Operative considerations and surgical treatment of sylvian fissure arteriovenous malformations: a 20-year experience

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OBJECTIVE Sylvian fissure (SF) arteriovenous malformations (AVMs) are among the most challenging vascular lesions amenable to neurosurgical treatment and account for 10% of all locations. As radiosurgery and endovascular techniques are increasingly involved in multimodal management protocols, the role of microsurgery needs to be reassessed as a stand-alone technique. The aim of this study was to show that total excision can be achieved with reasonable levels of morbidity and mortality in a real-world setting from a specialized high-volume center.

METHODS Forty-three patients with SF AVMs were identified from a series of 577 AVM patients treated microsurgically over a 22-year period. The mean patient age was 33.07 years (range 15–60 years), and there were 22 male and 21 female patients. The mode of presentation was headache in 51.2%, hemorrhage in 34.9%, seizures in 30.2%, and steal phenomenon in 9.3%. The authors analyzed the anatomical basis and angiographic characteristics of such lesions.

RESULTS In the preoperative period, 83.7% of the patients had a modified Rankin Scale (mRS) score of 0–2, and 16.3% had an mRS score of 3–5. After a 12-month follow-up, 95.3% of patients had an mRS score of 0–2, and 4.7% had a score of 3–6. The difference between pre- and postoperative scores was not statistically significant. SF AVMs have several particular features: 1) They produce angiographic steal of the anterior cerebral artery. 2) The nidus is fed by only one of the main trunks of the middle cerebral artery (MCA). 3) Participation of deep perforators is uncommon. 4) They have two or more early draining veins showing their fistulous nature. 5) Preoperative embolization and radiosurgery have a low rate of permanent cure.

CONCLUSIONS These AVMs represent a surgical challenge due to their proximity to critical structures such as the MCA, insula, internal capsule, and speech and memory functions in the dominant hemisphere. Essential key points are the wide opening of the SF and proper differentiation between feeders and normal vessels. Although this location can seem daunting, SF AVMs carry no additional surgical risk if adequately managed.

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KEYWORDS arteriovenous malformations; sylvian fissure; microsurgery; surgical treatment; vascular malformations

SYLVIAN fissure (SF) arteriovenous malformations (AVMs) represent approximately 8%–11% of all brain AVMs. These AVMs represent a surgical challenge due to proximity to critical structures such as the middle cerebral artery (MCA), insula, internal capsule, and speech and memory functions in the dominant hemisphere. Despite this, surgical management of SF AVMs seems to be the best treatment option. In 1987, Sugita et al. classified SF AVMs into four types according to their locations within the fissure: pure, medial (frontal), lateral (temporal), and deep (insular cortex). Since the original description, some other papers on AVMs in this particular location have considered some technical factors influencing the outcome after surgery.

Methods

From March 1997 to February 2019, the senior author (E.N.) operated on 577 AVMs at the National Institute of Neurology and Neurosurgery “Manuel Velasco Suárez,” Mexico City, Mexico. We selectively included patients with an AVM strictly confined to the SF, excluding cortical
lesions affecting the frontal or temporal operculum only. Forty-seven lesions (8.1%) were identified as SF AVMs. Four patients were excluded from the final analysis because of incomplete clinical or imaging records. Thus, 43 patients were included in this study, which was approved by the institutional review board. We classified the AVMs according to Spetzler-Martin and Sugita classifications (pure, medial, lateral, and deep).

At our institution, all patients who are diagnosed with an AVM are discussed at a joint session with the radiosurgery, endovascular therapy, and vascular neurosurgery departments to tailor a treatment plan to best meet the patient’s needs (e.g., observational, surgical, radiosurgery, endovascular, or any combination). This analysis considers the clinical mode of presentation and imaging workup (CT, MRI, and selective angiography). The modified Rankin Scale (mRS) was used to assess postsurgical clinical outcomes at discharge, and follow-up visits at 1 month, 6 months, and 1 year. The follow-up scores were compared with the preoperative clinical evaluations. Good outcomes were defined as a final mRS score of 0–2; poor outcomes were defined as a final mRS score of 3–6. Improvement was defined as a reduction in the preoperative mRS score of 1 point or more during follow-up, and worsening was considered when the score increased at least 1 point after treatment.

Statistical Analysis

We performed a descriptive and inferential analysis of the sociodemographic characteristics of the subjects by groups using IBM SPSS for Windows (version 25, IBM Corp.). First, the Kolmogorov-Smirnov normality test was used for determining the normal distribution of the mRS score before and after treatment. Afterward, a Kruskal-Wallis test was used to analyze continuous quantitative variables, and the Fisher and chi-square tests were used to compare qualitative variables by groups; p < 0.05 was considered statistically significant.

Operative Technique

All patients were operated on according to a previously described technique.\(^7\)

The patients were positioned supine, with the head fixed on the three-pin headrest. The head was rotated 30°–60° according to the position of the AVM in the SF. For AVMs located in the sphenoid compartment of the SF, we used a 30° rotation and a ptoral approach, and for those located in the operculoinsular compartment, we used a 60° rotation with a more extensive incision to expose the middle and posterior thirds of the SF. In all cases, the SF was opened using an arachnoid knife,\(^7\) taking care not to damage the superficial and turgescent sylvian veins. After opening the SF, the MCA was identified, and, according to the preoperative angiographic analysis, we searched for the main trunk feeding the nidus. We used 0.5–0.7 ml of 10% sodium fluorescein to identify the AVM vessels if available.\(^9\) The main artery was clipped, and a second fluorescein injection was administered to confirm flow changes at the nidus and veins of drainage. All arteries entering the nidus were coagulated using nonstick and highly conductive bipolar forceps. It is essential to identify AVM vessels from arteries en passage to avoid ischemic damage to normal neural tissue. During dissection of the AVM, in case of existing multiple superficial veins of drainage (superficial sylvian vein, Trolard vein, or vein of Labbé) obstructing access to the deep part of the nidus, we preserved the main draining vein based on size and intraoperative Doppler signal, maintaining the patency of the main draining vein until the nidus is resected. Finally, the surgical field is carefully inspected for residual nidus hidden under the neural tissue. Additional tools such as fluorescein, indocyanine green, or intraoperative angiography can be helpful in confirming the absence of any residual nidus. It is essential to mention that any AVM was operated on in the acute stage after bleeding; if necessary, the hematoma was evacuated due to mass effect, and the AVM was operated on in a second stage under optimal conditions.

Patient Characteristics

The mean patient age was 33.07 years (range 15–60 years). There were 22 males (51.2%) and 21 females (48.8%). The most common mode of presentation was a headache in 22 patients (51.2%), hemorrhage in 15 patients (34.9%), seizures in 13 patients (30.2%), and steal effect in 4 patients (9.3%). All patients with hemorrhage with mass effect required surgical evacuation. In 2 patients (4.7%), a ventriculoperitoneal shunt was placed and surgery of the AVM was delayed to 2–4 weeks after the initial episode. Four patients (9.3%) presented with hyperflow aneurysms. The mRS score before surgery was 0–2 in 83.7% of patients and 3–5 in 16.3% of patients.

AVM Characteristics

According to Spetzler-Martin classification, there were 6 (14.0%) grade I, 17 (39.5%) grade II, 14 (32.6%) grade III, and 6 (14.0%) grade IV AVMs; of these, 23 (53.5%) were considered to be eloquent locations, and 13 (30.2%) had deep drainage. According to the Sugita classification, 8 (18.6%) were pure, 11 (25.6%) were medial, 12 (27.9%) were lateral, and 12 (27.9%) were deep, with a relatively homogeneous distribution.

Presurgical embolization was performed in 10 patients (23.3%). The main feeding arteries were embolized to reduce the flow or, whenever possible, deep feeding arteries were also injected, as these tiny vessels may be difficult to reach at the beginning of surgery. Three patients (7.0%) had been treated with stereotactic radiosurgery with no subsequent obliteration after 3 years of follow-up, rendering surgical management the best available option.

Results

Clinical Results

In 21 patients (48.8%), a ptoral approach was chosen, and in 22 (51.1%), a fronto-temporo-parietal craniotomy using a Falconer-type incision was performed to expose the posterior third of the SF. Postsurgical angiography confirmed complete resection in 38 patients (88.4%) and residual lesion in 5 patients (11.6%) (Tables 1 and 2).

In the 5 patients with residual AVMs, 4 patients underwent reoperation with a successful complete resection.
The other patient refused to undergo reoperation and underwent radiation therapy for a small nidus (he had already been operated on twice: the first time for clot removal and the second for AVM resection).

After surgery, hemiparesis developed in 8 patients (18.6%), transient dysphasia in 7 (16.3%), abnormal camptometry in 6 (14.0%), and postoperative depression in 5 (11.6%). In patients with dysphasia, according to Sugita classification, 4 SF AVMs (9.3%) were in a pure location, 2 (4.7%) were in a medial location, and 1 (2.3%) was in a deep location. In the patients with hemiparesis, 5 SF AVMs (11.6%) were in a pure location, 2 (4.7%) were in a medial location, and 1 (2.3%) was in a lateral location.

Our results did not find a relation between Sugita type and outcome other than the AVM grade; however, pure AVMs required a longer operative time. In addition, 5 patients had a postoperative hemorrhage. In 2 of these patients, bleeding was considered due to occlusive hypoperemia without a residual nidus demonstrable by angiography. The hemorrhage was limited to the surgical bed without mass effect in the remaining 3 patients, so no action was necessary, and the hematoma was resorbed in the following weeks.

Most postoperative deficits were transient and were not related to a specific location of the AVM (p > 0.05). Surgical results were evaluated at 1, 6, and 12 months.
after surgery. At the 12-month follow-up, the mRS score was as follows: 0 in 24 patients (55.8%), 1 in 12 patients (27.9%), 2 in 4 patients (9.3%), 3 in 1 patient (2.3%), and 6 in 2 patients (4.7%; global mortality). The final mRS score was 0–2 in 95.3% of the cases and 3–6 in 4.7% (Table 2). There were two deaths, both occurring in patients with grade IV AVMs (one medial and one deep). The first patient presented with two bleeding episodes before surgery and had an unfavorable evolution. The second patient presented with a steal phenomenon producing a severe cognitive deficit. This patient developed postoperative brain swelling attributed to postoperative occlusive hyperemia despite complete excision of the AVM.

**Angiographic Characteristics of SF AVMs**

In addition to the anatomical location SF AVMs, we were able to identify five main characteristics (Table 3 and Figs. 1 and 2): 1) There exists an angiographic steal effect of the anterior cerebral artery (ACA), which is not visible on angiography (only the MCA is seen). 2) They are fed mainly by one of the two main trunks of the MCA, going directly into the nidus. From the noninvolved trunk, some vessels arise en passage around the nidus. 3) Participation of deep perforating vessels from the lenticulostriate arteries is uncommon. 4) With a very rapid flow, they behave as mainly fistulous, with more than 2 veins of drainage (sphenoparietal sinus, vein of Trolard, or vein of Labbé). However, deep drainage into a basal temporal vein is also present in less than one-third of the cases (Fig. 3). 5) Preoperative embolization and radiosurgery are not good options for treatment because of the fistulous nature of SF AVMs.

**TABLE 3. Five key characteristics of SF AVMs**

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<th>Characteristic</th>
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<td>Angiographic “steal” of the ipsilateral ACA</td>
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<td>Feeding by one main trunk (superior or inferior) of the MCA; vessels “en passage” around the nidus coming from the noninvolved main trunk</td>
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<td>Poor participation of deep perforating vessels</td>
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<td>Rapid blood flow (fistulous-type nidus) w/ multiple veins of drainage to the sphenoparietal sinus, vein of Trolard, &amp; vein of Labbé</td>
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<td>Difficult to embolize &amp; poor response to radiosurgery</td>
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**Discussion**

**Microsurgical Anatomy of the SF**

The SF is an anatomical-functional complex and is considered the most important landmark on the lateral surface of the brain (Figs. 4 and 5). 6
The SF has two portions: one superficial and one deep. The superficial portion has a stem and three rami; the stem begins medially at the anterior clinoid process and extends laterally along the sphenoid ridge to the pterion. The stem divides into anterior horizontal, anterior ascending, and posterior rami (Fig. 4A). The deep portion of the SF is called the sylvian cistern. It is divided into sphenoidal and operculoinsular compartments (Fig. 4A).

The SF is formed as follows. The opercular cleft is composed by the temporal operculum situated below the SF. The frontoparietal operculum is above the SF and is formed from anterior to posterior by the pars orbitalis, pars triangularis, pars opercularis, inferior part of the precentral and postcentral gyri, and the supramarginal gyrus. The only artery in the SF is the MCA with its branches. The M1 segment courses in the sphenoidal cistern of the SF, the M2 segment crosses the insular cistern of the SF, the M3 segment corresponds to the opercular cistern of the SF, and the M4 segment is situated in the perisylvian fissure (Fig. 5A–E).

The sylvian venous complex is formed mainly by the superficial sylvian vein. Superiorly, the vein anastomoses with the vein of Trolard and receives the frontal and parietal veins. Posteriorly, it anastomoses with the vein of Labbé. Anteriorly, it drains to the sphenoparietal sinus, cavernous sinus, or some variants to the middle fossa. Inferiorly, it receives the temporal sylvian veins. Inside the SF, it anastomoses with the deep sylvian vein, which drains the insular veins toward the basal vein (Fig. 4B). The Insula (Fig. 5F) is located medial to the SF and lateral to the extreme capsule; the insula is limited by the circular sulcus (inferior, anterior, and superior limiting sulci). The uncinate fascicle is below the limen insulae, and the temporal stem is located inside the line connecting the in-

**FIG. 1.** Angiographic characteristics of SF AVMs. **A:** Anteroposterior view of a right-sided SF AVM. The ACA is not seen (steal phenomenon from the MCA) (1). The M2 superior trunk is visualized toward the nidus, and the larger trunk is usually the main feeder (2). The inferior trunk (to normal brain tissue) is not clearly seen. Arteries en passage are detectable beyond the nidus (3). **B:** At least four different drainage veins are present in the late phase (arrows), arising from a venous pouch at the surface of the SF, confirming the fistulous nature (4).
The insular arteries emerge from the M2 segment of the MCA. The insular veins and the deep sylvian vein are also shown in Fig. 5D and E.

The white matter tracts medial to the opercula (Fig. 5F) are named the perisylvian region. The frontal and parietal opercula cover the superior longitudinal fascicle III, the arcuate fascicle, the aslant tract, the inferior fronto-occipital fascicle, and the corona radiata. The temporal operculum covers the ventral arcuate fascicle, the middle longitudinal fascicle, the inferior fronto-occipital fascicle, the uncinate fascicle, and the anterior commissure.

**SF AVMs**

SF AVMs are uncommon, representing approximately 10% of all AVMs (8.1% in our series). Sugita et al. classified them according to their location in the SF into four different types. Still, their original description omitted some specific surgical characteristics of each type. Our series confirms what other large studies have found; Sugita type does not influence prognosis but has a function of correctly locating the AVM. Nonetheless, approaching such challenging lesions with the proper presurgical considerations, as we have mentioned, is essential for better clinical and surgical outcomes.

There are only a few reports regarding surgical treatment of SF AVMs. However, SF AVMs continue to be challenging for most neurosurgeons. They are often subcortical and require significant subarachnoid dissection to open the SF, expose the nidus, and identify feeding arteries and draining veins. The insular cortex and basal ganglia, crucial eloquent areas, are neighbors. The internal capsule is on one margin, and language areas are located in the dominant hemisphere (Broca and Wernicke) on the other margin. In these AVMs, draining veins often come first during the approach, can cover the nidus, and need to be preserved throughout the resection. Transit or en passage arteries that continue beyond the AVM are macroscopically very similar to feeding arteries and must therefore be preserved. Smaller arteries such as the lenticulostriate and anterior choroidal arteries sometimes contribute to these AVMs and can be difficult to expose and control. These technical dangers can limit an overly optimistic approach for their microsurgical resection. However, excellent results have been reported due to improvements in microsurgical technique primarily because of technological advances in imaging, hybrid operating rooms, use of intraoperative indocyanine green and fluorescein, and development of microsurgical tools such as more conductive and nonstick bipolar forceps.

**Presurgical Considerations**

A proper assessment of the visual pathways and neuropsychological function (especially if on the dominant side)
is paramount to locating the lesion concerning these structures and may predict possible postsurgical morbidity.\textsuperscript{10} We consider pure sylvian AVMs as noneloquent; however, lateral AVMs may involve the Wernicke area, and medial AVMs are related to the Broca area and ventral portions of the motor area (Fig. 5). Deep AVMs may involve the basal ganglia and internal capsule. Diagnostic brain angiography can provide analytical evidence of feeding arteries and drainage veins to tailor the microsurgical strategy.\textsuperscript{11} According to the type of AVM, it is essential to localize the MCA, which is medial in pure AVMs, superior in lateral ones, inferior in medial ones, and lateral to the nidus in deep AVMs. The middle cerebral vein often drains pure AVMs; lateral AVMs drain inferiorty to the sphenoparietal sinus and vein of Labbé and infrequently can drain medially into the basal vein of Rosenthal. Medial AVMs drain into the superior sagittal sinus and the vein of Trolard, and deep AVMs may drain to the ventricular veins. One can often see two or three veins draining the nidus, which arise from a large venous dilation at the surface of the SF (Figs. 1–3).

Our study has identified five characteristics specific to SF AVMs that one should keep in mind when dealing with this location (Table 3). The preoperative angiographic analysis is used to identify the first four of these characteristics. Most of these distinctive features are associated with the high flow of these AVMs. It is common to see one of the main trunks of the MCA (superior/inferior) directed toward the nidus, with a diameter more prominent than the surrounding arteries. With temporary clipping of the main feeder, the AVM becomes less pulsatile and turgescent and can be handled more efficiently. Therefore, this is an important step for treating the lesion. Particular care should be given to en passage vessels; only vessels that go directly to the nidus should be cauterized. Otherwise, normal vessels might be obliterated with deleterious consequences. These features make SF AVMs challenging to approach with exclusive embolization or be considered for radiosurgery as a viable alternative method. Three of our patients originally referred for radiosurgery underwent reoperation because of failure of this modality. A proper decision tree must be clear: only SF AVMs with previous bleeding, those harboring hyperflow aneurysms, or those with notorious steal effect causing symptoms must be considered for treatment without delay.

However, in the elective setting (small- or medium-size incidental AVMs), one must carefully consider the best treatment method. Input from the patient or relatives must be supported by a clear understanding of the benefits and risks.

In contrast with other series in which risk factors for mortality have not been identified, we found that patients with Spetzler-Martin grade IV SF AVMs carry an increased risk of deadly complications. Of the 6 patients with grade IV lesions, 2 patients with a large Sugita’s medial-

\textbf{FIG. 3.} Illustrative case 2. \textbf{A:} Axial MR image showing a left-sided deep SF AVM (small perforating arteries at the medial aspect of the nidus). \textbf{B:} Angiogram showing the nidus without any clear differentiation between the AVM feeders and normal vessels. \textbf{C:} Three different veins drain the AVM at the SF surface, the first directed to the sphenoparietal sinus through a superficial sylvian vein, the second to the superior longitudinal sinus through the vein of Trolard, and a third to the lateral sinus through the vein of Labbé. \textbf{D:} This patient had undergone embolization prior to surgery. A small amount of embolizing agent is visible, demonstrating the very rapid flow and the difficulty of getting a substantial cast. Also, a small amount of embolizing agent can be seen at the superior longitudinal sinus. \textbf{E:} Postoperative angiogram showing the absence of the nidus and disappearance of the steal to the ACA. \textbf{F:} Left-sided pterional approach. The multiple veins of drainage at the surface of the SF correspond to the angiographic image (C).
type AVM died. Therefore, we advise caution if patients with grade IV or higher SF AVMs are to be considered surgical candidates. In addition, postoperative hyperemia after total nidus resection may cause uncontrollable postoperative edema, leading to a fatal outcome.

Considerations During Surgery

Proper head positioning must favor a physiological venous drainage and should offer an adequate view for the approach to the AVM.

Concerning the surgical technique, we previously described the “ACADEV” (angioarchitecture, craniotomy, attack, dissection, extensive coagulation of feeders, and drainage vein) method for a step-by-step approach. Unlike aneurysms, a keyhole approach is not a priority: the craniotomy must correctly expose the superficial vessels and, according to the particular configuration of the SF, a more comprehensive dissection must be performed when needed. In patients with pure and lateral AVMs or those located anteriorly at the sphenoid cistern, we used a classic perional transt Sylvian approach; for deep or medial AVMs, a more extensive craniotomy (Falconer type) is needed to decrease the likelihood of a corticotomy and secondary language deficits and to avoid excessive temporal retraction (Video 1).

VIDEO 1. Case presentation of a left SF AVM associated with hyperflow anterior communicating artery (AComA) and anterior choroidal artery (L-Acho) aneurysms and two de novo AVMs in the right hemisphere. © Edgar Nathal, published with permission. Click here to view.

Complete dissection of the SF is mandatory. This is the most important technical step for exposing the AVM and is illustrated in Video 1. This wide opening of the SF allows identification of the MCA and feeding arteries that can be temporarily clipped to assess their participation in the nidus, differentiating them from en passage arteries, which may otherwise vascularize normal brain tissue. Thus, it is vital to recognize their presence to prevent ischemic events. As we previously published, intravenous fluorescein helps with occlusion of nondominant veins, allowing a proper handling of the nidus, and gives access to deep feeders.

For ruptured lesions, we do not operate on the AVM immediately after a bleeding episode; instead, we operate when the patient is in good condition and the hematoma is no longer present. The residual cavity produces a surrounding interface facilitating the approach, thus decreasing the risk of additional sequelae.

Concerning anesthetic management, it is generally optimal to keep normotension. In cases in which there is bleeding from perforators, moderate hypotension can help control these small and aggressive vessels. As blood loss increases, one should avoid further hemodilution and transfuse the patient at the proper time.

Considerations After Surgery

If during surgery one has dealt with small aggressive vessels and profuse bleeding has occurred, a short course (24–48 hours) of sedation can be helpful to avoid hematomas due to sudden increases in blood pressure coming from these vessels during emergence from general anesthesia. Plain CT before awakening can reveal hematomas at the surgical site that might go unnoticed because of sedation.

Even in the absence of a statistically significant difference between pre- and postsurgical mRS scores (preoperative mRS score 0–2 in 83.7% of patients, mRS score 3–5 in 16.3% vs postoperative mRS score 0–2 in 95.3% of patients, mRS score 3–6 in 4.7%; p < 0.063), one should assess to see if the patient’s neurological condition improves after surgery. Most patients with a postoperative mRS score of 3–6 had presented with rupture.

A complete understanding of the microsurgical anatomy of the SF and some technical pearls such as avoiding retraction of the surrounding brain tissue is paramount to reduce the risk of complications and postsurgical neurological deficits.

Conclusions

We endorse microsurgery as the gold standard for the definitive management of SF AVMs. We also emphasize
the five characteristics that should be kept in mind when dealing with AVMs in this location, which we have summarized in Table 3. Although challenging, we deem that SF AVMs are amenable to surgical management in large-volume specialized centers. Our report shows that careful selection and meticulous surgical technique can allow angiographic cure with an excellent degree of efficacy and an acceptable level of safety. In the present era of multimodal management, endovascular and radiosurgical techniques face clear limitations in this particular location (high flow, multiple feeders, various compartments, and drainage multiplicity), and we deem that microsurgery remains an essential tool, often as a stand-alone technique, with good clinical results and an acceptable low rate of complications.

References


**Disclosures**
The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

**Author Contributions**

**Supplemental Information**
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