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**"STA-MCA bypass with encephalo-duro-myo-synangiosis combined with
bifrontal encephalo-duro-periosteal-synangiosis" as a one-staged
revascularization strategy for pediatric moyamoya vasculopathy**

Esposito, Giuseppe ; Kronenburg, Annick ; Fierstra, Jorn ; Braun, Kees P J ; Klijn, Catharina J M ;
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Abstract: PURPOSE Moyamoya vasculopathy progressively compromises cerebral blood flow resulting in chronic hypoperfusion. The middle cerebral artery (MCA) territory and the bifrontal areas are the regions most frequently affected. Although most techniques aim to only revascularize the MCA territory, augmentation of blood flow of the bifrontal areas is of importance in the pediatric moyamoya population since these regions play an important role in cognition, intellectual development, and in lower extremity and sphincter function. We recently described a one-staged surgical procedure combining revascularization of three regions, the MCA territory unilaterally and the frontal areas bilaterally. The purpose of this article is to report our surgical experience in eight children and to emphasize the rationale for bifrontal revascularization. METHODS We report a case series consisting of eight children where the following surgical strategy was applied: (1) a direct superficial temporal artery-to-middle cerebral artery (STA-MCA) bypass with encephalo-duro-myo-synangiosis (EDMS) for unilateral MCA revascularization; in combination with (2) a bifrontal encephalo-duro-periosteal-synangiosis (EDPS) for bifrontal revascularization. Patients' characteristics and 30-day follow-up data are reported. RESULTS The patient group consisted of six girls and two boys (mean age 10.0, range 4.2-17.5 years): six children presented with moyamoya disease, two with moyamoya syndrome. We performed a one-staged revascularization of one MCA territory and both frontal areas in all patients. No significant complications occurred. Two patients experienced postoperative focal seizures, successfully treated with anti-epileptic medication. CONCLUSIONS The single-staged STA-MCA bypass with EDMS combined with bifrontal EDPS allowed revascularization of three regions (the MCA territory unilaterally and the frontal areas bilaterally) and may serve as an alternative and safe treatment option for pediatric moyamoya patients.

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“STA-MCA bypass with encephalo-duro-myo-synangiosis combined with bifrontal encephalo-duro-periosteal-synangiosis” as a one-staged revascularization strategy for pediatric moyamoya vasculopathy.

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ABSTRACT

Purpose. Moyamoya vasculopathy progressively compromises cerebral blood flow resulting in chronic hypoperfusion. The middle cerebral artery (MCA) territory and the bifrontal areas are the regions most frequently affected. Although most techniques aim to only revascularize the MCA territory, augmentation of blood flow of the bifrontal areas is of importance in the pediatric moyamoya population since these regions play an important role in cognition, intellectual development, and in lower extremity and sphincter function. We recently described a one-staged surgical procedure combining revascularization of three regions, the MCA territory unilaterally and the frontal areas bilaterally. The purpose of this article is to report our surgical experience in eight children and to emphasize the rationale for bifrontal revascularization.

Methods. We report a case series consisting of eight children where the following surgical strategy was applied: 1) a direct superficial temporal artery-to-middle cerebral artery (STA-MCA) bypass with encephalo-duro-myosynangiosis (EDMS) for unilateral MCA revascularization; in combination with 2) a bifrontal encephalo-duro-periosteal-synangiosis (EDPS) for bifrontal revascularization. Patients' characteristics and 30-day follow-up data are reported.

Results. The patient group consisted of six girls and two boys (mean age: 10.0, range 4.2-17.5 years): six children presented with moyamoya disease, two with moyamoya syndrome. We performed a one-staged revascularization of one MCA territory and both frontal areas in all patients. No significant complications occurred. Two patients experienced post-operative focal seizures, successfully treated with anti-epileptic medication.

Conclusions. The single-staged STA-MCA bypass with EDMS combined with bifrontal-EDPS allowed revascularization of three regions (the MCA territory unilaterally and the frontal areas bilaterally) and may serve as an alternative and safe treatment option for pediatric moyamoya patients.

Key words: bypass; cerebral revascularization; children; frontal area; moyamoya; pericranial flap.

Abbreviations

ACA: anterior cerebral artery
CBF: cerebral blood flow
CVR: cerebrovascular reserve
CT: computed tomography
DSA: digital subtraction angiography
EDAS: encephalo-duro-arterio-synangiosis
EDMS: encephalo-duro-myo-synangiosis
EDPS: encephalo-duro-periosteal-synangiosis
EDS: encephalo-duro-synangiosis
EMS: encephalo-myo-synangiosis
EPS: encephalo-periosteal-synangiosis
ICA: internal carotid artery
IF: interhemispheric fissure
IQ: intelligence quotient
MCA: middle cerebral artery
MMD: moyamoya disease
MMS: moyamoya syndrome
MMV: moyamoya vasculopathy
MRA: magnetic resonance angiography
MRI: magnetic resonance imaging
PET: positron emission tomographic
SSS: superior sagittal sinus
STA: superficial temporal artery
STA-ACA: superficial temporal artery to anterior cerebral artery
STA-MCA: superficial temporal artery to middle cerebral artery
TIA: transient ischemic attack.

Running title.

One-staged unilateral MCA and bilateral frontal revascularization.

INTRODUCTION

In patients with moyamoya vasculopathy (MMV), surgical revascularization is performed to prevent recurrent stroke and to stabilize or improve neurological outcome and quality of life.[1] Applied techniques of revascularization vary and it remains unclear whether one technique should be preferred over the other, both in adults and in children.[1-3] The most commonly used direct revascularization procedure is the superficial temporal artery to middle cerebral artery (STA–MCA) bypass that instantly augments blood supply to the middle cerebral artery (MCA) territory. Indirect techniques rely on the overlay of vascularized tissue (like the temporal muscle, pericranium and dura) onto the cerebral cortex in order to promote neoangiogenesis over time.[1-3] Combined revascularization procedures provide the advantages of both techniques.[2-7]

In addition to symptoms that can be ascribed to the MCA territory, children may present with lower extremity motor weakness and neuropsychological dysfunctions probably due to involvement of the frontal lobes.[8-12] In pediatric MMV, the cerebral blood flow (CBF) in the bifrontal areas as well as in the anterior watershed territory may continue to worsen despite good collateral formation or successful revascularization of the MCA territory.[9-12] Therefore, it is important to consider timely revascularization of the frontal areas, to prevent neurocognitive decline in pediatric patients.[8-12]

We recently published the technique of a one-staged surgical procedure for children diagnosed with MMV, which combines revascularization of three regions, the MCA territory unilaterally and the frontal areas bilaterally. This technique consists of unilateral STA-MCA bypass with encephalo-duro-myo-synangiosis (EDMS) and bifrontal encephalo-duro-periosteal-synangiosis (EDPS).[3]

The purpose of this article is to report our surgical experience in a series of eight pediatric moyamoya patients and to emphasize the rationale for bifrontal revascularization.

PATIENTS AND METHODS

Patients

We retrospectively reviewed all pediatric patients with MMV who were operated on by performing the one-staged procedure (unilateral STA-MCA bypass with EDMS and bifrontal EDPS) between December 2009 and March 2012.

Pre-operative work-up includes Magnetic Resonance Imaging (MRI), 6-vessel digital subtraction angiography (DSA), H₂O-positron emission tomography (PET) and neuropsychological evaluation. These investigations are repeated one year after surgery.

According to our protocol, “unilateral STA-MCA bypass with EDMS combined with bifrontal EDPS in one step surgical procedure” was indicated for children presenting with both the following conditions: 1) hemodynamic compromise (impaired CBF and/or cerebrovascular reserve - CVR) or ischemic symptoms in a MCA territory; 2) hemodynamic compromise (impaired CBF and/or CVR) or ischemic symptoms in both frontal regions.

We registered clinical characteristics (disease, sex, age, pre-operative symptoms), surgical data (side and type of surgery, operative time), post-operative course and events (occurrence of complications, days of admittance, 30-days follow-up).

Unexpected events within 30 days after surgery are described as peri-operative complications. Episodic symptoms within 30 days postoperatively which resembled preoperative events in terms of frequency, duration and aspect (e.g. unchanged TIA's) were not included as peri-operative complications.

We report in details the treatment and follow-up data of a child affected by moyamoya disease (MMD).

Description of the surgical technique

Direct (STA-MCA) and indirect (EDMS) bypass for unilateral MCA territory revascularization

The patient is placed in supine position with the head mildly extended in the 3-points Mayfield headrest and 30° rotated to the opposite side. Care has to be paid not to injure the contralateral STA as this would compromise a future STA-MCA bypass on the opposite side. We do not shave the hair.

The incision starts over the parietal branch of the STA. The STA-MCA bypass is performed according to the classic technique described elsewhere.[13] In brief, the parietal branch of the STA branch is dissected and prepared under microscopic view: this donor vessel is kept intact up to the anastomotic procedure. The temporal muscle is cut along the skin incision and a craniotomy is performed on the Sylvian point over a large cortical MCA branch. The dura mater is opened in a star shaped fashion preserving the main branches of the middle meningeal artery. After meticulous hemostasis, the dural flaps are reflected subdurally under the bone window, to obtain encephalo-duro-synangiosis (EDS) (figure 2 a-b). The cortex is inspected for the largest cortical M4 recipient artery, which is dissected by means of arachnoid opening. A segment with no or only few cortical side-branches is chosen (1-2 of the tiny side-branches may need to be interrupted). Two silicon triangle-shaped background-sheets are inserted beneath the recipient artery, in order to facilitate the construction of the anastomosis. A temporary non-traumatic microvascular clip is placed across the exposed STA proximally. The distal STA is cut in a fish-mouth to increase the opening diameter of the donor vessel and prepared for the micro-anastomosis. A blue dye is applied onto the donor and recipient vessels to improve visualization during the anastomotic procedure. Non-traumatic temporary microvascular clips are applied on the recipient vessel. A linear arteriotomy on the cortical recipient is performed so that the micro-anastomosis is at least 2.5 times the size of the diameter of the recipient vessel. Two 10-0 monofilament sutures are applied at the toe and the heel of the anastomotic site to anchor the donor and recipient vessel. The micro-anastomosis is performed with interrupted 10-0 monofilament sutures to allow anastomosis growth with time. Before knotting the last suture, the anastomosis is flushed to clear air. Flow is re-established by removing first the distal and then the proximal temporary clips on the cortical MCA recipient artery, and finally the clip on the proximal STA (Figure 2c). Bypass patency is assessed with Indocyanine green videoangiography (performed by the use of a commercially available microscope, OPMI ® Pentero, Carl Zeiss Co, Oberkochen, Germany). The flow in the bypass is quantitatively assessed using an intra-operative flow probe (Transonic Systems Inc., Ithaca NY). Flow values over 15 ml/min are considered sufficient. In pediatric moyamoya patients, flow values are expected to be between 15 and 50 ml/min, depending on patients' age, donor and recipient characteristics and hemodynamic conditions. The micro-anastomosis is observed for 20 minutes to make sure there is no decrease in flow. Closure is performed by covering the exposed cortex with the temporal muscle and by suturing the muscle to the dural

edges (to obtain encephalo-myo-synangiosis - EMS). The bone flap is then secured into place above the muscle. Attention is paid to avoid any compression of the bypass (Figure 2f).

Bifrontal EDPS

After completing the direct (STA-MCA) and the indirect (EDMS) bypass for a unilateral MCA territory revascularization, the skin incision is extended frontally 4 cm over the midline, staying behind the hairline (Figures 1a, 2a). This extension can also be made in a zig-zag fashion[14]. The scalp flap is reflected anteriorly and a vascularized bifrontal pericranial flap, consisting of the periosteum and the overlying loose areolar layer, is dissected (Figure 1 a-b, 2d). The pericranial flap is kept pediculated towards the bitemporal and biorbital regions to maximize vascular supply. This pediculated pericranial flap will serve to perform the bifrontal encephalo-periosteal-synangiosis (EPS). Two separate frontal parasagittal craniotomies (4 x 5 cm) are performed: one on the left and one the right side. The craniotomies are localized 2 cm away from the midline to avoid injuring the superior sagittal sinus (SSS) and the parasagittal veins. The dura is then opened in a star shaped fashion and, after meticulous hemostasis, the dural flaps are inverted and reflected under the edges of each frontal bone window to obtain EDS (figures 1b, 2d). Small cortical arachnoidal openings are made. The periosteal flap is then positioned over the cortical convexity and sutured laterally to the dura (EPS) (Figures 1c, 2e). Both frontal bone flaps are repositioned and fixed (Figures 1d, 2e-f). The scalp flap is re-approximated and the skin incision closed in 2 layers taking care not to compromise the STA-MCA bypass.

RESULTS

Case series

Patient and operation characteristics, occurrence of complications and 30-day follow-up data are summarized in Table 1.

Between December 2009 and March 2012 we operated on eight pediatric moyamoya patients (6 girls; 2 boys) with the combined one-staged technique (Table 1). Mean age was 10.0 years (range 4.2-17.5). Six children were affected by moyamoya disease (MMD). Of the two patients with moyamoya syndrome (MMS), one patient had neurofibromatosis type I (case number 5) and the other trisomy 6 and a 17q25 translocation (case number 6). All patients were operated on by the same senior surgeon (L.R.) at the University Medical Center, Utrecht, The Netherlands.

The mean duration of the procedure (from incision to closure of the skin) was 6 hours and 54 minutes (range 5:10 – 9:35).

According to our protocol, we performed blood transfusions depending on the hemoglobin and hematocrit levels. In two children we administered transfusions peri-operatively (cases 5 and 7). In three other children, one-time blood transfusion was administered within 5 days postoperatively (case 1-3). The blood loss peri-operatively did not exceed 500cc in any patient.

Two patients experienced complications. One patient (case number 2) had a 30-minute episode of focal seizures with twitching of the left corner of the mouth 7 hours postoperatively that was treated with Oxcarbazepine. CT-scan showed diffuse edema in the treated right hemisphere, which resolved on follow-up neuroimaging. The other patient (case number 8) had short lasting symptoms (each lasting less than 10 minutes) on the fifth operative day consisting of sensibility disorders in his right arm and dysarthria. These symptoms were accompanied by aggressive behaviour, which he did not experience before. These symptoms partly resembled his pre-surgical events (before anti-epileptic drugs were prescribed) and were attributed to either TIAs or focal seizures. Valproic acid was restarted and symptoms resolved within 2 days. MRI revealed no new findings. At follow-up, no wound problems occurred and a good cosmetic outcome was achieved in all eight children.

Illustrative case

An 8-year-old previously healthy (case 3, Table 1) boy presented with multiple transient ischemic attacks (TIAs) over the span of one year. The TIAs consisted of symmetric leg weakness, dysphasia, right-sided hemiparesis and episodes of migraine, mostly following agitation and hyperventilation. The neurological examination showed no deficits. DSA revealed bilateral narrowing of the internal carotid artery termination including the M1 and A1 segments with presence of bilateral compensatory collaterals confirming MMD (Figure 3 left panel). The H₂O-PET scan showed evidence of decreased baseline CBF and impaired CVR to acetazolamide in both MCA territories and in the frontal areas bilaterally (Figure 3 right panel).

Based on the symptomatic course of the disease, the characteristics of the TIAs and the impaired CVR in the left MCA territory and bifrontal areas, we treated the patient with the described technique (Figure 1-2).

The post-operative course was uneventful. An early MRI examination at day 9 postoperatively did not reveal new ischemic lesions and MRA showed good patency of the bypass. Three TIAs were reported at 2-month follow-up (which resembled preoperative events in terms of duration and aspect). Thereafter no further ischemic episodes were reported and the boy remained asymptomatic for the next 10 months. At 6-months follow-up MRI/MRA showed no new ischemic lesions, stable of MMD and patency of the bypass. Repeat H₂O-PET after one year showed improvement of CBF and CVR in the left MCA territory and in the frontal areas bilaterally (Figure 3 right panel).

DISCUSSION

We report a case series consisting of 8 pediatric patients treated with a single stage direct STA-MCA with EDMS for unilateral revascularization of MCA territory, in combination with bifrontal EDPS for bilateral frontal revascularization [3]. The indication to perform the one-step combined revascularization procedure was to have hemodynamic compromise and clinical symptoms involving concurrently both a MCA territory and the bifrontal areas. No significant complications occurred.

Adequate CBF supply in the bifrontal areas is of importance, especially in pediatric patients with MMV.[3, 8, 9, 11, 15-18] Cerebral ischemia in this region can in fact lead to lower extremity motor weakness and to intellectual and neuropsychological dysfunction.[11, 17-21] Although little is known about the natural history of MMV,

steep decline of neurocognitive performance has been described in 44% of the pediatric population.[20] Furthermore, there is growing evidence that decreased CBF, especially in the frontal lobes, is correlated with diminished intelligence.[16] Most surgical approaches for MMV focus on increasing the blood supply to the MCA territory.[2, 3, 13, 22] In theory, by surgically restoring blood flow in the bifrontal areas, there may be a beneficial effect on neurocognitive performance.[12] A recent study analysed neurocognitive profiles pre- and postoperatively on 65 pediatric patients with MMV operated by means of a combination of indirect bypass procedures (unilateral encephalo-duro-arterio-synangiosis – EDAS - in 12 patients; bilateral EDAS in 11 patients, bilateral EDAS and bifrontal encephalo-galeal-periosteal synangiosis in 42 patients). This study demonstrated a retained intelligence quotient (IQ) and a significant improvement in performance IQ after surgery.[20] The benefits of bifrontal revascularization on long-term cognitive outcome in children with MMV, however, remain to be established in larger clinical trials.

Advantages and disadvantages of the proposed technique

The main advantage of this technique consisted of the possibility to revascularize in one-session 3 different vascular regions: the MCA territory unilaterally and the frontal areas bilaterally. The technique combined direct and indirect revascularization procedures: direct STA-MCA bypass increased flow immediately and EDMS promoted progressive neoangiogenesis over time in the MCA territory. Bifrontal EDPS aimed at inducing progressive neoangiogenesis over the frontal lobes bilaterally.

This technique also offered the advantage of revascularizing both frontal areas using two separate parasagittal frontal craniotomies, located 2 cm away from the midline SSS. This reduced the risk of injuries to the SSS and the parasagittal veins. Similarly, this technique avoided exposure and opening of the interhemispheric fissure (IF) and of the arachnoid membrane of the medial frontal lobes. Furthermore, the technique allowed inverting and reflecting dural flaps under the craniotomy edges expanding thereby the cortical coverage area for neoangiogenesis.

The scalp is not incised separately for this combined procedure. The skin incision is located behind the hairline and requires no shaving. The use of a single skin incision (either curvilinear or in a zig-zag fashion) and three craniotomies gave an excellent cosmetic result. Large craniotomy flaps or multiple burr holes might lead to less favourable cosmetic outcomes.

Finally, the proposed technique does not compromise eventual future contralateral MCA territory revascularization, as well as revascularization procedures in the posterior circulation territory.

EDPS may represent a very useful alternative to the existing indirect procedures for frontal lobe revascularization or to direct STA-ACA bypass for revascularization of frontal areas.[11] STA-ACA bypass is known to be technically challenging, especially in pediatric patients. In fact the site of micro-anastomosis into the ACA territory needs a very distal preparation of the STA frontal branch and the cortical recipient of the ACA is generally also very small and often located in a sulcus. Furthermore, performing a direct STA-ACA bypass may be difficult in combination with a direct STA-MCA bypass.

The EDPS is technically easier and therefore should be feasible in most children with MMV. The use of frontal pericranial flaps to induce neoangiogenesis in patients with MMV has shown to be an effective technique.[6, 11, 15, 23-26] The choice of using the periosteum (frontal pericranium) for the bifrontal revascularization relies on

the abundant blood supply, providing nourishment to the bone, and potentially promoting neoangiogenesis.[11] The frontal pericranium receives blood supply mainly from the supraorbital and supratrochlear arteries (as well as from frontal branches of the STA), emphasizing the importance of preparing the pericranial flap pediculated anteriorly over the orbits to preserve its vascular supply.[25, 27]

Although the one-stage combined revascularization technique represented a long surgical procedure, the immediate post-operative and short-term (within 30 days) follow-up of the reported patient-series indicated the feasibility and safety of this technique. Data on long term clinical, neuropsychological, radiological and hemodynamic follow-up of the whole case series is currently being collected.

The presented method for surgical revascularization in pediatric patients with MMV represents a modification of existing techniques [11, 15, 23]. Bifrontal EDPS by itself could also be used as a supplementary procedure in patients who already underwent previous revascularization procedures, in case of bifrontal hypoperfusion or progression of the MMV with symptoms referable to frontal lobe hypoperfusion. Bifrontal EDPS itself is doable by means of an incomplete bicoronal incision, from one superior temporal line to the contralateral one.

CONCLUSIONS

The novelty of this STA-MCA bypass with encephalo-duro-myo-synangiosis combined with bifrontal encephalo-duro-periosteal-synangiosis is the one-stage approach, combining direct and indirect revascularization techniques in three different vascular regions: the MCA territory unilaterally and the frontal areas bilaterally. Direct STA-MCA bypass and EDMS in the MCA territory achieves both an immediate flow augmentation and promotes neoangiogenesis over time; bifrontal EDPS aims at inducing neoangiogenesis on the frontal lobes bilaterally. Surgical risk is minimized by avoiding exposure of the superior sagittal sinus and opening of the interhemispheric fissure. In our series, no significant complications due to surgery expansion were encountered. Furthermore, bifrontal EDPS itself could be a valuable procedure in patients who already underwent other cerebral revascularization procedures and who present symptoms referable to frontal lobe hypoperfusion.

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FIGURE LEGENDS

Figure 1

Intraoperative pictures:

- After having performed a STA-MCA bypass and EDMS on the left side (the white arrow indicates the craniotomy and the black asterisk a cottonoid covering the bypass), the skin incision is extended 4-cm over the midline behind the hairline. The dissected frontal pericranial flap is indicated by the white asterisk (*no-shaving technique*).
- The scalp flap is reflected anteriorly; the vascularized frontal pericranial tissue is dissected and reflected on the scalp flap (see white asterisk); two symmetric bilateral frontal parasagittal craniotomies are performed; the underlying frontal dura is then opened in a star-fashion and the dural flaps are inverted onto the cortex around each frontal bone window, to obtain EDS (see multiple white arrows).
- The pericranial flap (white asterisk) is placed over the cortex surface and is sutured to dural edges to obtain EPS.
- The bone flaps are repositioned.

Figure 2

Sketch of the proposed technique:

- a. The black temporal curvilinear dotted line represents the first skin incision performed to microscurgically isolate and prepare the donor vessel (i.e.: parietal branch of the STA). The craniotomy needed to perform the STA-MCA bypass with EDMS is also indicated by the circular black temporal dotted line. The skin incision is extended 4-cm over the midline, after the completion of the procedure for unilateral MCA revascularization (see green dotted line). All the skin incisions are performed behind the hairline. The area for the two subsequent frontal craniotomies is also illustrated.
- b. After splitting the temporal muscle and performing a craniotomy over the Sylvian point, the dura is opened in a star-fashion way (see dotted lines). The donor vessel remains intact.
- c. The dural flaps are inverted on the cortex around the bone window (see dotted lines) in order to obtain the EDS. Thereafter the STA-MCA bypass procedure is completed.
- d. After having performed EMS (by covering the exposed cortex with the temporal muscle and by suturing the muscle to the dural edges), the bone flap is repositioned, the skin incision is then extended 4-cm over the midline behind the hairline. The scalp flap is then reflected anteriorly and the vascularized frontal pericranial tissue (in yellow) is dissected and reflected on the scalp flap. Two symmetric bilateral frontal parasagittal craniotomies are performed; the underlying frontal dura is opened in a star-fashion and the dural flaps are inverted on the cortex around the frontal bone window, to obtain bifrontal EDS (see dotted lines).
- e. To obtain bilateral frontal EPS, the pericranial flap is placed over the cortex surface and sutured to the dural edges bifrontally. The bone flaps are then repositioned.
- f. This coronal section showing the 3 performed craniotomies (1 temporal, 2 frontal parasagittal); the STA-MCA bypass; the dura inverted on the cortex around each bone window (to obtain EDS); the temporal muscle laying on the exposed temporal cortex (to obtain EMS) and sutured to the dural edges; the pericranial flap placed over the frontal cortex surface (to obtain EPS) and anchored to the dural edges.

Figure 3

Left-panel: DSA images (antero-posterior view) showing narrowing of the ICAs termination including the M1 and A1 segment. Extensive hypertrophic lenticulo-striatal collaterals are evident bilaterally.

Right-panel: Pre-operative H₂O-PET before and after Diamox showing bilaterally the evidence of decreased CBF and haemodynamic failure in MCA territory and frontal areas bilaterally. One year post-operative H₂O-PET documenting a clear hemodynamic improvement in bifrontal areas and left MCA territory.

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Case n°	Sex	MMD/MMS	Age (yrs) at surgery	Preoperative events	Side surgery	Peri-operative complications <30days*	Operating time (hrs;min)	Days of admittance
1	F	MMD	4.2	Infarction L hemisphere; TIAs R hemisphere (<10min)	Left (+ BF)	None	05:30	14 days
2	F	MMD	4.9	TIAs R hemisphere (<1hr)	Right (+ BF)	7 hrs postoperatively: Partial seizures R hemisphere (CT:edema,no infarction; oxcarbazepine prescribed)	07:53	10 days
3	M	MMD	8.4	TIAs L hemisphere and symmetric leg weakness (min-1hr); migraine	Left (+ BF)	None	05:10	11 days
4	F	MMD	7.9	TIAs L hemisphere (min-1hr)	Left (+ BF)	None	06:23	8 days
5	F	MMS	9.7	TIAs R hemisphere (min-1hr); migraine	Right (+ BF)	None	05:33	9 days
6	F	MMS	9.7	Collapses (10-30 min); bilateral TIAs and infarction (recent L)	Left (+ BF)	None	07:40	7 days
7	F	MMD	9.6	Severe cognitive impairment; dyskinesia R hand	Left (+ BF)	None	09:35	9 days
8	M	MMD	17.5	Stuttering infarction and parzial seizures L hemisphere (temporarily valproic acid prescribed)	Left (+ BF)	6 days postoperatively: 2 TIAs/Partial seizures L hemisphere (<10 min;MRI no new findings; valproic acid restarted)	07:28	6 days

Table 1: Patient and operation characteristics, occurrence of complications and 30-day follow-up.

BF=Bifrontal; F=female; hrs=hours; L=left; M=male; min=minutes; MMD= Moyamoya disease; no=number; R=right; yrs=years