arteriovenous malformations (AVMs) represent a great challenge for neurosurgeons, interventional neuroradiologists, and radiosurgeons because of the high procedural morbimortality rate and uncertainty about the natural history of these lesions; thus, there is debate on whether to treat all asymptomatic AVMs, only those thought to be dangerous (stenosis of the drainage vein, flow-related aneurysms), or none of them.

Surely the age of the patient represents a critical issue to consider when deciding whether to treat a patient. The clinical approach to AVMs in children might be more aggressive since AVMs are responsible for 30%–50% of spontaneous intracranial hemorrhages in childhood and because of the great cumulative lifetime risk of bleeding (rough annual rate of 1%–4%).

The therapeutic approach varies depending on the anatomical characteristics of the AVM and the expertise of the surgeons. Generally, surgery is preferred in AVMs with a cortical location or a low Spetzler-Martin (SM) grade, whereas embolization is performed for deep, large, and complex lesions; combined approaches are not excluded. At our institution, endovascular treatment is always the first approach because of its nontraumatic nature, even in cases with a low surgical risk. Radiosurgery is our third therapeutic choice because of the radiobiological risks to an immature brain even years after treatment; as a matter of fact, not enough studies with long follow-ups have been conducted to eliminate all doubts about the procedure’s teratogenic effects (maximum 10 years).

For endovascular embolization, great improvement was made by the introduction of Onyx liquid embolic, as it allows the surgeon to plan different strategies to achieve occlusion of an AVM in a safer manner. The arterial approach is classic and can lead to the exclusion of an AVM (when feasible) in one or more steps, depending on the AVM dimension, by using one or more microcatheters simultaneously.

Only a few cases of transvenous embolization in adults have been reported in the literature, but none in children. We describe here our preliminary experience in a small series of selected AVMs treated with the transvenous injection of Onyx 18 (ev3-Covidien).

Methods

Between April 2011 and September 2012, 4 children (epidemiological characteristics in Table 1) with brain AVMs underwent endovascular treatment with Onyx 18...
been treated at our institution: 11 with endovascular embolization and 6 with surgery. In that period, 17 children had occluded, and Onyx entered the arteriolar feeders in a retrograde manner. During maneuvers for microcatheterization, we provoked a severe spasm of the arterial feeder because of the difficulty in reaching the nidus. For this reason, a microcatheter was positioned through the superior sagittal sinus and the frontopolar vein within the plexiform nidus. The AVM was completely obliterated with a transvenous injection of 1.2 ml of Onyx 18 that initially filled the head of the drainage vein and then the arteriolar feeders. Computed tomography scanning performed after the procedure revealed no intraoperative hemorrhages, and the child had no deficit on awakening (modified Rankin Scale [mRS] 0; Fig. 1).

Posttreatment Course

The child had no deficit at the 6-month clinical examination (Fig. 1). The control DSA, performed as scheduled, confirmed complete occlusion of the AVM.

**Illustrative Cases**

**Case 1**

**History and Examination**

A 7-year-old boy was referred to our institution for a small left frontobasal AVM detected with MRI, which had been performed for a supposed psychomotor delay. No neurological deficits were observed at admission. Preoperative DSA examination confirmed the presence of a 1.2 × 1.3 × 1–cm left frontobasal, gyral AVM fed by the frontoorbital artery (from the anterior cerebral artery) with two small non-ectatic cortical draining veins directed individually to the superior sagittal sinus or to the vein of Trolard. Using the SM scale, we classified the AVM as Grade I.

**Treatment**

During maneuvers for microcatheterization, we provoked a severe spasm of the arterial feeder because of the difficulty in reaching the nidus. For this reason, a microcatheter was positioned through the superior sagittal sinus and the frontopolar vein within the plexiform nidus. The AVM was completely obliterated with a transvenous injection of 1.2 ml of Onyx 18 that initially filled the head of the drainage vein and then the arteriolar feeders. Computed tomography scanning performed after the procedure revealed no intraoperative hemorrhages, and the child had no deficit on awakening (modified Rankin Scale [mRS] 0; Fig. 1).

**Posttreatment Course**

The child had no deficit at the 6-month clinical examination (Fig. 1). The control DSA, performed as scheduled, confirmed complete occlusion of the AVM.

**Case 2**

**History and Examination**

A 15-year-old female was referred to our institution after a small (< 1 cm), left temporoparietal AVM close to Wernicke’s area was detected with MRI and DSA performed for a partial motor seizure. At admission, neurological examination revealed no deficits. The AVM, classified as SM Grade II, was fed only by the parietooccipital artery and drained by an ectatic median parietal vein.

**Treatment**

Through a microcatheter positioned right at the head of the draining vein, 1 ml of Onyx 18 was injected and the AVM was occluded. Computed tomography scanning performed after the procedure was negative for intraoperative hemorrhage, and the patient had no neurological deficits after the delayed awakening (mRS 0; Fig. 2).

**Posttreatment Course**

The 6-month control DSA showed complete and stable occlusion of the AVM.

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**TABLE 1. Summary of characteristics in 4 patients treated using transvenous embolization for an AVM**

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs)</th>
<th>Symptoms</th>
<th>Nidus Size (cm)</th>
<th>Location</th>
<th>Vascular Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7</td>
<td>None</td>
<td>&lt;1</td>
<td>Lt frontobasal</td>
<td>Venous</td>
</tr>
<tr>
<td>2</td>
<td>15</td>
<td>Seizures</td>
<td>&lt;1</td>
<td>Lt temporoparietal (Wernicke’s area)</td>
<td>Venous</td>
</tr>
<tr>
<td>3</td>
<td>11</td>
<td>Hemorrhage</td>
<td>&lt;1</td>
<td>Lt pontocerebellar</td>
<td>Combined</td>
</tr>
<tr>
<td>4</td>
<td>11</td>
<td>Headache</td>
<td>2.25</td>
<td>Rt frontoorbital</td>
<td>Venous</td>
</tr>
</tbody>
</table>

* Angiographic occlusion of the nidus was achieved in every patient, and no periprocedural adverse events occurred in any of them.

via a transvenous approach. In that period, 17 children had been treated at our institution: 11 with endovascular embolization and 6 with surgery.

All cases were discussed with the pediatric neurosurgical team, and endovascular treatment was chosen whenever surgical and endovascular risks were considered similar. The criteria for choosing this technique were a small AVM with a compact nidus, single venous drainage, and an arterio-venular shunt structure visible on superselective microangiography. The presence of small arteries hard to catheterize is also a good criterion for the transvenous approach, especially in eloquent areas where Onyx reflux could cause occlusion of functional arteries leading to neurological deficit. All procedures were performed with the patients under general anesthesia, after informed consent had been obtained from the parents. We chose the transvenous approach to avoid reflux into a functional artery or because arterial access was difficult due to vascular kinking or spasm of the arterial feeder that thwarted us in obtaining a good microcatheter position for intranidal injection. The goal of embolization was complete cure in all cases.

A triaxial system was used to navigate the drainage veins through the venous sinuses: a 6-Fr guide catheter (Envoy, Codman Neurovascular), an intermediate catheter (DAC 0.044, Concentric Medical), and a 3-cm detachable-tip microcatheter (Apollo, ev3-Covidien; not available in the US but particularly useful for this technique). Another microcatheter (Apollo) supported by a 6-Fr guide catheter has always been positioned within the arterial feeder to achieve a superselective study of the nidus and its venous drainage. In the patient in Case 3, transvenous embolization with Onyx 18 was completed with an injection of Glubran (GEM) from the arterial side. We considered the procedure to be completed when the AVM was totally occluded, meaning that the arteriovenous shunts were no longer recognizable during angiographic studies at the end of the procedure, the draining vein was completely occluded, and Onyx entered the arteriolar feeders in a retrograde manner.

All patients underwent CT scanning immediately after the procedure. Delayed awakening was used in the Pediatric Neurosurgical Intensive Care Unit approximately 6–12 hours later. A clinical evaluation was performed at discharge and at 6 months after treatment, and digital subtractions angiography (DSA) was performed at 6 months as well.

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Case 3
History and Examination
An 11-year-old girl was referred to our interventional neuroradiology unit after a hemorrhage in the posterior cranial fossa due to a small AVM (1 × 1 × 1.5 cm) of the left pontocerebellar edge, which was fed by small sub-branches of the rostrolateral branch of the anterior inferior cerebellar artery (AICA) and drained through the vein of the restiform body toward the petrosal vein and the superior petrosal sinus. At admission, the patient was asymptomatic.

Treatment
A microcatheter was positioned within the arterial feeder, a collateral of the rostrolateral artery, close to the nidus; however, embolization with Onyx 18 from that point was not possible given the danger of reflux in the rostrolateral branch itself along with the risk of seventh and eighth cranial nerve impairment. For this reason, a second microcatheter was positioned inside the nidus from the venous side, and from there 1.5 ml of Onyx 18 was injected, obtaining subtotal occlusion of the AVM (90%). We completed the procedure with an injection of 0.3 ml of Glubran from the arterial side. The final angiograms showed complete occlusion of the AVM (Fig. 3).

Posttreatment Course
The results remained stable at the 6-month DSA follow-up, and the patient was asymptomatic (mRS 0; Fig. 3).

Case 4
History and Examination
Because of recurrent headaches, this 11-year-old boy underwent MRI and DSA, which showed a small (2 × 1.5 × 1.5 cm), right frontoorbital AVM fed by two branches, both from the frontoorbital artery (anterior cerebral artery), with unique cortical drainage toward the superior sagittal sinus (SM Grade I).

Treatment
After positioning the microcatheter in the superior branch of the frontoorbital artery because of the difficulty in reaching the right position, we reached the head of the drainage vein through the superior sagittal sinus with another microcatheter. From that position we injected 4 ml of Onyx, attaining complete retrograde filling of the arteriolar feeders. The postprocedural CT scan was negative for intraoperative hemorrhages, and the patient awoke with no deficit.

Posttreatment Course
The result was stable at the 6-month DSA follow-up (Fig. 4).

Discussion
Complete cure of an AVM is attained when the nidus is excluded from the vascular circulation, meaning that venous drainage is no longer visible because it is completely occluded. The classic transarterial injection of Onyx leads
to a “centripetal” embolization: the arterial feeders are occluded first, and then Onyx reaches the nidus and the venous side at the end, when the radiopaque cast hides the anatomical details. For this reason uncontrolled progression of Onyx with critical stenosis of the outlet is possible.

In contrast, transvenous embolization is typically “centrifugal,” and the microcatheter positioned right inside the head of the vein, in the middle of the plexiform nidus, allows the interventionalist to create the plug under visual control, without overlapping other structures, and to progressively close the center of the nidus and the arteriolar feeders in a retrograde manner.

A concern with this technique could be the increased...
hemorrhagic risk due to venous outlet occlusion with a patent nidus. Indeed, the microcatheter positioned in the head of the vein ensures simultaneous closure of the drainage vein and the nidus itself.

Our results in this small series of pediatric patients, and even findings in other studies, confirm the hypothesis that a venous approach is feasible when the classic transarterial one is not possible because of anatomical kinking and/or short feeders originating directly from functional arteries.

The 4 cases described are important for underlining the criteria an AVM must have to be treated from the venous side. First of all, it must be small, as the first part to be closed is the venous drainage, and a big, high-flow AVM with multiple feeders does not support drainage reduction or stenosis and could bleed during the procedure. For that reason we have to be sure to completely fill the entire nidus in one section and in a relatively short time. (In our series, the mean time was 5 minutes.) Second, it is important that the AVM has an arterio-venular angioarchitecture that allows Onyx to penetrate backward from the head of the vein into the small feeders. Third, it is important to have only one or a maximum of two drainage veins; otherwise the risk of closing a vein without full control of the system increases. Finally, the nidus must be compact to allow Onyx to penetrate rapidly in all its parts.

The advantage of this technique is the absolute control of the reflux, which makes the procedure safe even in critical vascular territories (Case 3).

The nidus of the AVMs we have treated in this series all had a compactness score of 3, according to the classification by Frisoli et al.

Considering the AVM’s high risk of bleeding in its natural history, its complete occlusion in children is the target regardless of how it is treated (surgery or endovascular), and the transvenous approach could be the safer method of treating a difficult AVM in selected cases. This technique is especially useful in cases of deep AVMs fed by small perforating arteries and located in difficult cerebral territories, conditions that expose the patient to a high surgical risk and for which classic transarterial embolization is not feasible (Case 3).

Considering the technical aspects of the transvenous approach, a detachable-tip microcatheter is particularly useful because it allows the operator to have Onyx reflux with no risk of catheter sticking. In one case only, we had difficulty in catheterization of the cortical vein given the angle formed with the superior sagittal sinus.

Conclusions

The transvenous approach is an alternative to the classic transarterial one in very selected cases in which the AVM is deeply located or fits the criteria described above. Further studies are absolutely necessary to demonstrate the safety (higher risk of hemorrhage if incomplete occlusion of the feeders is achieved) and the risk-benefit rate of this approach, which seems to be very effective and interesting.

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