

Directional multistage intraoperative microvascular Doppler in the hemilaminectomy surgical obliteration of spinal dural arteriovenous fistular

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ABSTRACT

Objectives: To present our experience with the use of microvascular Doppler measurement procedure in spinal dural arteriovenous fistula (sDAVF) surgery.

Patients and methods: All patients with sDAVF from March 2008 to March 2017 who consecutively underwent hemilaminectomy surgical obliteration with the assistance of microvascular Doppler were included. We reviewed patient records, radiological images, operative notes, microvascular Doppler files, as well as intraoperative videos

Results: During the study period, 7 patients with sDAVF underwent surgical treatment facilitated by microvascular Doppler. Microvascular Doppler measurement was performed in all enrolled patients. Doppler measurement was reliable to define direction and the value of the flow of sDAVF vessels in all cases, thereby determining the location of fistula and confirming its obliteration. During temporary clip occlusion, Doppler identified successful disconnection in all cases by detecting a disappearance of arterial spectrum flow as well as a significant flow drop in venous drainages between before and after clip. At the final stage of obliteration, disappearance of the arterial spectrum and a significant flow drop in venous drainages was detected in all cases. No microflow probe-induced sDAVF vessel injury was detected. Complete obliteration of sDAVF was achieved in all cases. No recurrence was recorded during follow-up.

Conclusion: Multistage intraoperative microvascular Doppler measurement proved to be a feasible, safe, repeatable, and reliable methodology to assist surgery in different phases of sDAVF obliteration. Further studies are needed to assess the impact of this approach on sDAVF patient outcomes.

1. Introduction

Vascular malformations of the spine represent rare clinical entities with profound neurological implications. As the most common type of spinal arteriovenous malformation [1–3], spinal dural arteriovenous fistular (sDAVF) is fed by a radicular artery and drains into medullary veins with an arteriovenous fistula located in the dura of the nerve root and/or adjacent spinal dura. It is characterized by venous hypertension which finally results in irreversible subacute necrotizing myelopathy [3,4]. The essence of treatment of sDAVF is successful identification and complete obliteration of the fistula without aggravating of the spinal cord venous drainage [5]. Once the sDAVF is restored after incomplete interruption or failed embolization, it doubles the difficulty to cure the lesion. Treatment options of sDAVF include endovascular treatment with occlusion of the fistula or microsurgical occlusion of the

fistula. Microsurgical occlusion has been demonstrated the most definitive treatment modality for sDAVF with lower recurrence [6,7]. Hemilaminectomy surgical obliteration seems to be the optimal choice of sDAVF in terms of the minimal invasion and low recurrence. However, exact identification of the fistula and exclusion of the resident filling after obliteration remain great challenge for the patients with sDAVF, especially in a limited surgical space.

Intraoperative assessment by microvascular Doppler is an established technique in cerebrovascular surgery [8–10]. However, there are little documents about the systematic application of microvascular Doppler in surgery for sDAVF. Here, we focus on seven cases with the diagnosis of sDAVF to verify the value of multistage intraoperative microvascular Doppler with regard to location, and obliteration control. Our aim was to assess the feasibility and reliability of the technique in sDAVF surgery.

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2. Material and methods or patient and methods

2.1. Patients and sDAVF

Data from patients with sDAVF who underwent hemilaminectomy surgical obliteration from March 2008 to March 2017 with the assistance of directional multistage intraoperative microvascular Doppler were analyzed. Such techniques are included on the institutional informed consent form, which are also routinely used in our department in vascular and oncologic surgery. Character of each sDAVF was defined according to the preoperative digital subtraction angiography (DSA) and magnetic resonance imaging (MR). Clinical symptoms were scored using the modified Aminoff Logue Grading Scale [11]. Intraoperative data on flow and direction were reviewed in all cases. The preoperative and postoperative (1 year after surgery) modified Rankin Scale (mRS) scores were compiled in all cases to assess patient outcome. Postoperative obliteration results were assessed by DSA.

2.2. Surgical procedures

All the sDAVFs were approached by hemilaminectomy according to the located level in the prone position. A midline skin incision and a unilateral approach to the vertebral lamina were performed in all patients. We opened the dura and then found the tortuous, anomaly vessels. According to preoperative angiography, we traced down from the vascular around the dura of the nerve root to the tortuous vessels on the surface of spinal cord via Doppler. Indeed, fistula localization was facilitated by detection of the appearance of both arterial and venous spectrum flow approaching the fistula point which was usually around the nerve root sheave. Fistula disconnection was confirmed by both disappearance of arterial spectrum flow and a significant flow drop in venous drainage. After confirming the fistula by temporary aneurysm clip, we disconnected the fistula by mini-aneurysmal clip or coagulating then cutting it. Watertight closure of the dura was achieved. No lumbar drain was used.

2.3. Intraoperative microvascular doppler measurements

For intraoperative Doppler, we used transcranial Doppler ultrasonography machines (Viasys Healthcare, USA) equipped with 20-MHz ultrasound probes (1 mm in diameter). Doppler measurements were performed (1) Before and after dural opening on all exposed vessel; (2) During temporary clip occlusion on the vessels when it was considered relevant; (3) After final obliteration, on venous drainage. In all cases, the Doppler assessment was performed; after that, the fistula was determined and disconnected. Our strategy of directional multistage intraoperative microvascular Doppler monitoring is illustrated in Fig. 1.

In all cases, both flow direction and value change were recorded. The values of bispectral-index (BIS), end-tidal carbon dioxide (ETCO₂) and mean arterial blood pressure (MAP) were also recorded to determine the stability of anesthetic conditions and thus the comparability of the measurements. Any possible vessel injury by a microvascular probe was recorded.

3. Results

3.1. Patients and sDAVF

Seven patients were enrolled in the study (Table 1); the mean age was 58 years (range, 41–71 years). No multiple fistulas were recorded in our series. The mean preoperative mRS score was 2. Patients presented with spastic paraparesis in two, bowel/bladder dysfunction in five, gait instability in three, lower-extremity Numbness in one patient. Two sDAVFs were located in lumbar level and 5 in thoracic level. Preoperatively, patients presented the modified Aminoff Logue Grading Scale grade 2 in one case, grade 3 in four cases, grade 5 in one, and

grade 6 in one patient. The mean latency from presentation of the symptoms to surgery was 14.7 months (Table 1). No sDAVF had been previously embolized.

3.2. Intraoperative doppler measurements

Intraoperative Doppler measurements are summarized in Table 2. The procedure was used feasibly and safely in all patients according to the diagram. No vessel injury by a microflow probe was detected.

- 1 Before and after dural opening, arterial feeder flow ranged from 3 to 20 mL/min, and median flow was 11 mL/min. Hypertensive venous drainage flow ranged from 2 to 18 mL/min with an obvious arterial spectrum flow, and median flow was 12 mL/min. In all cases, Doppler was able to discriminate between arterial feeders and hypertensive venous drainages, by indicating coexistence of arterial and venous spectrum flow as well as flow direction. This was particularly helpful to determine the location of fistula. In all cases, the measurement was helpful for understanding the sDAVF angioarchitecture by distinguishing between arteries and veins (flow direction) and guiding surgical planning (identification of fistula).
- 2 During temporary clip occlusion, it was helpful to determine the fistula to assure the successful obliteration of sDAVF. The flow of these venous drainages, measured in all cases before temporary clip occlusion, ranged from 2 to 18 mL/min. The drop of flow (less than 1 mL/min) in venous drainages after temporary clip was attributed to the successful obliteration of sDAVF. The arterial spectrum flow disappeared in venous drainages after temporary clip occlusion also provided evidences of complete obliteration occlusion and could help exclude supplementary insidious fistula which was undiagnosed before operation.
- 3 After obliteration, the final flow measurement in the venous drainages, showed flow data less than 1 mL/min values and the arterial spectrum flow disappeared in all cases.

3.3. Patient outcomes

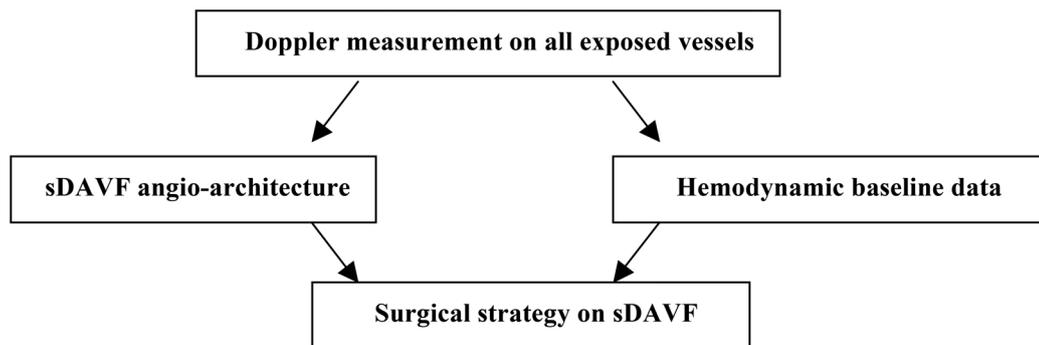
All sDAVFs were successfully obliterated evidenced by postoperative DSA. Long term follow-up (median interval of 47 months, range 12–96), showed that no recurrences were occurred. One patient (14.3%) had aggravation of neurological deficit with a mRS score 5 in 1 year after surgery, however, no evidence of recurrence was detected in the DSA at the same time. One patient (14.3%) remained neurologically stable and the other 5 patients (71.4%) clinically improved when compared to the pre-operative neurological status. A significant change of modified Rankin Scale score was observed, from a median of 2 (range 1–4) pre-operation to a median of 1.28 (range 0–5) post-operation.

4. Discussion

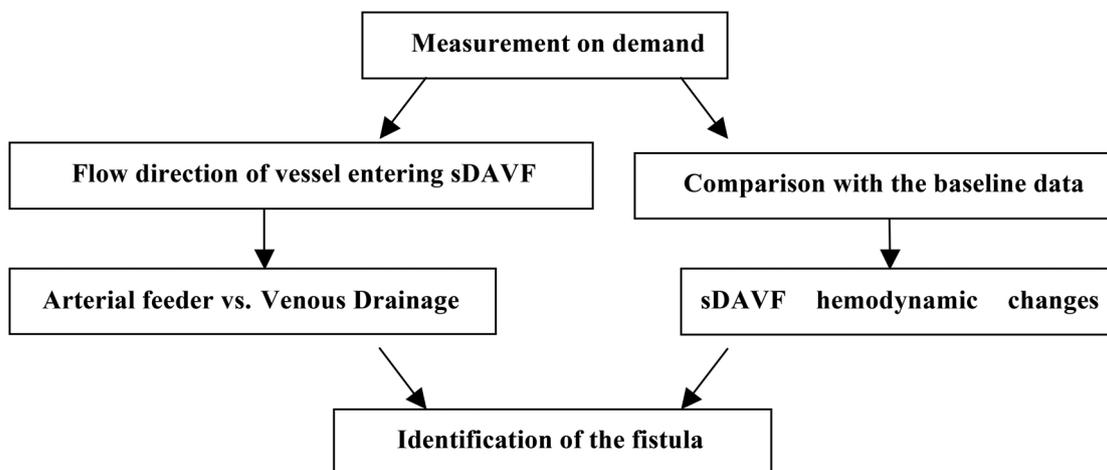
We here present a relatively large series focused on the use of doppler in surgery of sDAVF. Compared with the previous case reports, our case series offered good illustration and detailed algorithm of systemic application of Doppler in sDAVF and indicated that Doppler allows both quantification and visualization of blood flow direction in sDAVF, resulting in several benefits: unequivocal identification of veins with cortical venous reflux, verification of complete occlusion of the sDAVF, and identification of insidious arterial feeders not visualized well on the angiograms, which can help the surgeon in obliterating the fistula, especially for new surgeons.

sDAVF is at many instances overlooked during diagnosing the cause of progressive myelopathy and weakness. Prompt diagnosis and treatment have great implication in achieving good outcomes in symptomatic spinal DAVF cases because the degree of preoperative neurological deficit can be a strong prognostic factor of the outcome [12,13].

Before and after dural opening



During temporary clip occlusion



After obliteration

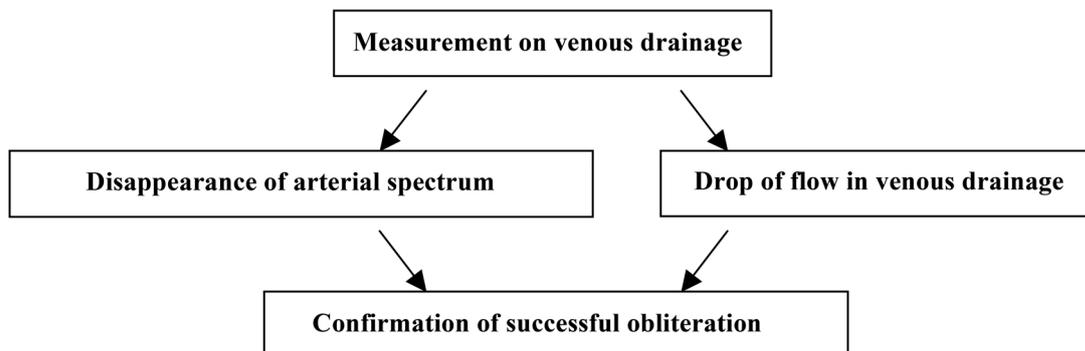


Fig. 1. The diagram shows the multistage intraoperative application of the microvascular Doppler at the different stages of surgery and for the different issues to be addressed.

However, diagnosis of an sDAVF is often challenging because of its heterogeneous and insidious presentation that can mimic other neurological disorders. At the end stage of sDAVF, the myelopathy caused by hypertension of drainage vein is irreversible. Steinmetz et al. demonstrated about 11% patients remained worsen after surgical obliteration [14]. In our serial, the patient who suffered from aggravation of symptom regardless of successful obliteration of sDAVF might be attributed to his latency as long as 4 years before exact diagnosis and surgery which subsequently lead to spinal cord infarct. Therefore, we suggest that clinical vigilance is critically important as early diagnosis

and timely treatment is the key to long term prognosis. Patients with persisted symptoms of spastic paraparesis or bowel/bladder dysfunction or gait instability should raise the suspicion of sDAVF, and MR scan of spine should be recommended as routine screening protocols. For those patients with suspicion in MR scan, DSA is recommended.

Although endovascular techniques and materials have generally improved, microsurgical treatment of sDAVF still shows an advantage over endovascular treatment in terms of initial fistula disconnection and fistula recurrence [6,15–17]. Clinical outcome of sDAVF is dependent on definitive fistula occlusion. Exact localization and complete

Table 1
spinal dural arteriovenous fistula feature and outcome.

Patients	Gender/Age	Level	Symptoms and time from start of symptoms to surgery (months)	Aminoff score	Preop mRS	Postop mRS (1year Postop)
#1	M/64	L1	progressive spastic paraparesis sphincter disturbances (11m)	5	3	3
#2	M/55	T7	gait instability low extremity numbness(24m)	2	1	0
#3	M/71	T6	sphincter disturbances gait instability(12m)	3	2	0
#4	M/58	T7	spastic paraparesis sphincter disturbances (1m)	3	2	1
#5	M/41	L1	spain; sphincter disturbances (2m)	3	1	0
#6	M/56	T6	gait instability fatigue (5m)	3	1	0
#7	M/57	T10	progressive spastic paraparesis bowel/bladder dysfunction (48m)	6	4	5

Table 2
Intraoperative Doppler measurement data.

	Flow Value, mL/min, Arterial Feeders	Median (Range) Venous Drainages
Before temporary clip	11(3–20)	9(2–18)
After temporary clip	12(4–22)	< 1
At the end of final obliteration	11(4–22)	< 1

obliteration of the fistula are of utmost importance but not always obvious during surgical treatment. The fistulas of most sDAVF can be detected during preoperative DSA. However, some sDAVFs with multiple fistulas are missed in preoperative examination [18–20]. To assure the successful surgery of sDAVF, confirmation of the exact disconnection during operation is of great importance, especially in those with insidious multiple fistulas. Some authors confirm the disconnection of sDAVF according to visual inspection such as the color and tension of venous drainage [21,22]. However, such method requires more experience and is sometimes insufficient to make the determination and even miss the residual shunt flow. Doppler can provide the hemodynamic confirmation of abolition of any residual flow in the fistula, in a way that is not possible with a simple visual inspection. It is difficult to identify the remaining insidious fistula just according to the change of the color and tension of venous drainage in such case. Hiroharu et al. reported one case with duplicated fistulas, which presented with a drop of flow but without disappearance of arterial spectrum flow after coagulating one fistula [23]. They suggested intraoperative microvascular Doppler measurement could provide more reliable information and the disappearance of the arterial spectrum flow was more reliable and repeatable than the change of color and tension of venous drainage. Notably, the normal internal vertebral venous plexus sometimes also looks enlarged. Before coagulating vessels around the root, it is also necessary to differentiate the epidural veins draining the AVF from the normal venous drainage pathway. This can be also achieved by detecting the arterial spectrum using intraoperative Doppler. Moreover, intraoperative microvascular Doppler measurement can also provide a more accurate hemodynamic evaluation to determine the threshold of flow change in venous drainage after successful obliteration. However, for the limitation of small serial, we failed to determine a reliable threshold, which will be assessed in our next study with a larger scale.

Indocyanine green video angiography (ICG-VA) has been demonstrated great potential in management of cerebrovascular disease [24–26]. However, there are also some contradictions for the use of

ICG-VA. The limitation of ICG-VA have been paid attention [27]. Only vascular structures visible in the surgical field can be analyzed using ICG-VA; As a result, vessels blocked by a clot, dural sheet, atheroma, or brain parenchyma, as well as blind angles, are invisible. Recently the influence of residual ICG-VA has also been realized [28,29], which may supply misleading hemodynamic information and make it uncertain whether fistula had been occluded. Hence, repeat indocyanine green assessments within a short time period are impossible. In fact, the role of ultrasonography in the surgery of AVF has received more and more attention, such as color Doppler ultrasonography [30] as well as contrast-enhanced ultrasound [31]. In our study, intraoperative microvascular Doppler can play a role in some stages of sDAVF surgery when doubt may arise as to the surgical obliteration strategy, which characters by feasibility and less cost and can be repeated anytime when needed. The intraoperative microvascular Doppler measurement was demonstrated reliable for understanding the sDAVF angioarchitecture and guiding surgical planning and sDAVF obliteration in all of our cases. We suggest that Doppler may be an effective complementary to other imaging modalities such as ICG-VA.

Case Illustration of Intraoperative Microvascular Doppler Probe Application

A 55-year-old male patient presented with gait instability and was diagnosed as sDAVF (Figs. 2). The patient was operated in the prone position. After the hemilaminectomy on the located level was performed, Doppler was scanned before and after dural opening. After the opening of the dural, the tortuous, anomaly venous drainages was exposed under the microscope (Fig. 2B). Flow assessment with the Doppler probe on different vessels was then performed to have baseline flow data and to evaluate direction of flow as illustrated in Fig. 2C and 2D. Then, Doppler measurement was performed on vessels in the dural root sleeve (Figs. 2E) to identify the arterial feeders and fistula. During temporary clip occlusion, Doppler measurement on venous drainage (Fig. 2F, 2G, 2H and 2I) allowed differentiation between temporary clip occlusion (1 mL/min, disappearance of arterial spectrum) and removing clip occlusion (9 mL/min, appearance of arterial spectrum), enabling safe and successful obliteration of the sDAVF (Figs. 2J). At the end of obliteration, Doppler (Fig. 2K) detected a significant drop of flow (0.5 mL/min) as well as disappearance of arterial spectrum. The postoperative DSA (Fig. 2L) demonstrated the complete obliteration.

5. Conclusion

With the limitation of our relatively small series, multistage

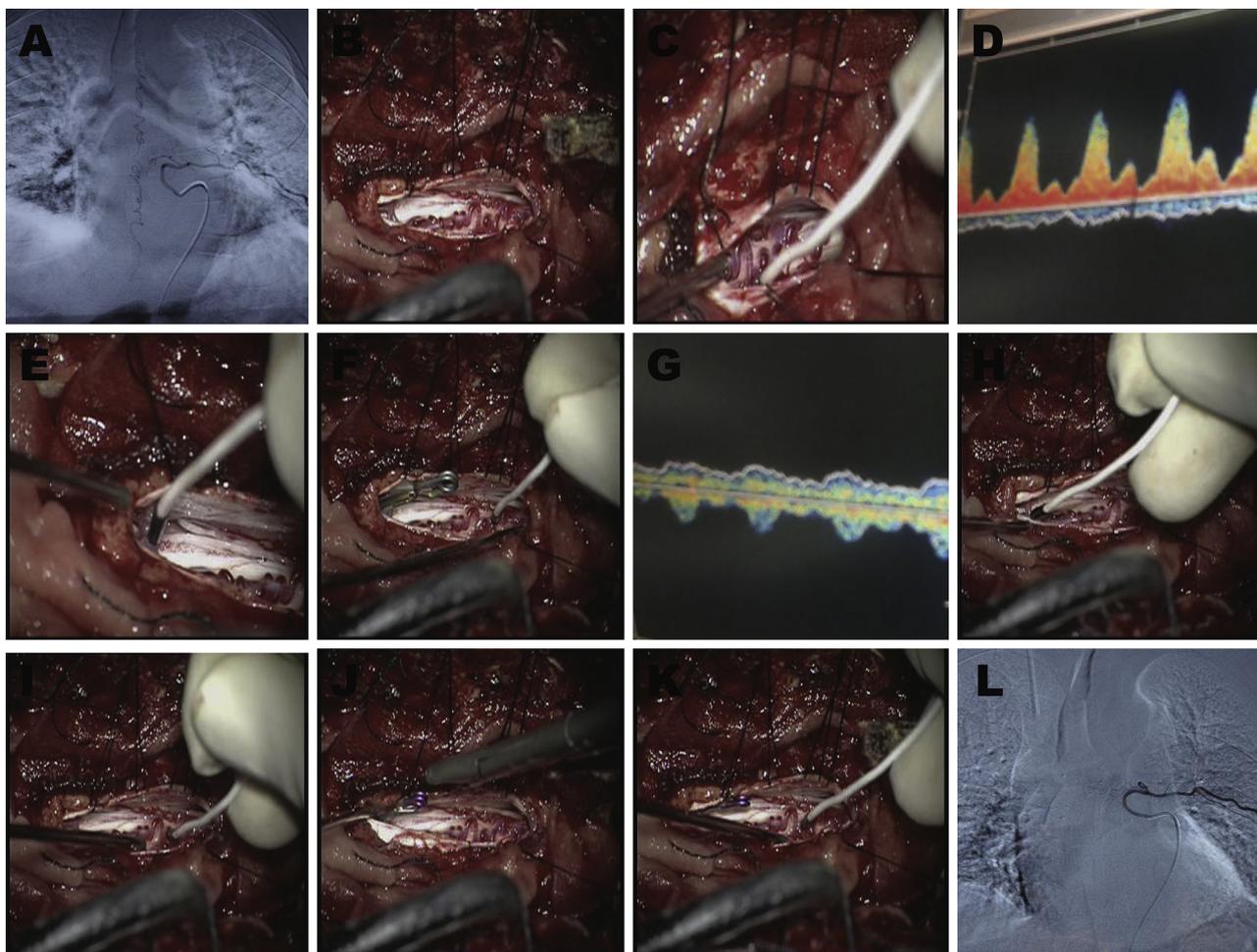


Fig. 2. The patient is a 55-year-old man. T7 spinal dural arteriovenous fistula (sDAVF). A, Preoperative digital subtraction angiography (DSA). B, The tortuous, anomaly vessels after opening the dura. C, Doppler measurement on the vessel. D, The arterial spectrum on the tortuous, anomaly vessels and base line data of the vessels. E, Doppler measurement on the doubting fistula. F, Doppler measurement on the vessel after temporary clip. G, The arterial spectrum on the tortuous, anomaly vessels disappeared after temporary clip. H-I Doppler measurement on the vessel after removing temporary clip to confirm the fistula. J, Disconnect the fistula by mini-aneurysmal clip after confirmation the fistula. K, Doppler measurement on the vessel to verify the successful obliteration of the sDAVF. L, DSA 3 months postoperative.

intraoperative microvascular Doppler measurement during sDAVF surgical obliteration is a feasible, safe, repeatable, and reliable methodology with real-time quantification and visualization of blood flow direction, which might be an effective supplement of ICG-VA.

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