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Update

Microsurgical neurovascular anastomosis: The example of superficial temporal artery to middle cerebral artery bypass. Technical principles

L'anastomose neurovasculaire microchirurgicale : exemple de l'anastomose temporo-sylvienne. Principes techniques

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ABSTRACT

The superficial temporal artery to the middle cerebral artery (STA-MCA) bypass is a good example of cerebrovascular anastomosis. In this article, we describe the different stages of the procedure: patient installation, superficial temporal artery harvesting, recipient artery exposure, microsurgical anastomosis, and closure of the craniotomy. When meticulously performed, with the observance of important details at each stage, this technique offers a high rate of technical success (patency > 90%) with a very low morbi-mortality (respectively 3% and 1%). Some anesthetic parameters have to be considered to insure perioperative technical and clinical success. STA-MCA bypass is a very useful technique for the management of complex or giant aneurysms where surgical treatment sometimes requires the sacrifice and revascularization of a main arterial trunk. It is also a valuable option for the treatment of chronic and symptomatic hemispheric hypoperfusion (Moyamoya disease, carotid or middle cerebral artery occlusion).

RÉSUMÉ

L'anastomose temporo-sylvienne (ATS) est un parfait exemple d'anastomose neurovasculaire microchirurgicale. Dans cet article, nous en décrivons les étapes successives : installation du patient, prélèvement de l'artère temporale superficielle, préparation de l'artère receveuse corticale, anastomose microchirurgicale, fermeture de la voie d'abord. Lorsqu'elle est réalisée méticuleusement et en respectant certains détails importants à chaque étape, elle offre un taux de succès élevé (taux de perméabilité > 90 %) avec une morbi-mortalité faible (respectivement 3% et 1%). Certaines particularités anesthésiques sont à prendre en compte pour assurer la réussite technique et clinique périopératoire. L'ATS est une technique utile à la prise en charge de certains anévrismes géants ou complexes dont le traitement chirurgical comporte parfois l'occlusion volontaire puis la revascularisation d'une artère essentielle. Elle est également une option thérapeutique intéressante dans le traitement des tableaux d'hypoperfusion hémisphérique chronique et symptomatique tel que la maladie de Moyamoya ou les occlusions symptomatiques athéromateuses de l'artère carotide interne ou cérébrale moyenne.

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1. General aspects [1–18]

The first superficial temporal artery (STA) bypass to the cerebral vessels was reported in 1967 by M. Gazy Yasargil for a patient harboring an internal carotid artery (ICA) occlusion. This technique then became very popular and was exported to North America, Europe and Asia. After the initial and rapid expansion of indications, the number of performed procedures dramatically decreased in 1985 following the results of the cooperative study of the EC/IC bypass study group. This study failed to demonstrate the superiority of surgical treatment versus medical management in reducing the risk of recurrent stroke in patients with severe stenosis or occlusion of ICA or middle cerebral artery (MCA). Nevertheless, this technique survived in other treatment indications as complex or giant aneurysms and Moyamoya disease. The technique has been even proven to be safe and useful in a specific subgroup of patients with severe chronic hemispheric hypoperfusion and recurrent stroke despite aggressive medical management.

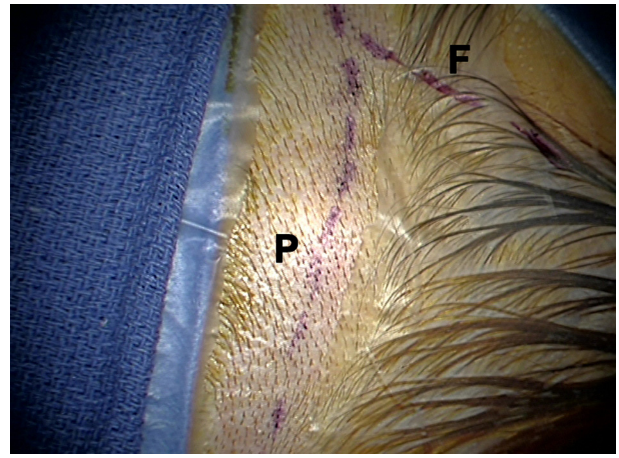

Fig. 1. Patient preparation (left side): shaving and skin marking along the frontal (F) and parietal (P) branches of the superficial temporal artery (STA) is performed guided by a mini-Doppler.
Le rasage et le marquage cutané son réalisés en fonction du trajet des branches frontale (F) et pariétale (P) de l'artère temporale superficielle repérées au doppler (côté gauche).

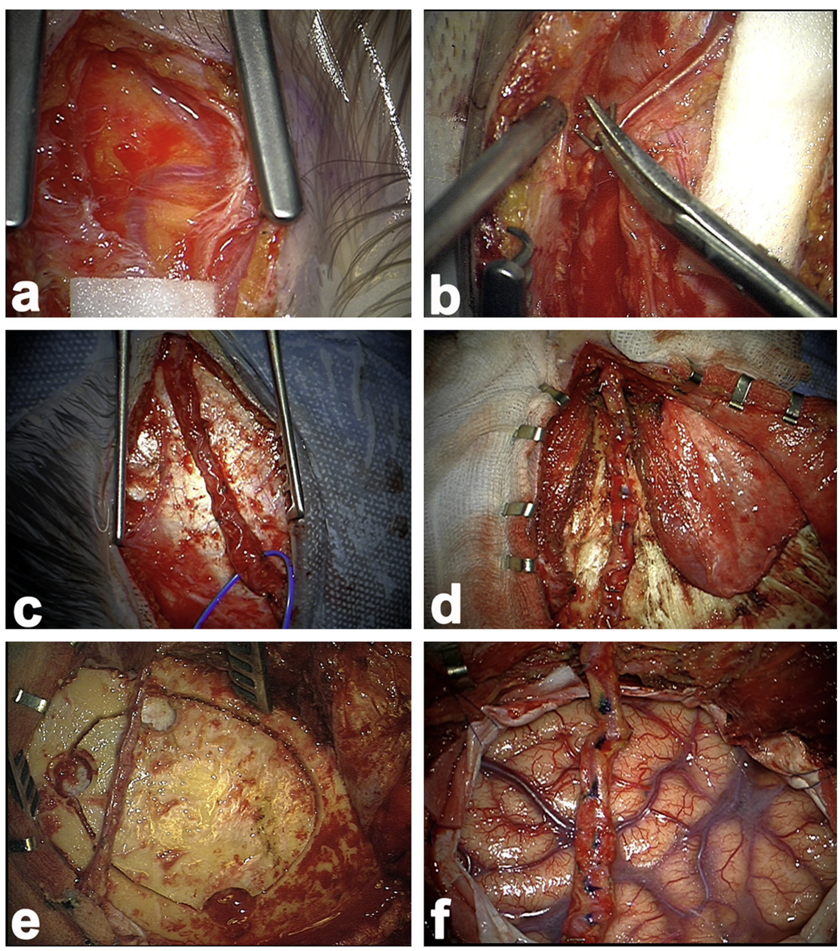

Fig. 2. Harvesting of the superficial temporal artery: a: individualization of the superficial temporal artery (STA) under microscope magnification; b: clipping and division of a collateral branch; c: the STA is exposed along 8 to 10 cm and freed from the periosteum; d: a T-like incision of the temporal muscle is performed along the course of the STA and the muscle is then retracted on both sides; e: a circular craniotomy is performed in projection of the sylvian fissure; f: the dura is opened in a cross-like fashion and the STA colored on its upper surface.
Prélèvement de l'artère temporale superficielle : a : dissection sous microscope opératoire de l'artère temporale superficielle ; b : clippage et section d'une branche collatérale ; c : l'artère temporale superficielle est exposée sur 8 à 10 cm et libérée du plan périosté ; d : le muscle temporal est incisé verticalement en T le long du trajet de l'artère temporale superficielle puis désinséré de la voûte ; e : une craniotomie circulaire est réalisée en regard du trajet de l'artère temporale superficielle et en projection de la vallée sylvienne ; f : la dure-mère est ouverte de façon cruciforme avec un trait de refend vertical inférieure en prévision du passage de l'artère temporale superficielle dont la face supérieure est ici marquée au bleu de méthylène pour détecter les torsions.

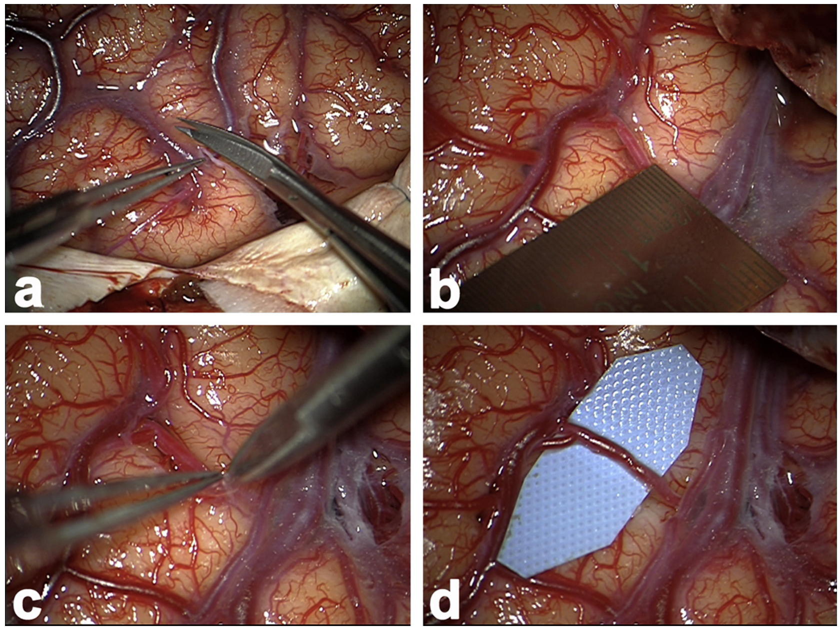

Fig. 3. Cortical recipient artery preparation: a: the arachnoid is widely opened; b: a MCA (M3 or M4) collateral branch is selected; c: the recipient artery is freed from its arachnoid adherences and its small collaterals are divided; d: a plastic background is applied underneath the artery to ease vessel manipulation and suturing.
Préparation de l'artère corticale receveuse : a : l'arachnoïde est largement ouverte ; b : une branche artérielle de division de l'artère cérébrale moyenne (M3 ou M4) est sélectionnée ; c : l'artère receveuse est libérée de ses adhérences arachnoïdiennes et ses fines collatérales sont interrompues ; d : un arrière plan plastifié est disposé sous l'artère receveuse corticale.

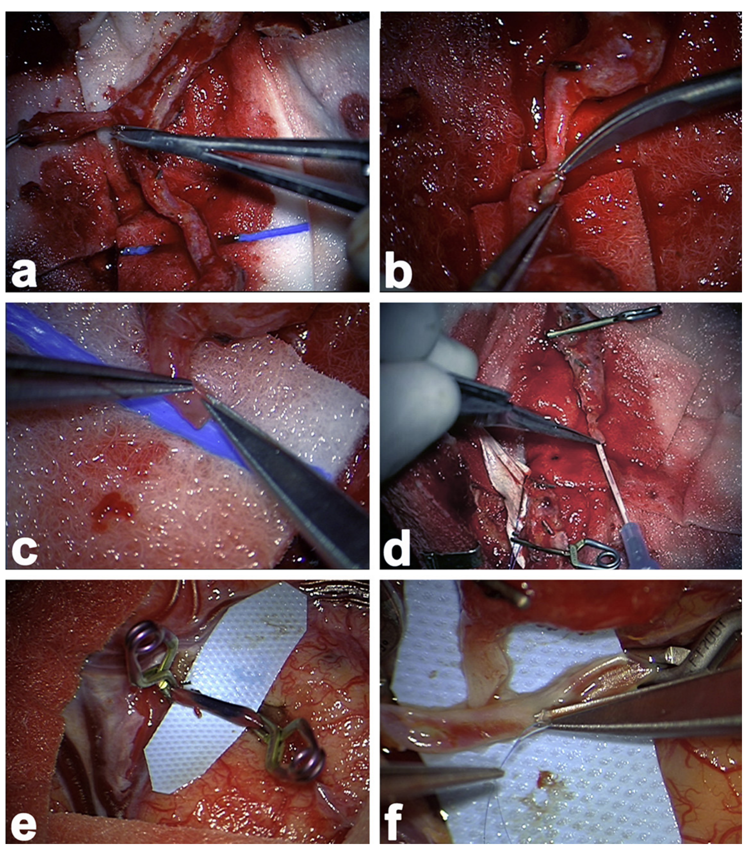

Fig. 4. Microsurgical anastomosis preparation: a, b: the appropriate length of the donor vessel is calculated and redundant tissues around the superficial temporal artery (STA) are resected along its last 10 mm; c: the STA is obliquely cut and only a thin adventitial layer is left at the future anastomotic site; d: the STA is retrogradely flushed with heparinized saline and then temporary clipped; e: the arteriotomy area is marked and the recipient artery is temporary clipped; f: the STA length is verified and the arteriotomy is performed on the recipient vessel by puling its outer wall with a 10.0 traction.
Préparation de l'anastomose microchirurgicale : a, b : la longueur utile d'artère temporale superficielle est définie et les tissus surnuméraires sont réséqués sur 10 mm en regard de la future extrémité ; c : l'artère temporale superficielle est sectionnée à 45° et seule une très fine couche d'adventice est laissée à son extrémité ; d : l'artère temporale superficielle est purgée à rétro au sérum hépariné puis clampée ; e : la zone d'artériotomie est marquée au bleu de méthylène et l'artère corticale est clampée ; f : la longueur de l'artère temporale superficielle est vérifiée pour une suture sans tension et une artériotomie losangique est réalisée sur l'artère receveuse à l'aide d'un point de traction au fil 10.0.

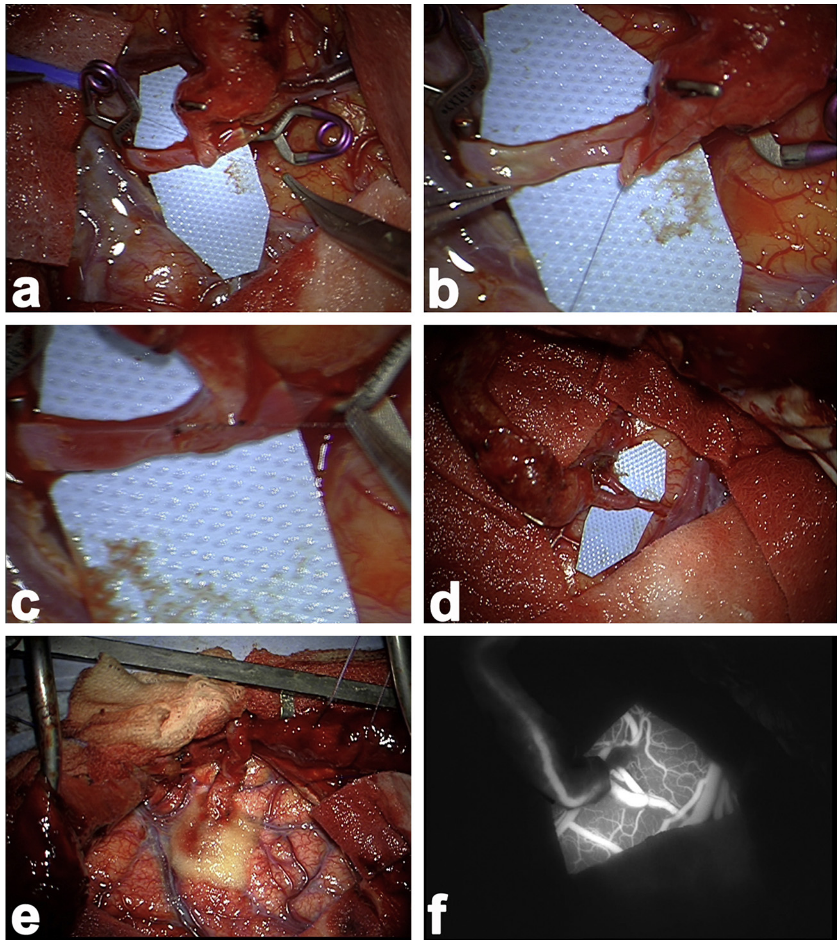

Fig. 5. Microsurgical anastomosis: the heel (a) then the toe (b) of the superficial temporal artery (STA) end are attached with two 10.0 Prolene® sutures; c: the first half-running suture is performed on the less accessible side and the second one is tightened after having checked for the presence of anterograde and retrograde flow through the recipient vessel and having flushed air bubbles and clots from the anastomotic site; d: final view of the bypass; e: Floseal® application to reinforce water-tightness of the suture; f: intraoperative indocyanine green video angiography (Pentero II microscope, Flow 800 software, Zeiss®) confirming good patency and flow through the bypass.
Anastomose microchirurgicale : le talon (a) puis la pointe (b) de l'extrémité de l'artère temporale superficielle sont fixés par un point de Prolène 10.0® ; c : après avoir réalisé un premier hémi-surjet sur la face la moins accessible, le deuxième hémi-surjet est achevé et serré après avoir purgé l'air et vérifié la présence d'un flux rétrograde et antérograde dans l'anastomose ; d : vue finale de l'anastomose ; e : renforcement des hémostases par application de Floseal® ; f : vidéoangiographie au vert d'indocyanine (microscope Pentéro II, Flow 800®) confirmant la bonne perméabilité de l'anastomose.

2. Anesthetic considerations [2,8,14,16,17]

In patients with pre-existing severe cerebral hypoperfusion when treating this type of revascularization procedure, it must be remembered that important alterations of cerebrovascular reactivity are present (maximal dilatation of the vascular bed) which are often associated with an absent or impaired cerebrovascular reserve. Due to these anomalies, any physiological stress, such as acute hypotension or major variations in capnia can induce severe changes in regional cerebral perfusion leading to a secondary stroke. It is therefore fundamental to maintain, from induction to extubation of the patient, a perfect stability of arterial blood pressure (corresponding to the patient's usual range), usually monitored by an invasive method and permanent normocapnia (35–40 mm Hg).

In each case, during the temporary clipping of the cortical recipient vessel, the arterial blood pressure should be elevated by 10 mmHg or 20% from basal values and burst-suppression (pentothal) should be induced in order to minimize the risk of secondary ischemia.

The treatment of these patients involve the periprocedural management of antiagregant and anticoagulant treatment used to reduce the risk of thrombosis of the donor vessel or of the anastomosis. Although there is no clear consensus, most teams introduce antiagregant treatment (acetylsalicylic acid 75 mg daily) 10 days prior to surgery (except in the case of ruptured giant aneurysms), 300 mg daily for the first following week and then 75 mg daily for life. Heparin is only used during surgery (except if a ruptured giant aneurysm is not secured) and at the time of temporary proximal occlusion of the donor vessel (STA) with a single moderate dose (2000 to 3000 non-fractioned heparin units). Spontaneous normalization of coagulation should be assessed at the end of the procedure before reintroducing antiagregant treatment.

3. Patient preparation and positioning [2,8,14,16,17,19]

A standard preoperative asepsis protocol should be applied. Head positioning in the Mayfield® or Sugita® clamp should aim at guiding the fronto-pterional region horizontally, the vertex slightly facing downward in order that the operative fluids flow away from the anastomotic site, or at least more horizontally than for a conventional fronto-pterional approach, in order to ease the anastomosis phase of treatment in the case of a giant aneurysm. A mini-Doppler is very useful to locate and draw the course of STA branches under the scalp (Fig. 1) and hair shaving can then be extended anteriorly to allow a large skin flap. No preincison or

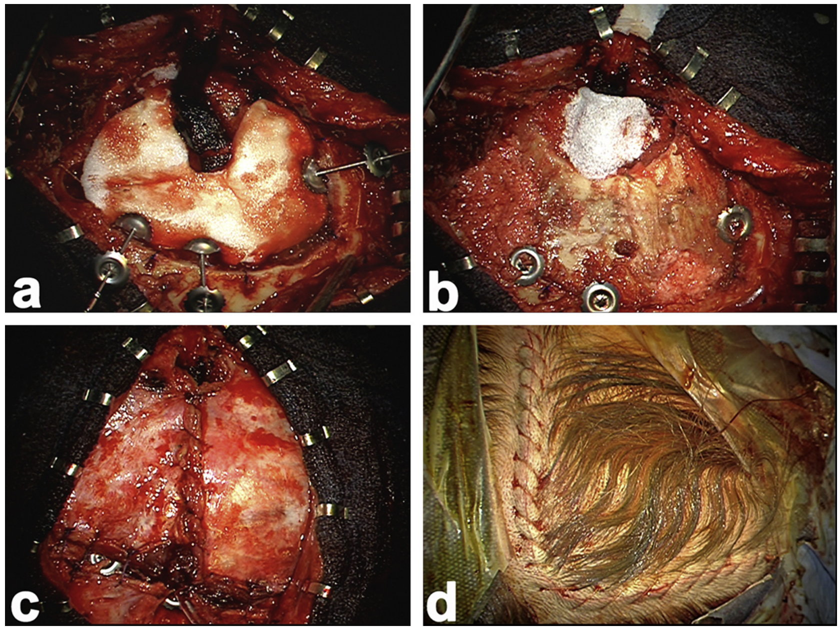

Fig. 6. Surgical approach closure: a: the dura is incompletely closed to allow the entrance of the superficial temporal artery (STA); b: the lower margin of the bone flap is resected and reattached with several Craniofix® (B Braun aesculap); c: the temporal muscle is incompletely closed at its lower part; d: skin closure.
Fermeture de la voie d'abord : a : la dure-mère est fermée de façon non étanche pour laisser passage à l'artère temporale superficielle à sa partie inférieure ; b : le volet qui a été encoché largement à sa partie basse est fixé par un dispositif d'ostéosynthèse crânienne (Craniofix® B Braun) ; c : le muscle temporal, incisé en T, est suturé en laissant une large ouverture à sa partie basse pour l'artère temporale superficielle ; d : l'incision cutanée est fermée en deux plans en prenant garde à la partie basse au greffon d'artère temporale superficielle.

xylocain/adrenalin infiltration is performed in order to avoid STA branch injury or spasm. An armrest is installed to stabilize the surgeon's hands during micro-suturing.

4. Surgical tools [2,14,16,17]

This procedure requires some specific microsurgical instruments: micro-forceps (Dumont n° 5), micro-needle-holder and curved micro-scissors, dissection scissors (Cotrel or Stevens), micro-bipolar forceps, mini-temporary clips (Yasargil clip FT 200T, B Braun Aesculap), mini-vascular clips. The microsurgical anastomosis is performed with non-absorbable microsutures: 10.0 Ethylon® or 10. 0 Prolene®. Heparinized saline and papaverin should be prepared at the beginning of surgery.

5. Superficial temporal artery harvesting [2,6,8,9,13,14,16,17,19,20]

Surgery starts under microscopic magnification with the harvesting of the STA (usually the parietal branch) along its course previously marked using the mini-Doppler (Fig. 2a). This artery is about 1.93 mm (± 0.48) mean diameter. A focal skin incision is usually performed right on the middle of the artery location and is then extended on both sides with a dissecting scissors. The STA can also be individualized from the inside of the skin flap if the skin incision is performed more posteriorly. The artery is progressively isolated and its collaterals clipped or coagulated and divided (Fig. 2b). Arterial vasospasm is avoided by leaving a conjunctive cuff around the artery and regularly irrigating it with papaverin saline. The proximal bifurcation should be exposed to allow full mobilization of the donor artery or to interrupt the frontal branch and improve flow into the donor parietal branch. The continuity of the frontal branch could initially be preserved in order to keep the proximal trunk of the STA patent during temporary clipping of the parietal branch or to retrogradely flush the anastomosis. The superior surface of the donor vessel should be colored to detect any secondary twisting. The donor artery is then left intact until final anastomosis (Fig. 2c).

The skin incision can be prolonged anteriorly to perform a larger skin flap and if necessary a conventional fronto-pterional bone flap. The temporal muscle is sectioned vertically along the projection of the STA and then retracted on both sides (Fig. 2d). A large craniotomy is performed in the fronto-pterional region (giant aneurysm) or above the sylvian fissure (Fig. 2e), the hypoperfused area diagnosed on PET or SPECT or a recipient vessel detected on preoperative MRI in the cases of Moyamoya disease or carotid/MCA occlusion patients.

6. Recipient artery preparation [2,8,9,13,14,16–21]

The dura is tacked to the bone flap margins and usually opened in a cross fashion to allow wide exposure of the cortical arteries (Fig. 2f). In the particular case of Moyamoya patients, attention should be paid not to interrupt pre-existing meningo-cortical feeders detected on preoperative external carotid angiography.

The arachnoid is often thick (i.e. Moyamoya disease patients) and it is recommended to open it widely above the sulci to optimize secondary development of neovascularization. This stage is also useful to identify the most appropriate cortical vessel (Fig. 3a).

The recipient artery is usually a distal branch of the MCA (M3 or M4). Its selection relies on several parameters: accessibility, caliber, proximal and distal vascular bed. The opercular or cortical branch is most frequently chosen with a diameter of at least 1 mm (in general > 0.5 mm) (Fig. 3b). According to Kawashima et al. [20], the caliber of cortical arteries decreases as follows: frontal branch 1.19 mm (± 0.32) < temporal branch 1.22 mm (± 0.23) < parietal branch 1.36 mm (± 0.24), the larger artery being the angular artery. A more proximal branch (M2) with a larger diameter (1.76 mm ± 0.36) could be selected in cases of a large STA or for total replacement procedures of MCA flow (proximal complex or giant aneurysm). If possible a non-functional branch should be chosen and prepared along with an appropriately oriented segment producing few collaterals. The recipient artery is individualized by cutting its arachnoid adherences, coagulating and dividing its collaterals along at least one centimeter (Fig. 3c). A

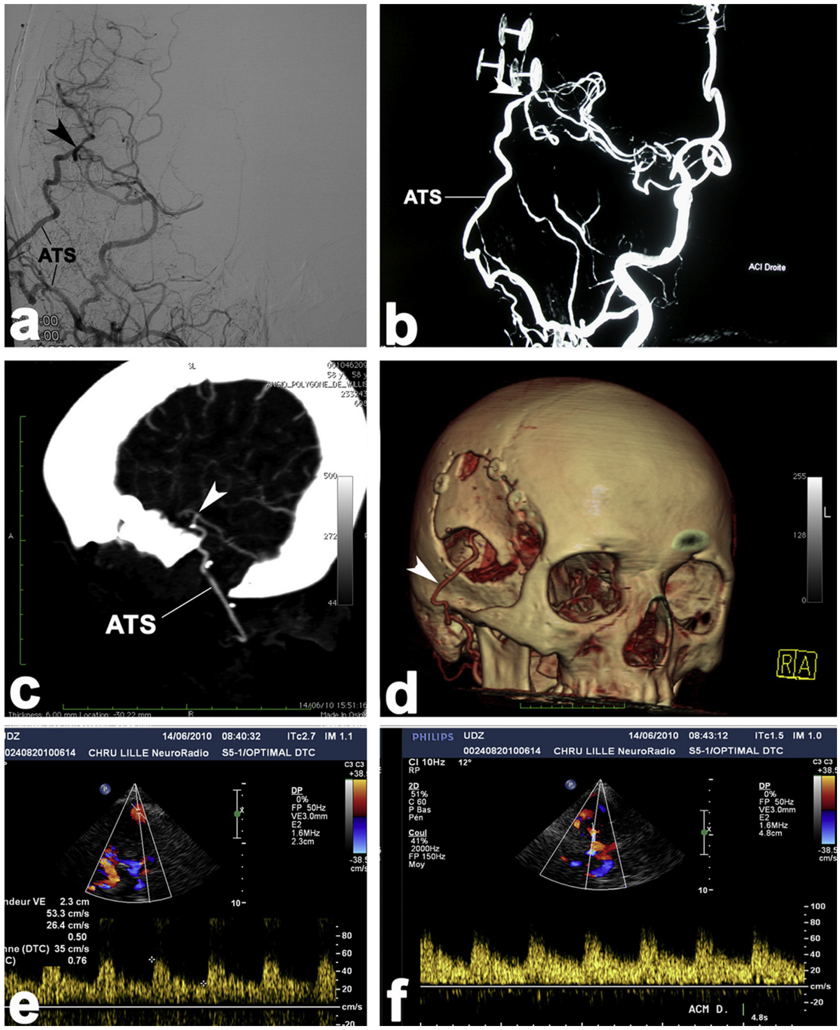

Fig. 7. Postoperative assessment of a right superficial temporal artery to the middle cerebral artery (STA-MCA) bypass: a, b: right external carotid artery angiography (a) and three-dimensional reconstruction showing the STA (ATS) and the anastomosis site (arrow); c, d: sagittal view from a postoperative CTA (c) showing the STA (ATS) and the anastomosis site (arrow) and three-dimensional reconstruction (d) showing the STA (arrow) coursing through the craniotomy opening; e, f: transcranial Doppler with contrast confirming appropriate flow in the donor STA (60 cm^3/min) (e) and recipient MCA distal branches (f).

Contrôle postopératoire d'une anastomose temporo-sylvienne droite : a, b : artériographie carotidienne externe droite (a) et reconstruction tridimensionnelle montrant l'artère temporale superficielle (ATS) et la zone d'anastomose (flêche) ; c, d : angioscanner cérébral en coupe sagittale (c) montrant l'ATS et la zone d'anastomose (flêche) et reconstruction trimensionnelle (d) montrant l'artère temporale superficielle (flêche) passant dans l'ouverture de la craniotomie ; e, f : échodoppler transcranien avec contraste montrent la présence d'un flux satisfaisant (60 cm^3/min) dans l'artère temporale superficielle (e) et dans les branches distales de l'artère cérébrale moyenne (f).

plastic background is then opposed underneath the cortical artery so that it can be protected under a cottonoid impregnated with papaverin saline (Fig. 3d).

7. Microsurgical anastomosis [2,6,8,9,13,14,16,17,19,20,22]

The length of the STA segment is calculated in order to perform a tension-less suture as well as to avoid a redundant artery that would favor secondary twisting. The distal end of the donor segment is prepared along its last 5 to 10 millimeters. Conjunctive and adventitial tissues are removed (Fig. 4a and b) until squeletonization of the artery leaving a very thin adventitial layer (Fig. 4c). The distal end is then obliquely cut at 45° ("fish-mouthed") in order to enlarge the anastomotic surface (Fig. 4c, f). The STA is temporary clipped after being flushed and filled with heparinized saline (2.000 to 3.000 UI) (Fig. 4d). Collateral water-tightness is then checked under clamping.

When ready for micro-suturing, the recipient vessel is occluded using two mini-clips (Fig. 4e). The arteriotomy length is chosen according to the size of the STA extremity: 2 to 3 times the arterial diameter. This area could be colored to improve visualization of the outer arterial wall (Fig. 4e). The arteriotomy is performed in a diamond-shaped fashion with micro-scissors while pulling the outer arterial wall with micro-forceps or a 10.0 traction (Fig. 4f). The arterial lumen is irrigated with heparinized saline and picking of the inner wall (intimal layer) with the micro-forceps is avoided during the procedure, the micro-forceps being used as counter-pressure for the needle during suturing.

After having checked for arterial twisting, the STA end is attached by its heel (Fig. 5a) then its toe (Fig. 5b) using two 10.0 stitches, ideally from the inside to the outside of the recipient vessel in order to avoid intimal dissection at both extremities of the anastomosis. Good patency of the recipient artery extremities can be assessed with a smooth stylus. Both margins of the anastomosis are then closed with 8 to 10 interrupted or 2 half-running 10.0 sutures, the needle being driven perpendicularly (90°) to the arterial wall (Fig. 5c). Initial suturing will start on the less accessible side and could be checked from the inside before closing the other side. Before final closure, the donor and recipient artery are flushed by shortly releasing the temporary clips. The final stitch being tightened, the cortical artery is first distally then proximally unclamped to evaluate anastomosis water-tightness (Fig. 5d). If a significant leakage is identified, a complementary stitch should be added. Conversely, if only limited bleeding is observed, application of an absorbable gaze (Surgicel®) or a hemostatic gel (Floseal®) (Fig. 5e) will complete water-tightness. Good functioning of the anastomosis can be assessed at the end of the procedure by performing an intraoperative video angiography (Pentero II Flow 800, Zeiss®) (Fig. 5f), by using a mini-Doppler or a debimeter (HT331, Transonic®).

8. Closure of the surgical approach [2,8,13,14,16,17,19]

The inferior branch of the dural opening is left unclosed and even enlarged at its lower end in order to insure the entrance of the STA without any stenosis (Fig. 6a). In the particular case of Moyamoya disease, dural flaps are reversed at the margins of the craniotomy and a periosteal and/or a muscular flap can be applied on the cortex in order to favor postoperative neoangiogenesis (encephalo-duro-myo-synangiosis).

The lower margin of the bone flap itself is widely resected to avoid compression of the donor vessel (Fig. 6b) and is then attached in a proper fashion. The temporal muscle can be closed except at its lower part for similar reasons (Fig. 6c). Conventional skin closure is performed, being careful not to injure the donor vessel by suturing too deep at the lower end of the incision (Fig. 6d).

9. Postoperative care and follow-up [2,7,8,13,14,16,17,19,23]

A non-compressive conventional head bandage is applied and direct lying on the bypass side is avoided for a few days. After the patient is fully awake and coagulation is spontaneously normalized, aspirin is reintroduced at 300 mg daily the first week and 75 mg thereafter. Patient monitoring in the intensive care unit is performed during the first 24–48 hours.

Bypass patency and flow could be postoperatively assessed with cerebral angiography (Fig. 7a and b), or non-invasively with computerized tomography angiography (Fig. 7c and d), transcranial Doppler (Fig. 7e and f) or MRA.

10. Conclusion [2,7–9,12,16,17]

STA-MCA bypass is a technique that allows flow augmentation in the MCA territory (mean flow 50–80 cm^3/min) and is fully indicated for the treatment of chronic and symptomatic hemispheric hypoperfusion states (Moyamoya disease, ICA or MCA occlusions). When methodically performed, it is associated with a high rate of patency (superior to 90%) and low morbi-mortality (about 3% and 1% respectively). In giant or complex aneurysmal treatment, it would be helpful to maintain or replace the flow in the main artery or one of its collateral vessels that otherwise would have been sacrificed. Nevertheless, when the artery carrying the aneurysm is large (ICA, proximal MCA) and cannot be preserved, a high-flow bypass with interposed saphenous or a radial graft is sometimes required in order to insure appropriate distal brain perfusion.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

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