Superficial-Temporal-Artery-To-Middle-Cerebral-Artery Bypass in Cerebrovascular Occlusive Disease and Hemodynamic-Related Ischemia: Illustrative Case and Literature Review

Bypass STA-MCA para doença cerebrovascular oclusiva e isquemia hemodinâmica: Caso ilustrativo e revisão da literatura

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Abstract

Stroke is the third most common cause of death worldwide. About 10% to 15% of strokes related to the territory of the carotid artery are associated with its complete occlusion. There is an important subgroup of patients with cerebrovascular occlusive diseases who might benefit from an external-carotid-to-internal-carotid bypass. In the present study, we report a case of a 53-year-old male patient with stenosis of the M2 branch of the middle cerebral artery (MCA), with a history of ~20 episodes of transient ischemic accidents (TIA)s, in whom an anastomosis of the M4 branch of the superficial temporal artery-MCA was performed. The patient was discharged in three days, and in the two years of follow-up, they were no more TIAs. We also conducted a review of the literature on cerebrovascular occlusive disease and extracranial-intracranial bypass surgery. New methods to evaluate cerebral hemodynamics made it possible to classify a new subgroup of patients with symptomatic cerebrovascular disease and documented cerebrovascular compromise in whom the drug therapy fails, who can benefit from the extracranial-intracranial bypass. Our case report illustrates the advantages of revascularization in these selected patients.

Keywords

- ► extracranial-intracranial bypass
- ► middle cerebral artery
- ► superficial temporal artery
- ► microvascular anastomosis
- ► cerebrovascular occlusive disease

Resumo

Acidentes vasculares cerebrais (AVC) são a terceira causa de mortalidade mundialmente. Entre 10 e 15% dos AVCs relacionados à artéria carótida estão associados com sua oclusão completa. Há um subgrupo importante de pacientes com doenças cerebrovasculares oclusivas que podem se beneficiar de um by-pass carótida-externa-carótida-interna. Neste

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estudo, reportamos o caso de um homem de 53 anos com estenose do ramo M2 da artéria cerebral média, com história de 20 acidentes isquêmicos transitórios (AIT), que foi tratado com anastomose de M4 com a artéria temporal superficial. O paciente foi de alta no terceiro dia pós-operatório e, em dois anos de follow-up, não houve mais AITs. Também conduzimos uma revisão da literatura sobre doença cerebrovascular oclusiva e by-pass intra-extracraniano. Novos métodos para avaliar a hemodinâmica cerebral tornaram possível a classificação de um novo subgrupo de pacientes com doença cerebrovascular sintomática em quem a terapia medicamentosa falhou, que podem se beneficiar de um by-pass intra-extracraniano. Nosso relato de caso ilustra as vantagens de revascularização em pacientes selecionados.

Introduction

Stroke is the second most common cause of death around the world, according to World Health Organization (WHO).[1] About 10% to 15% of strokes related to the territory of the carotid artery (CA) are associated with complete CA occlusion, which means, in the United States, an estimated 61 thousand patients with first-ever strokes, and 19 thousand patients every year with transient ischemic accidents (TIAs) associated with complete CA occlusion.[2] With the advent of different diagnostic imaging methodologies that enable the study of cerebral hemodynamics, an important subgroup of patients has emerged. This cluster is composed of subjects in maximal medical therapy with hemodynamic compromise and symptomatic cerebrovascular occlusion disease ipsilateral to the occlusion. This group might benefit from external-CA-to-internal-CA bypass since their annual risk of stroke is $\sim$ 10% to 14% against 4% to 6% in those with preserved cerebral vasomotor reactivity.[3,4] The present article aims to discuss the surgical approach in these cases through an illustrative case and a short review of the literature.

Illustrative Case

A 53-year old male was found to have a stenosis of the M2 segment of the middle cerebral artery (MCA) on cerebral angiography. His past medical history accounted for $\sim$ 20 episodes of TIAs with right-sided facial-brachial hemiparesis and aphasia events. He also had controlled diabetes and hypertension, and was in dual-platelet anti-aggregation therapy. An anamostosis of the M4 branch of the superficial temporal artery (STA) was performed to increase the blood flow in the MCA territory. The patient was discharged in three days, and, in the two-year follow-up, there were no more TIAs. ►**Fig. 1** shows the pre- and postoperative arteriographies.

Surgical Technique

Under general anesthesia and intraoperative monitoring with an electroencephalogram and somatosensory evoked potentials, the patient is put in the supine position, with the head tilted to contralaterally to the craniotomy and fixed with the Mayfield three-point head holder. For patients with restriction of lateral neck rotation, a rolled blanket is put under the ipsilateral shoulder. The Doppler examination helps locate the branches of the STA on the scalp. Unless angiography or magnetic resonance angiography (MRA) shows a larger frontal branch, the posterior branch is chosen. The frontal branch must be used in cases of atresia of the parietal branch, previous craniotomy with a lesion to the parietal branch, or anterior-branch dominance.

An incision is made along the delineated course of the greater branch of the STA, extending from the preauricular region superiorly and then curved anteriorly. If the anterior branch is chosen, the surgeon must consider the fact that fibers of the superior division of the facial nerve can be crossing the region, and that this branch is anterior to the hairline. An

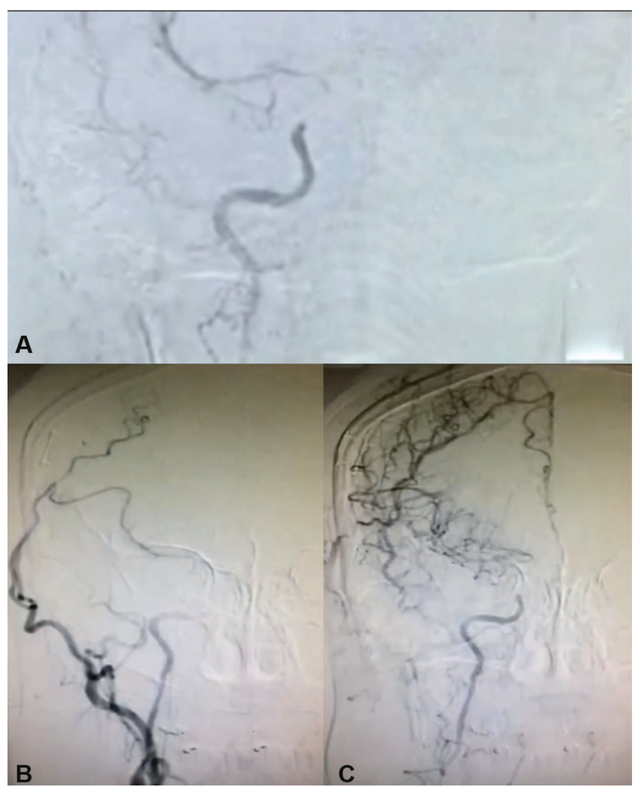

Fig. 1 Pre- and postoperative arteriography. (**A**) Preoperative arteriography showing significant occlusion of the internal carotid artery. (**B and C**) Postoperative arteriography showing significant reperfusion from the superficial temporal artery-middle cerebral artery (STA-MCA) bypass.

option in such cases is direct dissection over the artery or "from the underside of the scalp flap distally".[5]

After choosing the branch, the incision is deepened under magnification into the subcutaneous layer, where the STA branches run. Most commonly, the posterior branch is identified and followed to its origin using sharp dissection under microscope magnification. It is crucial to preserve the tissue adjacent to the vessel, except for the site used in the anastomosis (including the tip in which the adventitia is dissected) (►**Fig. 2A**).

Craniotomy is started by cutting the temporalis muscle, dissecting it with Bovie electrocautery, and fixing it with retractors. Following the exposure of the underlying bone, two burr holes are made, and the craniotomy is performed using a drill. Afterward, the dura is opened in a curvilinear fashion and tacked around the margins of the craniotomy to avoid postoperative epidural hematoma. The cortical branch of the MCA is chosen based mainly on the size of the vessel ($\geq$ 1.5 mm is ideal). To facilitate the procedure, the site of anastomosis must be located far from the borders of the craniotomy, and the vessel must be oriented tangentially.

After establishing the cortical branch that will be used, attention is redirected to the STA. The tip of the artery is dissected and cut in a sharp fashion (►**Fig. 2B**). The surrounding fascia of the adventitia is stripped out only on the border side of the anastomosis. It is not recommended to dissect all of the vessel's extension because it is not helpful, and there is an increased risk of injury. A small microclip is placed proximally to the stump of the artery, which is then directed down into the level of the isolated cortical branch.

The anastomosis site of the STA is cut at a 45° angle. The proximal clip is removed to check the free flow through the end of the vessel. Then, an arteriotomy is performed on the cortical branch using sharp microscissors. The edges of both sides of the anastomosis are marked with a marking pen to highlight the lumen. At this moment, the lumen of the STA must be inspected to observe the conditions of its margins.

Temporary clips are placed proximal and distal to the site of the anastomosis in the cortical vessel, which receives an incision with the same length as that of the STA diameter. Under further magnification using the microscope, the anastomosis is performed using 10–0 sutures, with approximately 6 interrupted sutures in an end-to-side fashion preceded by anchoring sutures. To reduce injury to the endothelium of the vessel, the suture is passed through the recipient vessel from the inside out (►**Fig. 2C**). Subsequently, the hemostatic clips are removed from both the proximal and distal aspects of the cortical vessels, and then the ones in the superficial temporal artery are also removed. A small piece of absorbable hemostat is wrapped around the anastomosis site (►**Fig. 2D**). At this stage, papaverine is applied at the suture line for hemostasis (►**Fig. 3**).

The Doppler is used to confirm the patency of the STA branch, which must pulse along with the rest of the anastomosis. Currently, we are using the cut flow index for evaluation.

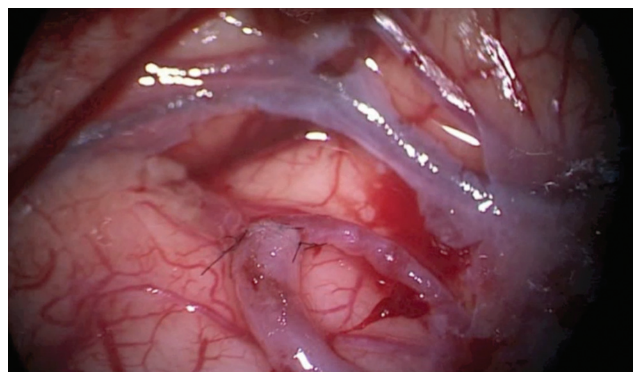

Fig. 3 Final aspect of the anastomosis: STA-MCA bypass.

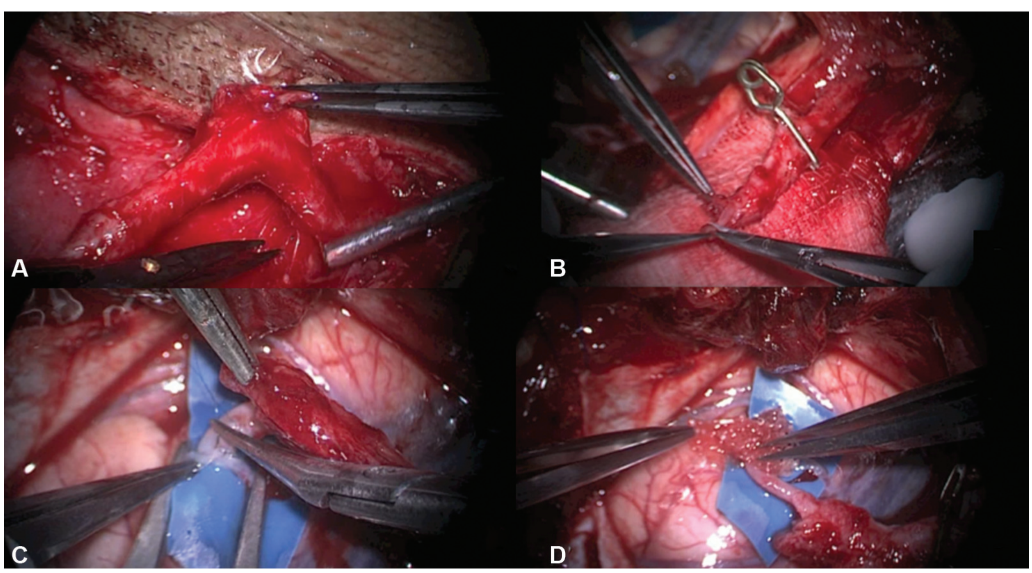

Fig. 2 Bypass preparation. (**A**) Dissection and preparation of the donor vessel, the STA. (**B**) Temporary clip placed in the STA. The vessel is then dissected and cut in a sharp fashion. The surrounding fascia of the adventitia is stripped out only in the border side of the anastomosis. (**C**) The anastomosis is performed using 10–0 sutures with around 6 interrupted sutures in an end-to-side fashion preceded by anchoring sutures. To reduce injury to the vessel's endothelium, the suture is passed through the recipient vessel from the inside out. (**D**) A small piece of absorbable hemostat is wrapped around the anastomosis site. At this stage, papaverine is applied at the suture line for hemostasis.

Closure begins by approximating the dura and applying Gelfoam (Upjohn, Kalamazoo, MI, US) to the epidural space. The bone flap is trimmed to allow a window for the entrance of the STA into the intracranial cavity. The bone is placed in position and held in place using miniplates. The temporal muscle is then approximated loosely without constriction around the pedicle of the STA. To optimize flow through the anastomosis, the unused branch of the STA is ligated. The scalp is closed using 2–0 Vicryl (Ethicon, Somerville, NJ, US) in an interrupted inverted fashion, approximating the subcutaneous tissue to the galea.

Literature Review

Historical Background

Nicholls et al.[6] concluded that unilateral CA occlusions are mainly associated with cases of ipsilateral strokes (25%) and ipsilateral TIAs (16%). Cote et al.[7] reported that, over 34 months, patients with occlusion of the internal carotid artery (ICA) with no or mild neurological deficit have an overall stroke risk of 15% – similar to that of patients suffering from TIAs or minor strokes –, and 63% of these strokes were ipsilateral to the occlusion. In patients with CA occlusion and contralateral stenosis, Hammacher et al.[8] documented a rate of stroke of 33% to 40% per year. For those patients with symptomatic CA occlusion confirmed angiographically, a 5.9% yearly risk of ipsilateral stroke was described by Hankey and Warlow.[9]

Professor M. Gazi Yaşargil,[10] a pioneer in cerebrovascular anastomosis, started to perform this procedure in dogs, and later published his results on human patients.[11,12] The technique was widely propagated, but there was no proof of the procedure's efficacy in preventing new strokes.

In the 1980s, the EC/IC Bypass Study Group[13] also failed to confirm whether the surgery was effective in preventing ischemic events in patients with atherosclerotic arterial disease in the CA or MCA territory. After that, extracranial-intracranial (EC-IC) bypass has been restricted for cases of moyamoya disease and patients who need ICA occlusion due to an unclipplable aneurysm or skull-base tumor.

Nonetheless, at the time when both studies were conducted, there was no physiological knowledge or a reliable and proven method to identify crucial hemodynamic factors that would enable the stratification of patients according to the risk of new ischemic events,[2,14–16] thus detecting a subgroup of patients that could benefit from the revascularization procedure.

Grubb Jr. et al.,[17] in the St Louis Carotid Occlusion Study (STLCOS), established that such subgroups could be identified through indirect assessments based on the brain's compensatory mechanisms regarding progressive reductions in cerebral-perfusion pressure (CPP). In the same study,[17] the authors also concluded that those patients with symptomatic CA occlusion and stage-II hemodynamic failure (decreased cerebral blood flow [CBF] with increased oxygen extraction fraction [OEF]) who were medically treated were at a higher risk for subsequent stroke.

Current Perspective

It is currently well known that a decreased CBF is generally unhelpful to detect the risk of future stroke because it cannot distinguish whether the cause of this reduction is an occlusive event or a compensatory physiological response due to reduced metabolic demands.[17]

On the other hand, the accuracy increases if activated studies are used, which means obtaining an initial measurement at rest and another after provision of a cerebral vasodilatory stimulus (with acetazolamide, hypercapnia, or physiological tasks). A reduced responsiveness of the CBF to these stimuli means that the capacity for compensatory vasodilation is exceeded, and there is an impaired cerebral vasomotor reactivity to the diminished CPP.

There are different methods to measure the cerebrovascular reactivity (CVR) indices, and thus estimate the risk of stroke, such as xenon computed tomography (XeCT) with and without acetazolamide,[18] positron-emission tomography (PET),[19,20] and transcranial Doppler flowmetry,[21] which is much less sensitive than XeCT.[22]

In subsequent series, Nussbaum and Erickson[23] were able to show improvement in patients with symptomatic cerebrovascular disease refractory to medical treatment submitted to EC-IC bypass surgery, and Charbel et al.[5] reported that careful attention to the technique could result in consistent success.

Recent Advances

Two recent multicentric randomized trials tried to validate the use of EC-IC anastomosis: the Carotid Occlusion Surgery Study (COSS),[29] in the United States, and the Japanese Extracranial to Intracranial Bypass Trial (JET).[30] The latter tested patients with XeCT, PET, or single-photon emission computed tomography (SPECT), while the former tested with PET.

The COSS was halted due to futility. The perioperative ipsilateral stroke rates were higher in the surgical group compared with the medical group. Moreover, the study concluded that the surgical treatment, in the selected patients, was not of clinical benefit. Still, later publications[24] showed that in two years the surgical group achieved high rates of bypass graft patency, improved cerebral hemodynamics, and much lower rates of recurrent ipsilateral ischemic stroke after the second postoperative day compared with medical group.[25] In a subsequent paper, the authors concluded that the majority of ischemic strokes that occurred in the postoperative period were not related to the bypass grafting but to hemodynamic fragility of the study population.[26]

The COSS was received with some criticism, primarily related to: 1) the unexpected low rate of stroke in the medical group[27,28]; 2) its semiquantitative method to measure the OEF ratio, which was different from the quantitative method applied in the STLCOS[27,29–31]; and 3) its clinical selection criteria, which included patients with a single ischemic event or those relatively neurologically stable.[27,28,32]

Nearly all of the ctiticismswere addressed by Powers et. al.[33] Still, as Esposito et al.[32] highlight that there are factors regarding the perioperative stroke rates that should have been debated, such as the lack of an established perioperative protocol for the COSS, or the recruitment requirements of the other health professionals involved in the study.

Table 1 Studies evaluating extracranial-intracranial bypass

Study	Year	Nº of patients	Hemodynamic cerebral ischemia eligibility criteria	Surgical group	Medical group	Primary end points per group	Primary end points	Remarks
EC/IC Bypass Study[13]	1985	1.377	—	663	714	Postrandomization occurrences of fatal and nonfatal stroke	Medical: 205 (29%) Surgical: 205 (31%)	1. The surgical group presented fatal and nonfatal stroke events earlier 2. Bypass patency rate of 96% 3. Lack of hemodynamic selection criteria
JET[34]	2006	196	3D quantitative blood-flow measurement in active study with acetazolamide	98	98	Major stroke or death in the two-year period after surgery	Medical: 14 (14,3%) Surgical: 5 (5,1%)	1. Able to show statistically significant benefit for the surgical group 2. No events in the first 30 postoperative days
COSS[29]	2011	195	Hemispheric OEF ratio in semiquantitative measurement	97	98	All cases of stroke and death within 30 days postoperatively, plus ipsilateral hemispheric stroke within 2 years	Medical: 20 (22,7%) Surgical: 20 (21%)	1.High rates of graft patency (98%) 2. OEF ratio improvement 3. On the surgical group, 14 of 20 events were ipsilateral stroke within 30 days postoperatively. Of these 14, 12 occurred in the first 2 days
CMOSS[31]	—	330*	CTP showing misery perfusion	165*	165*	Strokes or deaths occurring between randomization and the 30-day postoperative time point, plus ipsilateral ischemic stroke within 2 years postrandomization	—	1. Not published yet

Abbreviation: 3D, three-dimensional; COSS, Carotid Occlusion Surgery Study; CMOSS, Carotid and Middle Cerebral Artery Occlusion Surgery Study; CTP, computed tomography perfusion technique; EC/IC, extracranial-intracranial; JET, Japanese EC-IC Bypass Trial; OEF, oxygen extraction fraction.
Note: *Numbers proposed in the study design.

In contrast, the JET Study,[34] in a second interim analysis, affirmed that the surgically-treated group presented a lower incidence of stroke recurrence compared with those who had only been submitted to medical therapy. Nevertheless, in the published Kaplan-Meier curve, there were no deaths within the first month in the surgical group – which seems unlikely to occur, given that the perioperative morbidity and mortality rate was of 12% in the EC-IC Bypass Trial, and of 15% in the COSS.[25,32,35]

Later, a multicentric prospective cohort, the JET-2 Study,[30] compared a total of 132 enrolled patients with symptomatic cerebrovascular occlusive disease and mild-to-moderate hemodynamic impairment with the medical arm group of the JET Study. The objective was to determine the real threshold of CBF and CVR for subsequent ischemic events only among the medically-treated patients. The authors found that patients with rest CBF > 80% or CVR > 10% present a lower risk, and they thus concluded that this population is unlikely to benefit from the EC-IC bypass surgery.

Due to all the controversial results and doubts surrounding the latest studies, there are still questions concerning this subject. Therefore, another trial[31] is being conducted in China under registration code NCT01758614. All the aforementioned trials were synthesized in ►**Table 1**.

Assessing Bypass Function

Regarding the technique, there are several ways to assess bypass function transoperatively, such as observing the pulsations within the donor vessel subsequently to the anastomosis, intraoperative microvascular Doppler sonography, and intraoperative angiography. The observation is inaccurate, for it is highly subjective. The Doppler enables us to properly evaluate the site of anastomosis. However, the intraoperative angiography assessment of graft patency can increase the success of the EC-IC bypass not only because it enables physicians to assess the site of anastomosis but also the extent of reperfusion from the bypass.

Yanaka et al.[36] assessed the intraoperative angiography method in 42 STA-MCA bypass procedures. The imaging findings prompted two additional procedures, and there were no complications. However, there was no systematic comparison with an ultrasonography method.

Therefore, until a large clinical study compares, in long-term follow-up, both methods and proves superior results for angiography, we do not recommend such a procedure, because, while sonography is a rapid, noninvasive, sensitive, and easily performed method, cerebral angiography is a time-consuming, invasive procedure with cost-benefit limitations. Microvascular Doppler sonography, however, does not distinguish between a poor and a robust flow in the anastomosis.

Currently, a quick and straightforward method to predict graft success after EC-IC bypass is the cut flow index, through which a quantitative assessment of graft patency may be performed. This approach was a significant predictor of bypass patency in 51 review retrospective cases of EC-IC anastomosis.[37] Although our rates of patency had an excellent correlation with the Doppler sonography, we must consider that the cut flow index is a very reasonable method, and we have recently started to use it.

Concerning flap necrosis, Katsuta et al.[38] studied the relationship between cutaneous necrosis after STA-MCA bypass and surgical methods or risk factors. The authors found that postoperative necrosis and arteriosclerosis obliterans were related. In a univariate analysis, smoking was a statistically significant risk factor – but not in a multivariate analysis. All seven patients with necrosis were treated with the flap method. They concluded that: 1) arteriosclerosis obliterans in the lower extremities is probably the best predictor of postoperative cutaneous necrosis; 2) the cut-down method may be preferable in patients with arteriosclerosis obliterans or smokers. In the Katsuta et al.[38] series, one patient developed scalp necrosis.

Finally, microsurgical laboratory training is paramount. A technically-perfected microanastomosis begins in the microsurgical laboratory. The neurosurgeon who wishes to perform this procedure must understand that this is the first and most crucial step for the future outcome of their patients. The continuous exercises in vessels of the placenta and later in vessels of rats will indicate essential aspects to pay attention to, such as unwilling suture of the anterior and posterior wall of the vessel, traumatic lesion of the vessel that can be avoided by careful manipulation of the adventitia, asymmetry of the suture's borders, inappropriate tension of the suture, and others.[39] The surgeon will become apt only with hard training in the laboratory. Professor Yaşargil[10] recommended training anastomosis in the laboratory for at least three months.

Conclusion

The exact parameters to indicate the STA-MCA bypass in cerebrovascular occlusive disease have not been established yet. First, because the population addressed in the recent trials seems to be comprised of patients with a more stable neurological condition. Second, because these studies point to different results. Lastly, they were criticized due to possible methodological flaws. Therefore, there is still controversy about the indications and benefits of EC-IC bypass surgery, which could be elucidated by ongoing trials. As illustrated by our case, selected patients could significantly benefit from this approach

Conflict of Interests
The authors have no conflict of interests to declare.

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