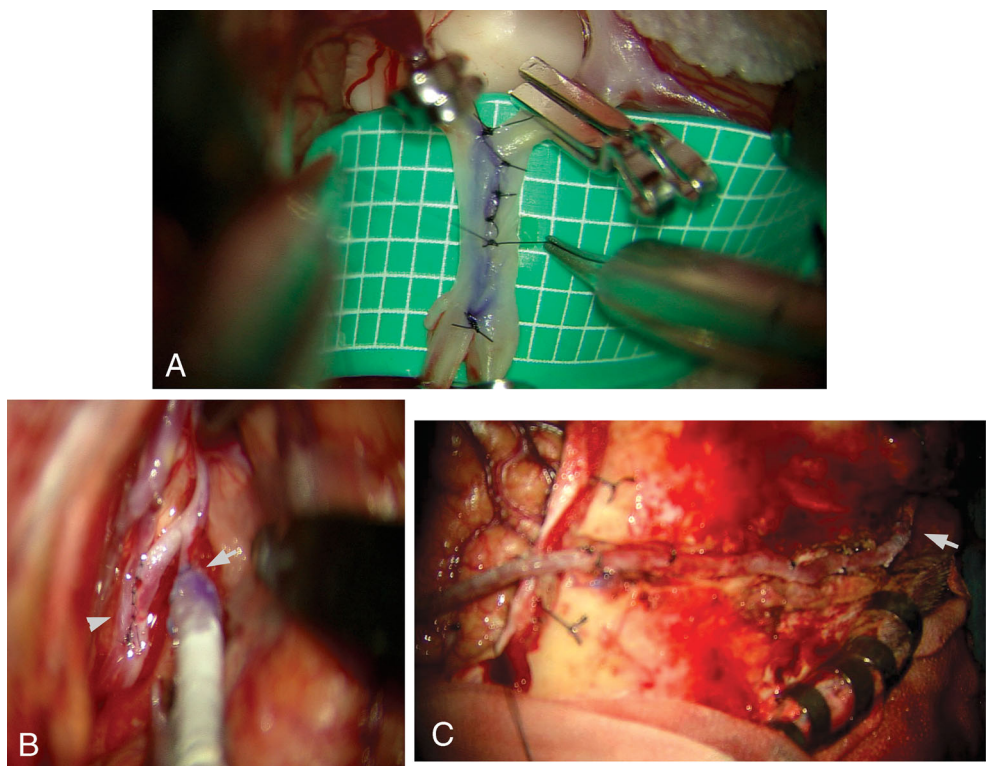
A 74-year-old woman with a history of hypertension and diabetes mellitus was admitted to our hospital for gait disturbance and poor responsiveness. Slight left hemiparesis was detected (Brunnstrom stage of 5). At the time of admission, she required a wheelchair and could take in oral nutrients only with intensive aid. She was almost apallic, and the reaction to conversation was quite poor and sluggish. Cognitive impairment was confirmed by a Mini-Mental State Examination (MMSE) score of 11/30 and the Revised Hasegawa's Dementia Scale (HDS-R) of 8/30, both of which were markedly abnormal. She showed unilateral spatial neglect in the left, diagnostic apraxia (alien hand syndrome), and compulsive manipulation of tools [12].

Diffusion-weighted imaging (DWI) showed high intensity in the pericallosal area of the right hemisphere (Fig. 3a). Magnetic resonance angiography (MRA) showed occlusion of the right A2 as well as stenosis of the left A2 (Fig. 3b). DSA confirmed nearly complete occlusion in the right A2 (Fig. 3c and d) and severe stenosis in the left A2 (Fig. 3e and f). Dual antiplatelet therapy with aspirin (100 mg) and clopidogrel (75 mg) was started immediately after admission, but her disease progressed, and follow-up MRI showed expansion of DWI high-intensity lesions (Fig. 3g). Single-photon emission computed tomography (SPECT) showed decreased cerebral blood flow (CBF) in the bilateral frontal lobes as well as severely impaired cerebrovascular reactivity (CVR) to an acetazolamide challenge with steal phenomenon (Fig. 4a and b).

Surgical procedures were performed as described in the *Operation* section.

No obvious perioperative complications occurred. Postoperative acute rehabilitation was performed and she seemed better motivated toward the rehabilitation postoperatively than she had been before the surgery. Postoperative MRA showed good patency of the bypass (Fig. 4a) with no expansion of DWI high-intensity lesions (Fig. 4b). Postoperative DSA confirmed good patency and smooth blood flow in the bilateral ACA through the bypass (Fig. 4c and d). Postoperative SPECT demonstrated increased CBF at rest as well as improved CVR in the bilateral frontal area with resultant disappearance of steal phenomenon (Fig. 5c and d). She was able to ambulate with minimal

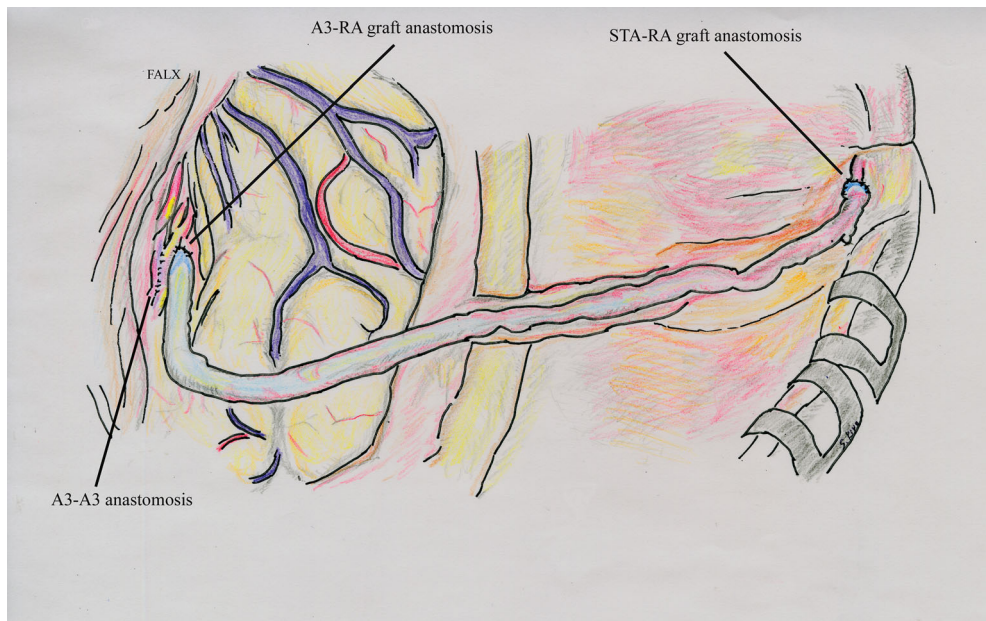
Fig. 1 Intraoperative pictures. Bilateral A3s are anastomosed in a side-to-side fashion after being secured by a rubber sheet that is put below the arteries (a). A radial artery graft is anastomosed to another A3 portion in a side-to-end manner (arrow), approximating to the anastomosis site of A3-A3 (arrowhead) (b). To embed the radial artery graft, a suitable groove in the cranium is drilled out, and the graft is proximally anastomosed to the superficial temporal artery (STA) in an end-to-end fashion (c, arrow)



assistance despite absence of significant improvement in her slight left hemiparesis. Independent oral intake was achieved. Her cognitive function increased (MMSE from 11 to 17; HDS-R from 8 to 16). An occupational therapist reported that her responses in conversation were smoother than they had been before the surgery and that her voluntary speech had improved significantly when compared with her preoperative apallic status. Some degree of impaired cognitive function

persisted, including unilateral spatial neglect in the left, diagnostic apraxia, and compulsive manipulation of tools. Long-term rehabilitation was performed, which enabled her to walk with slight assistance (modified Rankin Scale (mRS) 4), speak fluently with her family, and eat independently. She was discharged from our hospital 31 days after the bypass surgery and was reported to be free from stroke for at least 11 months postoperatively.

Fig. 2 The entire interposition bypass is demonstrated in an illustration, showing the concept of the surgery



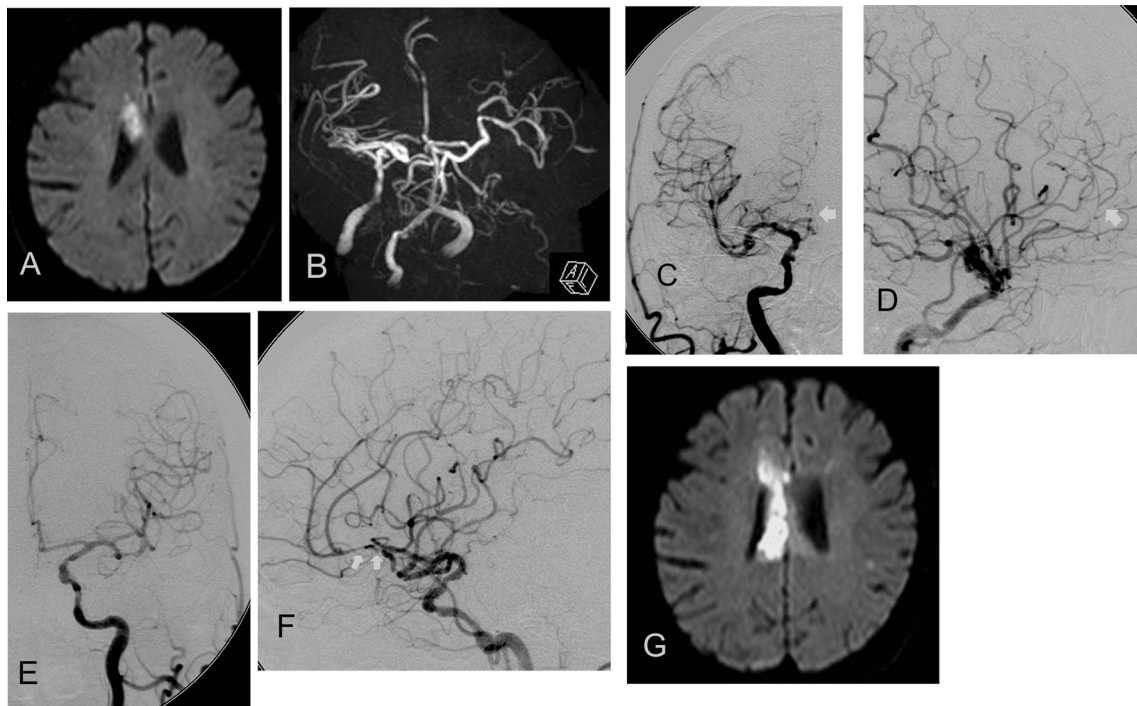


Fig. 3 Preoperative imaging studies of case 1. Magnetic resonance imaging (MRI) at admission (**a** and **b**), digital subtraction angiography (DSA) before the surgery (**c–f**), and follow-up diffusion-weighted imaging (DWI) just before the bypass surgery (**g**). DWI at admission (**a**) shows fresh infarction in the right pericallosal area. Magnetic resonance

angiography (MRA) (**b**) demonstrates occlusion of the right A2 and stenosis of the left A2. DSA confirms near occlusion of the right A2 (**c** and **d**, *arrow*) and stenosis of the left A2 (**e** and **f**, *arrow*). DWI just before the bypass surgery (**g**) shows expansion of the infarction

Case 2

A 73-year-old woman with a history of hypertension presented to her nearby clinic complaining of weakness of her left lower extremity. She was referred to our hospital for right frontal lobe infarction. Left-sided weakness was noted (Brunnstrom stage of 6), and she was unable to ambulate without help. Her MMSE was 24, and HDS-R was 27. Clopidogrel (75 mg) was started, and various examinations were performed.

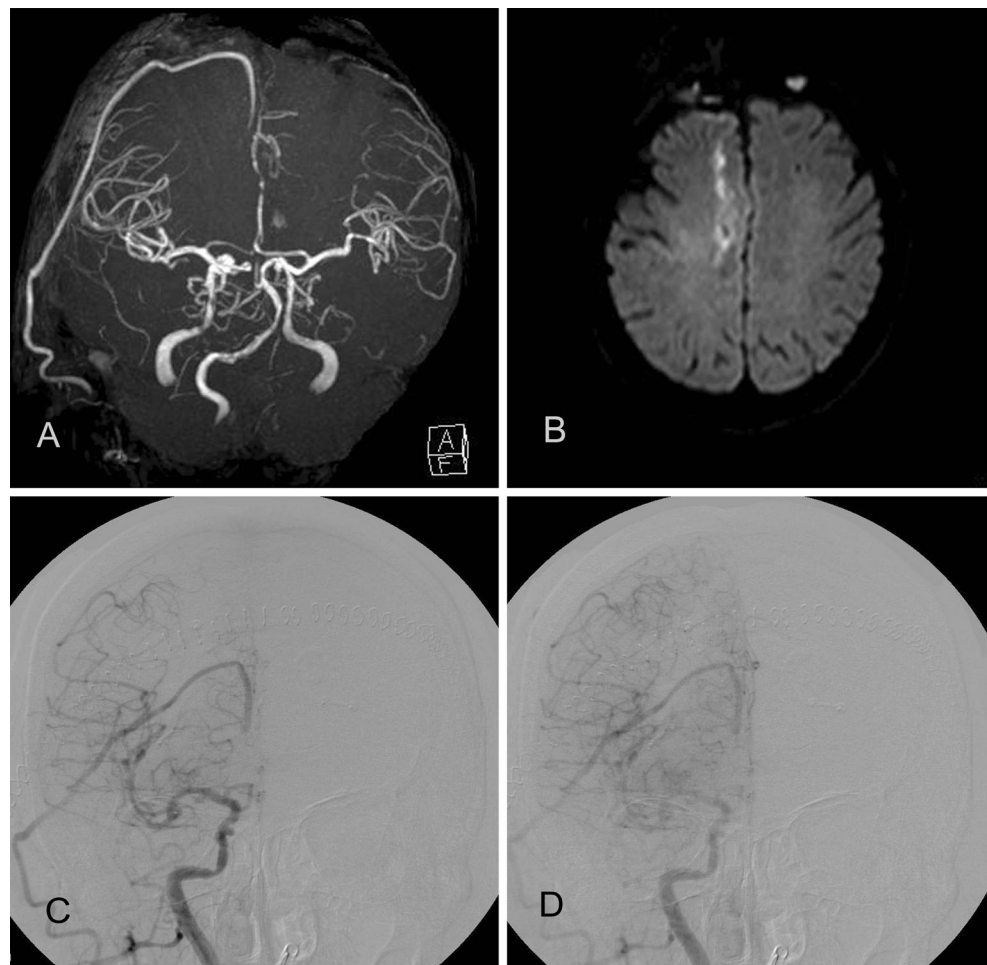
Her cognitive function was compromised as follows: her Wechsler Adult Intelligence Scale-third (WAIS- III) edition showed verbal intelligence quotient (IQ) of 81, performance IQ of 74, and full-scale IQ of 75. Her Wechsler Memory Scale-Revised (WMS-R) showed verbal memory of 98, visual memory of <50, general memory of 79, and attention/concentration of 81. She could complete the trail making test part A within 105 s, but was unable to finish part B because she could not trail two different sequences alternatively. Her Frontal Assessment Battery (FAB) score was 10: she scored 1 out of 3 in components of similarities, lexical verbal fluency, Go-No Go, and prehension behavior and 3 out of 3 in motor series and conflicting instructions.

Her DWI showed an acute ischemic lesion in the right frontal lobe (Fig. 6a), and MRA showed occlusion of the right

A2 and stenosis of the left A2 (Fig. 6b). Follow-up MRA at 6 days after admission demonstrated recanalization of the right A2, which turned out to be also stenosed (Fig. 6c). DSA confirmed severe multiple stenotic lesions in the bilateral ACA (Fig. 6d and e: right, and f and g: left, respectively). SPECT was technically suboptimal but suggested reduced CBF in the right frontal lobe as well as reduced CVR in the right ACA area in response to an acetazolamide challenge.

Postoperative MRI showed good patency of the bypass (Fig. 7a) and no expansion of infarction. DSA confirmed smooth blood flow from the STA to the bilateral ACA (Fig. 7b and c). At 3-month follow-up, MRA showed consistent patency of the bypass (Fig. 7d). SPECT at 3 months postoperatively showed improvement in CVR in the whole cerebrum when compared with that of the preoperative study. She lived at home independently, and her mRS was 2. Her WAIS-III increased (verbal IQ from 81 to 93, performance IQ from 74 to 75, and full-scale IQ from 75 to 83), and her WMS-R generally increased (language memory of 95 from 98 (only one component with postoperative decrease), visual memory from below 50 to 77, general memory from 79 to 87, and attention/concentration from 81 to 92). Her FAB score increased from 10 to 14 (similarity component from 1 to 3, lexical verbal fluency from 1 to 2, motor series from 3 to 3, conflicting instructions from 3 to 3, Go-No go component

Fig. 4 Postoperative imaging study in case 1. Magnetic resonance angiogram (MRA) demonstrates good patency of the superficial temporal artery (STA)-radial artery (RA) graft-A3 bypass (a). No expansion of diffusion-weighted imaging (DWI) high-intensity lesion is seen (b). Digital subtraction angiography (DSA) confirms smooth blood flow through the bypass to the bilateral anterior cerebral artery (ACA) (c and d)



decreased from 1 to 0, and prehension behavior from 1 to 3). The results of trail-making tests did not change dramatically (part A from 105 to 113; part B with persistent failure). Her family also recognized her cognitive improvement after the surgery. Her psychotherapist described her postoperative improvement as having better understanding of instructions and a decrease in abrupt conversations. No stroke events occurred for at least 7 months postoperatively.

Discussion

In 1967, STA-middle cerebral artery (MCA) bypass was first clinically applied, and bypass surgery for intracranial or extracranial arterial steno-occlusive diseases had been widely performed hereafter [13, 14]. Since the EC/IC Bypass Study Group failed to prove benefit of bypass surgery as compared to medical therapy alone in symptomatic atherosclerotic steno-occlusive disease in the MCA or ICA [15], various neuroimaging modalities such as positron emission tomography (PET) or SPECT have been investigated to identify

hemodynamically high-risk patients [16–18]. However, after the failure of the Carotid Occlusion Surgery Study randomized trial, the indication of bypass surgery to prevent recurrent stroke has remained controversial [19]. Meanwhile, the efficacy of bypass surgery in prevention of progressing stroke or in cognitive improvement in an atherosclerotic large vessel occlusive disease has not been denied so far.

Bonnet bypass was first described in 1980 as applied to a skull base tumor in a patient without availability of an ipsilateral donor artery [1]. In a series of more than 300 skull base tumors, Lawton MT et al. sacrificed internal carotid artery (ICA) in ten cases, and bonnet bypass was utilized in two cases [2]. Bonnet bypass has been used not only for skull base tumors but also for other pathologies. There are two reported cases of successful bilateral ACA revascularization in the context of giant anterior communicating artery aneurysm surgery [3, 4]. Lawton et al. reported their experience of ACA aneurysms requiring bypasses and reviewed varieties of ACA revascularization in detail [20]. In the context of ischemic stroke, bonnet bypass has been used in patients with a multiple cerebrovascular occlusive disease including the common carotid artery [5–7]. Sanada et al. reported good patency of the

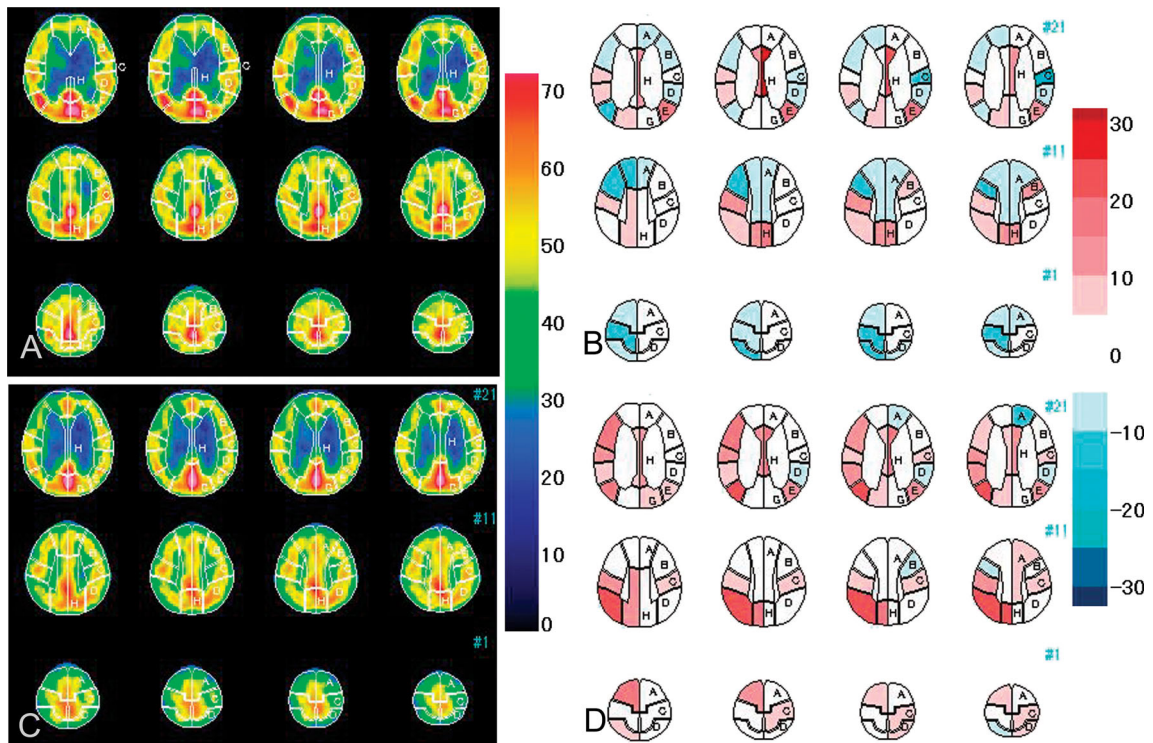


Fig. 5 99mTc-ethyl cysteinate dimer (ECD) single-photon emission computed tomography (SPECT) before (a and b) and after (c and d) the bypass surgery in case 1. Cerebral blood flow (CBF) is decreased in the bilateral frontal area (a), and after injection of acetazolamide, steal

phenomenon is noted (blue area, b). After the bypass surgery, no remarkable change is seen at rest (b). However, after acetazolamide challenge, area of steal phenomenon decreases (d)

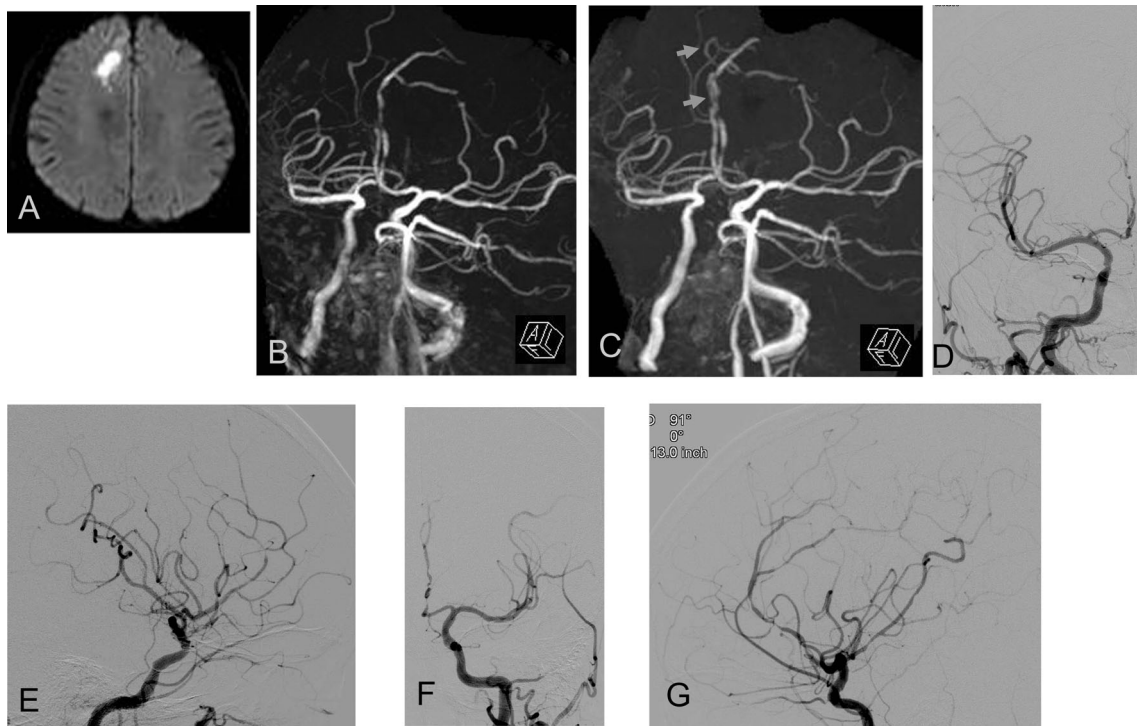
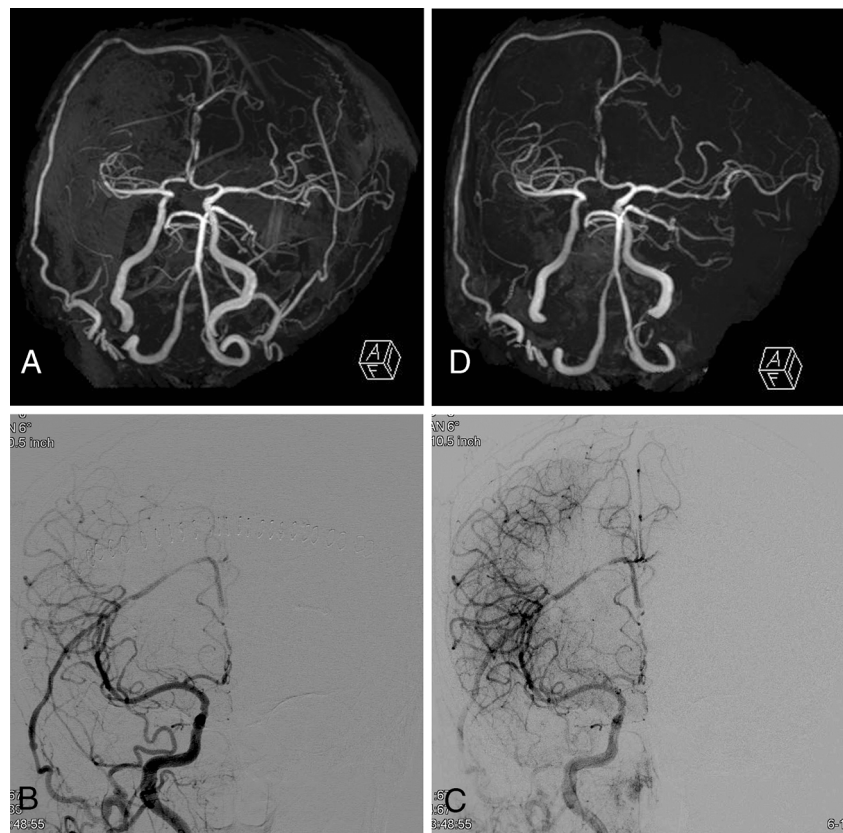


Fig. 6 Preoperative imaging study in case 2. Fresh infarction is seen in the right frontal lobe (a). Magnetic resonance angiogram (MRA) demonstrates occlusion of the right A2 and stenosis of the left A2 (b). Follow-up

MRA shows recanalization of the right anterior cerebral artery (ACA) (c, arrow). Digital subtraction angiography (DSA) shows stenosis of the bilateral ACA (d and e: right, and f and g: left)

Fig. 7 Postoperative imaging study in case 2. Magnetic resonance angiogram (MRA) demonstrates good patency of the bypass (a). Digital subtraction angiography (DSA) confirms satisfactory flow of contrast medium from the STA to bilateral ACA (b and c). Follow-up MRA at 3 months shows consistent patency of the bypass (d)



bypass at 1 year after surgery in two cases [6]. Zumofen et al. described one case of postoperative improvement in perfusion as assessed by H₂O- PET scan and cessation of transient ischemic attack (TIA) at the 3-month postoperative follow-up time point [7]. The present report is the first to describe bilateral ACA revascularization for bilateral atherosclerotic steno-occlusive ACA in patients with dysexecutive syndrome.

Classically, the frontal lobe has been recognized to play an important role in cognition and character.[9] Executive functions are cognitive control functions needed when we have to concentrate and think, when acting on our initial impulse would be ill-advised, and the prefrontal cortex is central to these highly advanced functions [8]. Recent studies of moyamoya disease have suggested that frontal lobe ischemia is also associated with dysexecutive syndrome. Karzmark et al. reported impaired cognitive function, especially executive function, in adult patients with moyamoya disease [11]. Calviere et al. suggested that impaired frontal CVR was associated with dysexecutive cognitive syndrome, despite maintenance of CVR in the temporo-parietal region in patients with moyamoya disease [10]. In the present cases, although the pathology was atherosclerotic rather than moyamoya disease, SPECT showed a decrease in CBF and CVR in the bilateral frontal lobes. These results suggest that dysexecutive syndrome can exist in patients with hemodynamic impairment in the bilateral frontal lobes due to severe atherosclerosis.

Karzmark et al. and Calviere et al. reported that dysexecutive syndrome was suggested by impairment in Trail Making Test Form B (TMTB; 42 % [11]- 67 %, [10]). Compared with the Trail Making Test A (TMTA), in which patients plot only one sequence for evaluation of concentration ability, the TMTB requires patients to plot numbers and characters reciprocally and thus evaluates more complex executive function requiring cognitive set shifting [21]. Prefrontal cortex activation increases to a greater degree in TMTB than in TMTA, according to near-infrared spectroscopy (NIRS) [21]. In the present study, the patient in case 2 had difficulty but was able to accomplish TMTA both before and after the surgery, although the result did not significantly change after the surgery. However, she was unable to accomplish TMTB, either before or after the surgery. Meanwhile, more primary function scores (verbal IQ, full scale-IQ in WAIS-III, visual memory, general memory, and attention/concentration in WMS-R, and FAB) increased postoperatively. In case 1, MMSE and HDS-R scores increased postoperatively, and social activity expanded markedly when compared with the patient's preoperative apallic status. We suspect that bilateral ACA reconstruction ameliorated frontal hemodynamic impairment or that recovery from stroke resulted in regain of primordial cognitive function, such as those measured by the memory scale. Further, some complex executive functions, such as those measured by TMTB, may not be

reversible despite recovery from stroke or hemodynamic rescue of the frontal lobes. Additional cases are needed to validate these suppositions, although this might be difficult due to the relative rarity of this pathology and the use of bypass surgery for bilateral frontal atherosclerotic disease.

The use of bonnet bypass for multiple intracranial artery stenoses should be discussed. Currently, the main treatment strategy for intracranial artery stenosis is medical and/or endovascular treatment. It is well known that intracranial artery stenosis carries a high risk of recurrent stroke. The Warfarin and Aspirin for Symptomatic Intracranial Arterial Disease (WASID) trial showed a 1-year risk of stroke in the territory of the stenotic artery of 11 % despite medical therapy [22]. Sub-cohort analysis demonstrated that patients with 70–99 % intracranial stenosis have a two-fold risk of stroke in the territory of the stenotic artery when compared with the patients with 70 % stenosis [23]. Although the efficacy of endovascular treatment toward intracranial artery stenosis has been demonstrated elsewhere, the additional efficacy over medication therapy alone has not yet been proven [24–26]. Further, the optimal treatment strategy for multiple or bilateral intracranial artery stenosis remains unclear. The present two cases experienced improved vascular reserve postoperatively, which may suggest that the bypass surgery might prevent stroke to a great degree than medical treatment alone [27].

Bilateral frontal lobe damage can result in severe disruption of a patient's character [28, 29]. Because treatment options for bilateral ACA steno-occlusive pathology are limited, bilateral ACA reconstruction using bonnet bypass should be taken into consideration.

Conflicts of interest None

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Comment

This manuscript highlights a rare but interesting indication of using the bonnet bypass and ACA side-to-side anastomosis for bilateral ACA occlusion/stenosis. Although the indication is rare, the technical description and consideration of this option in treatment of intracranial occlusive disease are of interest to vascular neurosurgeons. Preoperative flow measurement by NOVA MRA would be another important adjunct to preoperative assessment of these patients.

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