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Cerebral Arteriovenous Malformations in Children

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Summary

In spite of their congenital origin, only 18–20% of cerebral AVMs are diagnosed during infancy and childhood. Intracranial haemorrhage is the presenting clinical manifestation in 75–80% of paediatric patients and is associated with a high morbidity and mortality. The natural history of untreated cerebral AVMs in children is worse than in adults, in relation to a longer life expectation, a higher annual risk of AVM bleeding (3.2% vs. 2.2%) and a higher incidence of posterior fossa and basal ganglia AVMs, most of which present with massive haemorrhages. The surgical excision remains the treatment of choice for parenchymal AVMs in children; AVM complete removal is currently achieved in 70–90% of the patients. With the advent of new agents for endovascular management, preoperative AVM embolization has further improved surgical results. Stereotactic radiosurgery appears to be a successful treatment option in small or moderate sized AVMs. Recent studies have demonstrated low complication rates with this technique in paediatric patients.

We reviewed our experience with 37 paediatric AVMs treated at the Section of Paediatric Neurosurgery of the Catholic University of Rome between 1980 and 1997. Twenty-three patients underwent surgery as the only treatment modality; endovascular embolization was combined with the surgical treatment in a further four cases. Radiosurgery was utilized as the only treatment in three patients and in combination with other techniques in an other three children (with surgery in one case and with AVM embolization in the remaining two subjects). No treatment was carried out in three patients because of excessively critical condition on admission; endovascular embolization failed in a further patient because of the anatomical complexity of the malformation. Previous studies have demonstrated a quite strict correlation between AVM complexity based on Spetzler and Martin's grading system and patients outcome. A less direct relationship has been observed in the present study. In our experience the factors which were more closely predictive of patients' outcome were the occurrence of an AVM bleeding and the neurological status on admission. In spite of the low number of cases in the single subsets of patients this study seems to support the role of AVM embolization and radiosurgery as effective adjuvant techniques in the management of cerebral AVMs in children.

Keywords: AVM; paediatric.

Introduction

Most of cerebral parenchymal arteriovenous malformations (AVMs) are diagnosed between 20 and 40 years [24, 32], and only 18–20% of them become symptomatic under the age of 15 years [13, 21, 32]. Haemorrhage is the most frequent clinical presentation both in adults and children, but is more commonly recorded in the paediatric than in the adult population (75–80% vs 50–65%) [24, 32]. A greater tendency to bleed is also recognized for AVMs occurring in young patients, with related major morbidity and mortality [4, 13, 14, 17, 21, 28, 32, 33, 47]. Such a characteristic, combined with long life expectation of young patients, justifies the special interest paid to the treatment of this type of malformative lesion in paediatric neurosurgical practice. In recent years, the advances in microneurosurgical techniques, the availability of new agents for endovascular treatment and the wider use of radiosurgery have greatly contributed to improving the outcome of patients harbouring AVMs [1, 8, 10, 30, 44–47, 49]; in spite of this advance, however, about 10% of cases still can not be helped neither by operative, interventional or radiosurgical techniques [22]. The aim of this study is to report our experience with 37 cases of paediatric parenchymal AVMs treated at the Section of Paediatric Neurosurgery of the Catholic University of Rome in an eighteen year period of time.

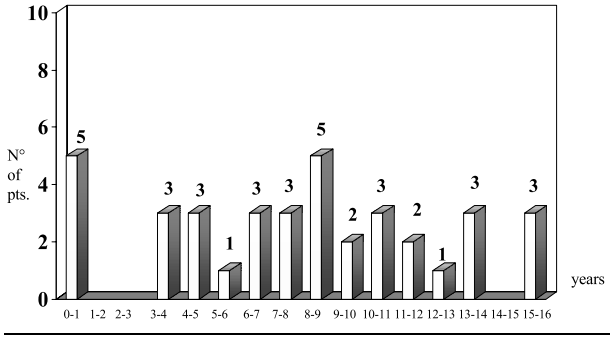

Fig. 1. *Age Distribution at the Onset of Clinical Manifestations*

Patients and Methods

Between 1980 and 1997, 47 cases of parenchymal AVMs were evaluated and treated at the Section of Paediatric Neurosurgery of the Catholic University of Rome; ten of these cases were excluded because of incomplete clinical records. Thirty-seven patients were considered for the present study. Twenty-one of them were males and sixteen females (M/F ratio: 1.31). Age at the clinical onset ranged between 1 month and 15.2 years (Fig. 1), with a mean value of 8.15 years. Two peaks were observed in the age distribution: one in the first year of life (13.5%) and the second between 8 and 9 years (13.5%).

Clinical onset, pre-operative neurological status, anatomical characteristics of the lesion and treatment modalities were evaluated and compared with clinical outcome. Computed tomography scan (CT) represented the first neuroradiological investigation in 34 children; magnetic resonance imaging (MRI) was the first pre-operative examination in the remaining 3 patients. Diagnosis was confirmed by angiography in all cases. For the present study the Spetzler-Martin grading system [39] was used retrospectively to classify the AVMs by size, eloquence of the involved cerebral area, presence or absence of a deep venous drainage; the analysis was based on data collected by reviewing neuroradiological studies, the findings of the clinical examination on admission, and the results of the post-operative clinical observation.

Results

Clinical Presentation and Pre-operative Neurological Status

Twenty-seven patients (72.9%) presented with symptoms and signs of intracranial hypertension; 19 children (51.3%) complained of focal neurological deficits; seizures were the first clinical manifestation in 6 cases (16.2%). Intracerebral haemorrhage was documented at diagnosis in 26 cases (70.3%) (Table 1). Twenty (54.1%) of the 37 patients here considered presented without any alteration of consciousness; 7 patients (18.9%) were admitted in coma grade I–II and 10 (27%) in coma grade III–IV.

Table 1. *Cerebral Arteriovenous Malformations in Children*

Clinical onset (37 cases)	No.	H	NH
Intracranial hypertension (ICH)	15	13	2
Motor deficits (MD)	4	4	–
Seizures	2	1	1
ICH + MD	9	5	4
MD + seizures	2	–	2
ICH + MD + seizures	1	1	–
ICH + cranial nerve deficits (CND)	1	1	–
MD + CND	1	–	1
ICH + seizures	1	1	–
Asymptomatic	1	–	1

Table 2. *Cerebral Arteriovenous Malformations in Children*

Site (37 cases)	
Temporal	6 (16.2%)
Parietal	5 (13.5%)
Frontal	3 (8.3%)
Fronto-temporal	3 (8.3%)
Temporo-parietal	3 (8.3%)
Fronto-parietal	1 (2.5%)
Basal ganglia	6 (16.2%)
Hemispheric	1 (2.5%)
Cerebellar	6 (16.2%)
Brain-stem	3 (8.0%)

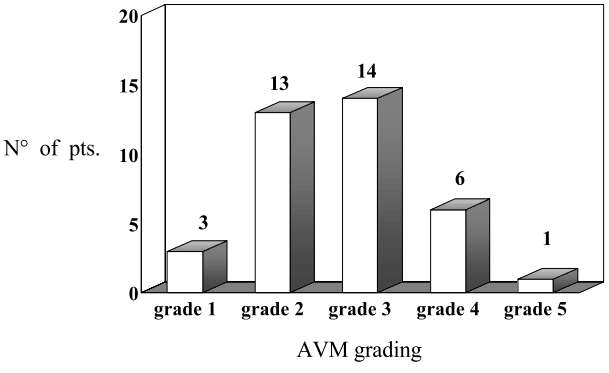

Fig. 2. Patients' classification according to Spetzler and Martin AVM grading.

Location and Grading of the AVMs (Table 2; Fig. 2)

Twenty-eight of the 37 AVMs were supratentorial in location and nine infratentorial; the basal ganglia and the cerebellum were involved in 16.2% of the cases, respectively (Table 2).

The distribution of the AVMs according to the Spetzler and Martin grading system is represented in Fig. 2: grade II and grade III AVMs were the most

Table 3. *Cerebral Arteriovenous Malformations in Children*

Treatment (37 cases)	No. cases
Surgery	23 (62.2%)
Endovascular tr. + surgery	4 (10.8%)
Surgery + radiosurgery	1 (2.7%)
Radiosurgery	3 (8.1%)
Endovascular tr. + radiosurgery	2 (5.4%)
No treatment	4 (10.8%)

common lesions in our series (72.9%); grade I, grade IV and grade V AVMs accounted for percentages of 8.2%, 16.2% and 2.7%, respectively. Aneurysms on the afferent vessels or within the nidus of the AVM were found in seven patients (18.9%), whereas a postnidal aneurysm was revealed by angiography in four cases (10.8%).

Management (Table 3)

Surgical excision was the only treatment modality in 23 (62.1%) out of the 37 patients here considered. The AVM was surgically removed in 22 of these children; exclusion of the AVM by clipping the afferent vessels was performed in the remaining patient.

Pre-operative embolization associated with direct surgical treatment allowed the AVM total removal in four patients.

Radiosurgery was the only treatment in three cases of deeply located brainstem AVMs. The technique was combined with surgical treatment in a child with a superficial brainstem AVM and with partial embolization of the malformations in two further subjects harbouring a huge Sylvian and a basal ganglia AVM respectively.

Three patients, admitted in extremely severe clinical conditions after an extensive intracranial haemorrhage, did not receive any management of their AVM; all these children harboured complex arteriovenous malformations ($\geq$ grade 3 of the Spetzler and Martin grading system) located in the basal ganglia in two cases, and involving the whole left hemisphere in the third subject. Two of them died a few fours after admission whereas the third one still survives in a persistent vegetative state, thirty-one months after the acute episode; this patient, presenting with a huge basal ganglia and intraventricular haemorrhage, underwent external ventricular drainage on admission and a right ventriculo-peritoneal shunt one month later. A further patient was admitted in coma grade I with headache and vomiting after an intraventricular haemorrhage from a left choroidal AVM; he spontaneously recovered in a few days. Surgical excision and radiosurgery were excluded because of the complexity of the arteriovenous malformation; an endovascular embolization was attempted in another hospital without success, because of the numerous small size and low-flow afferents to the AVM; actually he is in a normal clinical condition without neurological sequelae and is waiting for control angiography and a new AVM embolization attempt.

Treatment Results (Figs. 3–6)

Four patients, severely compromised at diagnosis, died a few days after surgical treatment. The control angiographic examination was not performed in further two cases, whose significantly impaired neurological condition did not improve after surgery. Complete AVM exclusion was confirmed by angiography in sixteen out of the twenty-three surgically treated children. In the last patient the post-operative angiographic investigation demonstrated a minimal remnant of his cerebellar AVM which underwent spontaneous thrombosis as demonstrated by successive angiographic controls.

A total disappearence of the AVM was also angiographically documented in the four children who were operated on after a partial AVM embolization and in the patient who received radiosurgery after a subtotal AVM removal. The AVM was, instead, only reduced in size in the three children who underwent radiosurgery as the only treatment modality (mean follow-up 72.0 months) and in the two patients in whom radiosurgery was combined with endovascular treatment (mean follow-up: 19.5 months).

Clinical outcomes (Tables 4–6)

(mean follow-up: 64.7 months)

Twenty-one (67.7%) of the 31 survivors of this series lead a normal life, without neurological deficits; mild neurological deficits persist in eight cases (25.8%); two patients (6.4%) present severe neurological sequelae. The correlation between AVM grading and clinical outcome is reported in Table 4. Table 5 outlines the relationship between the neurological status on admission, the clinical presentation and the outcome. The haemorrhagic onset and the severity of pre-operative neurological conditions correlated to the outcome more accurately than the AVM grading.

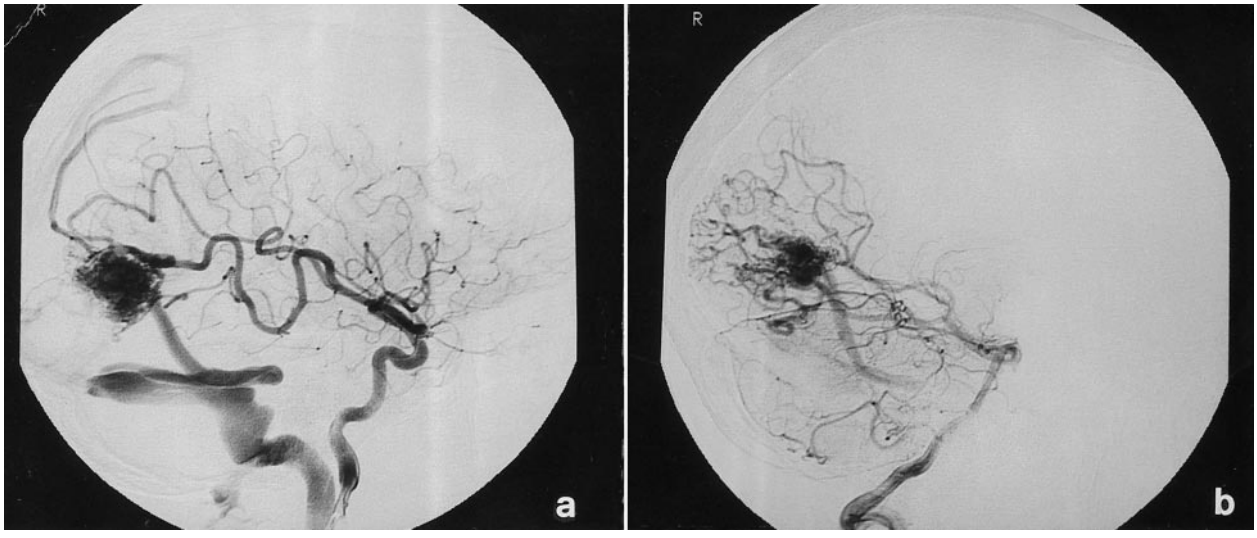

Fig. 3a, 3b. Right carotid and vertebral angiograms, showing a right posterior temporal arteriovenous malformation, with afferents from the middle cerebral artery, posterior choroidal artery and posterior cerebral artery and an early outflow to the sagittal sinus and the deep venous system.

Discussion

Cerebral AVMs are uncommon lesions with an overall population prevalence of about 0.5–1% [32, 35]. Prevalence in paediatric patients is of 0.014–0.028% [13]. Taken as a group AVMs are ten times more frequent in children than saccular aneurysms [13, 21]. Only 19.6 up to 42% of the cases are diagnosed under the age of twenty [13]. According to some authors [21] the late clinical presentation of these congenital vascular malformations could correspond to progressive structural changes of the abnormal vessels, which would increase the tortuosity of their feeding and draining channels with time; secondary modifications in vascular wall resistence as well as haemodynamic changes in the near brain structures could then account for the more frequent recognition of these malformative lesions in later ages [21]. A second explanation for late clinical presentations takes into account a potential for growth of AVMs [12, 26, 32]. Such hypothesis seems to be supported by reports of AVMs regrowth after an apparently total surgical removal [12, 25, 26, 28, 50, 51]. A number of theories have been proposed to explain the phenomenon. AVM growth may result from small haemorrhages, which progressively destroy surrounding neural tissue and favour vascular dilation and tortuosity [26]. Two decades ago Krayenbuhl suggested that a vascular shunt itself could stimulate proliferation of new abnormal blood vessels [29]. On the other hand Yasargil argued that AVMs occur because of an abnormal proliferation of capillaries rather than failure of capillary formation; he coined the term "proliferative capillaropathy" [50].

Haemorrhage is the most frequent clinical manifestation of cerebral AVMs and occurs in 55–75% of patients in all age groups [3, 5, 13, 19, 24, 34, 35, 36, 47]. However children have a specific high risk for haemorrhagic events as compared to adults, with up to 85% of the subjects presenting an episode of intracranial bleeding in their clinical history [4, 7, 9, 13, 21, 22, 28, 32, 47]. The annual risk of haemorrhage is also higher in paediatric patients (3.2%) as compared to adults (2.2%) [21, 32]. The risk of rebleeding is 6–33% in the first year after the first haemorrhage and decreases thereafter stabilising on the above mentioned values after the fourth year [21]. One of the factors that can be advocated in explaining the higher rate of haemorrhage in children is the high incidence of malformations localized within the basal ganglia and the thalamus [17, 22]. In 1989, Itoyama [23] found that deep AVMs were more prone to bleed when compared to the hemispheric ones. Our data support this observation. Six of the 37 AVMs here considered (16.2%) were located in the basal ganglia. Five of them were associated with an intracranial haemorrhage (83.6%), compared to 63.6% of the cases with hemispheric lesions.

The relationship between AVM size and bleeding rate is a controversial subject. Some authors [15, 22, 23, 43] have reported that small AVMs (< 3 cm.) have

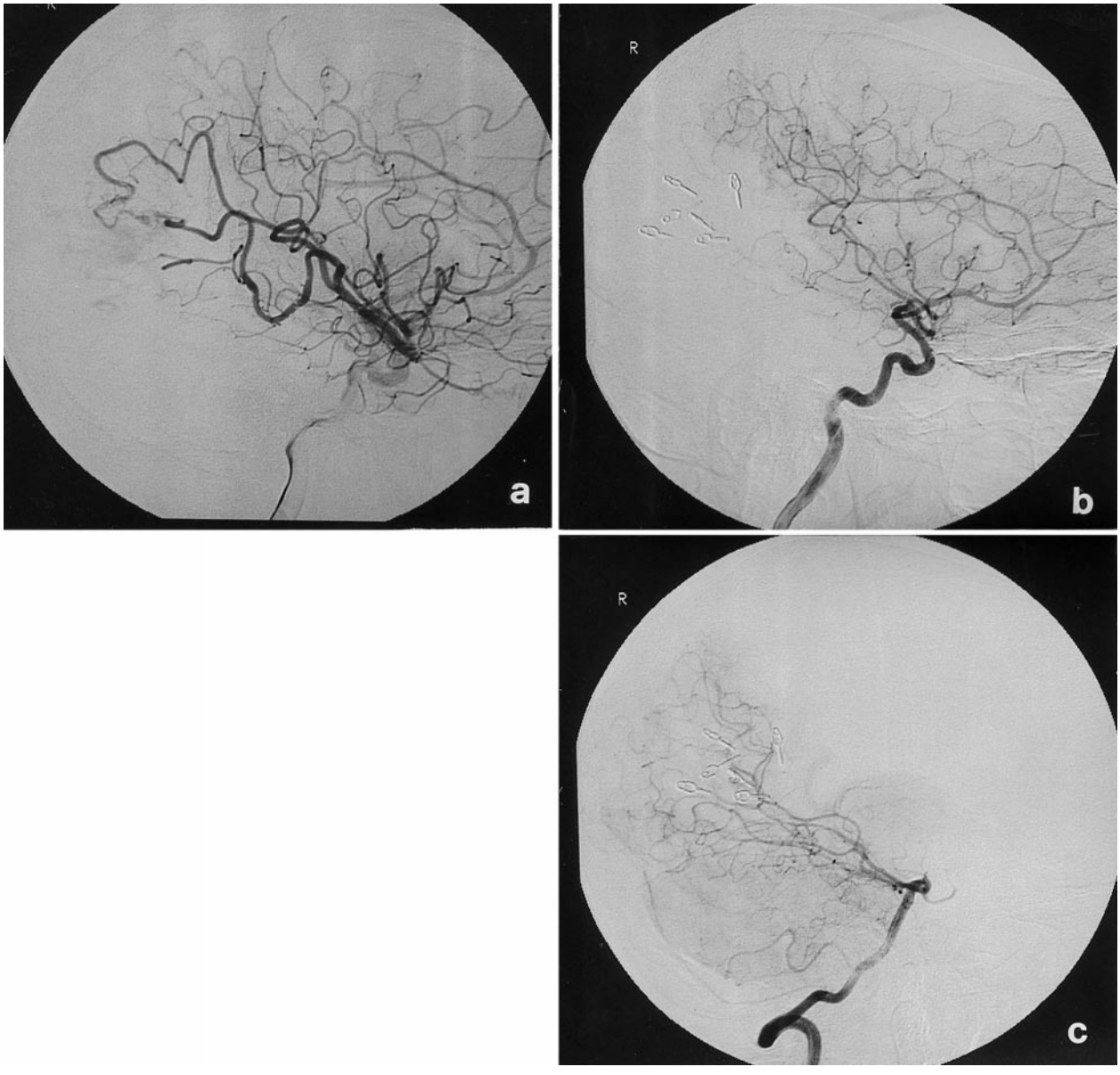

Fig. 4a, 4b, 4c. Right carotid angiogram of the same patient after a subtotal endovascular embolization of the AVM (4a); post-operative carotid and vertebral artery angiograms, showing the complete removal of the AVM (4b, 4c).

a higher tendency to bleed than larger AVMs. However other authors [2] did not confirm this correlation. In our series small AVMs represented half of the cases ($20/37 = 54.1\%$); they showed a higher percentage of bleeding ($16/20 = 80\%$) as compared to medium and large size lesions ($10/17 = 58.8\%$).

The presence of aneurysms on the AVM course has been also associated with a higher rate of haemorrhage [45]. We observed that only afferent or intranidal aneurysms increased the risk of intracranial bleeding in our series (5/7 cases = 71.4%, presenting with haemorrhage), whereas postnidal aneurysms did not seem to have any influence.

Mori *et al.* [33] described a higher mortality rate from AVM haemorrhage in children as compared to adults. This observation was confirmed by Celli *et al.* [4] who reported a 24% mortality in children vs. 6–10% in adults, and by Kondziolka *et al.* [28] who also described a worse prognosis in young patients in terms of morbidity and clinical outcome. In our series 26/37 patients (70.3%) experienced an intracranial haemorrhage with a mortality rate of 23.1% (6/26 cases). The

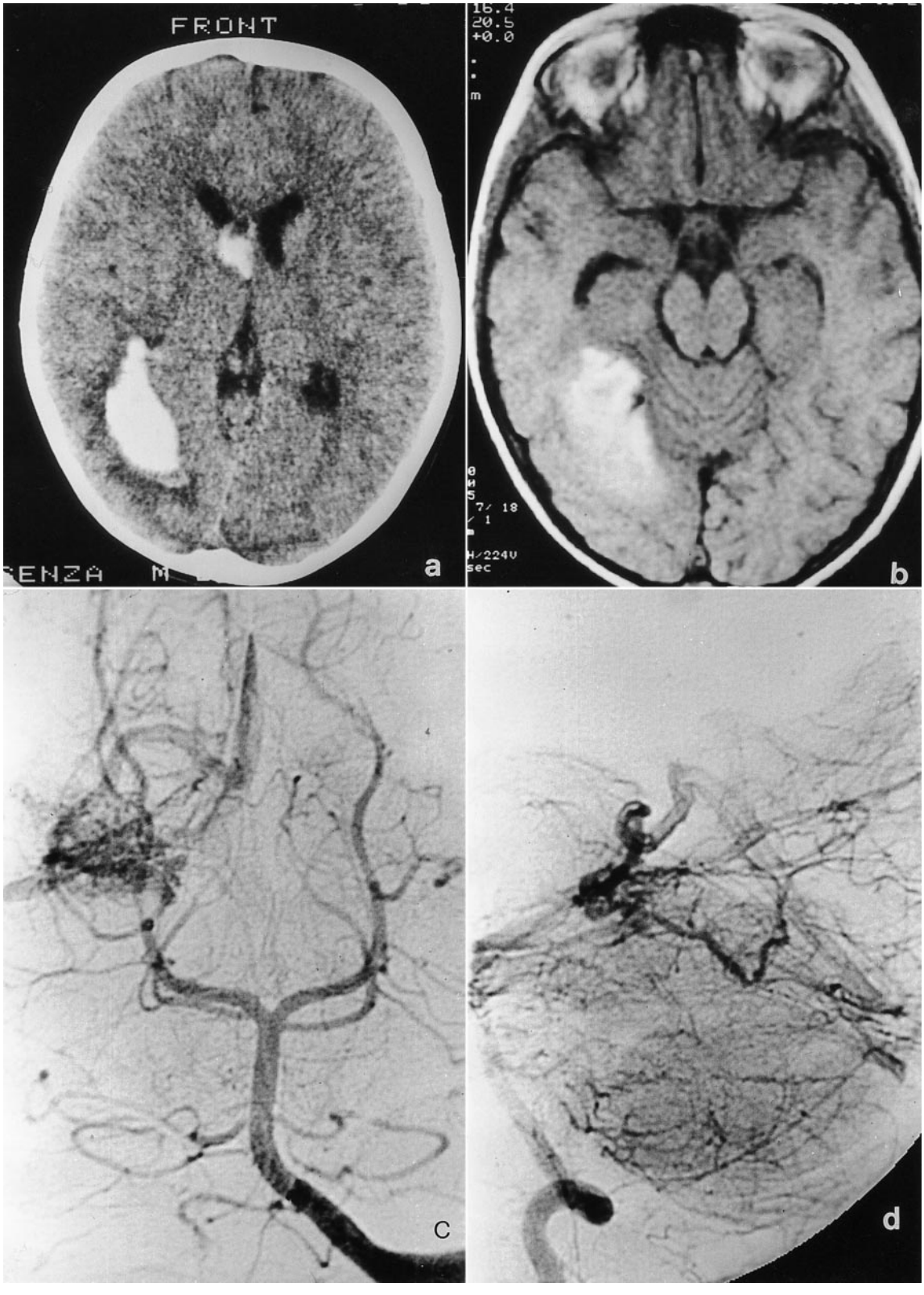

Fig. 5a, 5b, 5c, 5d. CT and MRI scans showing a right parieto-occipital intracranial haemorrhage (5a, 5b) with ventricular bleeding; vertebral angiogram of the same patient in the AP and LL views showing a right posterior temporal AVM with afferents from the posterior choroidal and posterior cerebral arteries (5c, 5d).

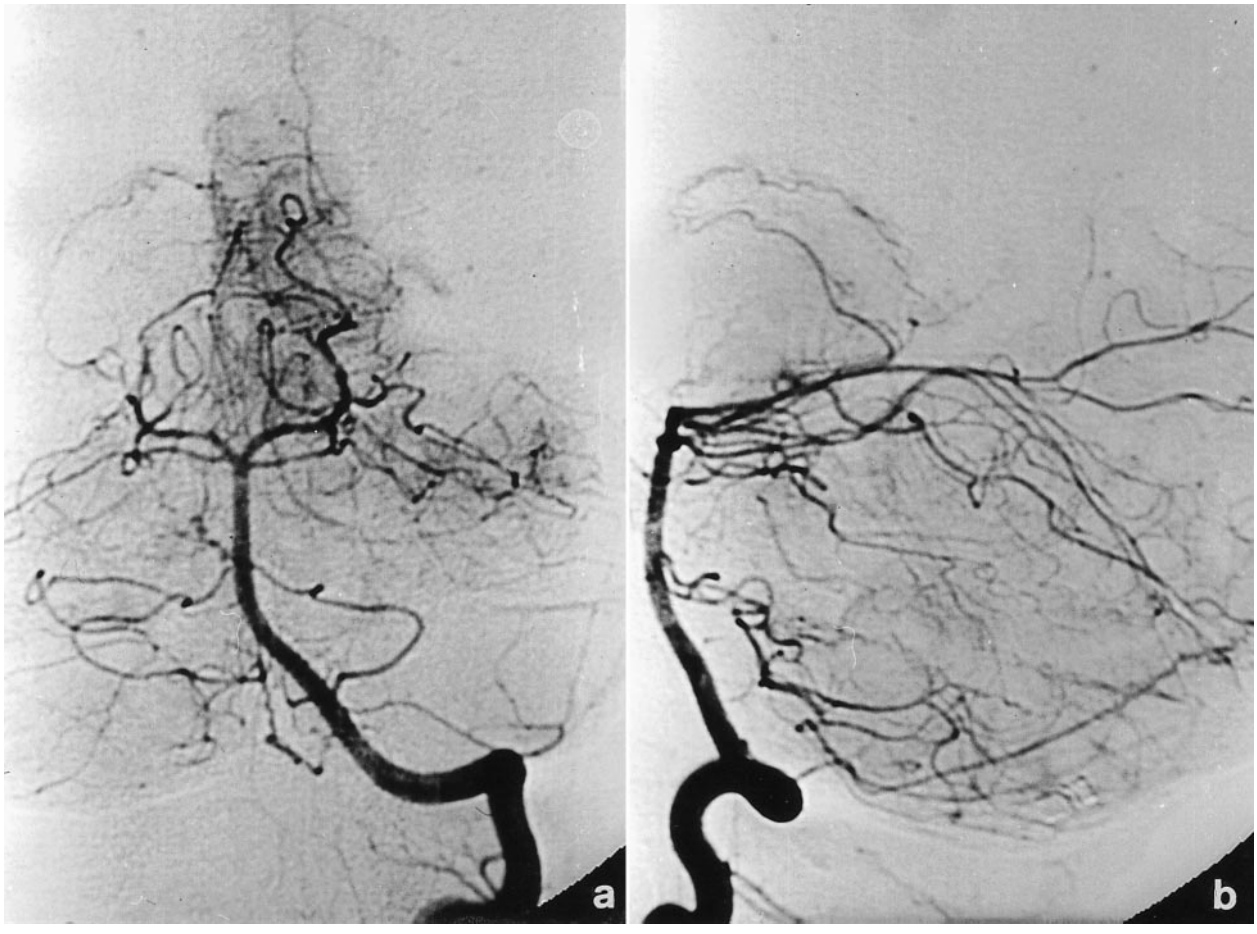

Fig. 6a, 6b. Post-operative angiogram of the same patient in the AP and LL views confirming the complete surgical excision of the AVM.

Table 4. *Cerebral Arteriovenous Malformations in Children*

Spetzler and Martin AMV grade/outcome (mean follow-up: 5.4 years)

Sp. Mart. grade	No. cases	Excellent	Good	Fair	Dead
Grade 1	3	2	1	–	–
Grade 2	13	8	3	1	1
Grade 3	14	7	3	–	4
Grade 4	6	4	1	1	–
Grade 5	1	–	–	–	1

Table 5. *Cerebral Arteriovenous Malformations in Children*

Pre-operative neurological state/outcome (mean follow-up: 5.4 years)

Neurological state	N	Hem.	No hem.	Ex.	Good	Fair	Dead
No alt. of consc.	20	9	11	15	5	–	–
Coma grade I–II	7	7	–	5	2	–	–
Coma grade III–IV	10	10	–	1	1	2	6

most tenable explanation for the high mortality rate in children is the extent of the intracranial haemorrhage which is often more massive and violent in the paediatric population than in adults [4, 20, 21].

Kondziolka *et al.* [28] reported a high number of posterior fossa AVMs in their paediatric series and suggested the possible role of the topographic distribution in explaining the worse prognosis for children with intracranial haemorrhage. Actually, haemodynamic and compressive effects of infratentorial haemorrhages can lead to life-threatening symptoms earlier than in cases of supratentorial malformations [6, 11, 20, 28, 42]. Also in our series posterior fossa AVMs

Table 6. *Cerebral Arteriovenous Malformations in Children*

Treatment/outcome (mean follow-up 5.4 years)					
	No.	Ex.	Good	Fair	Dead
Surgery	23	12	6	1	4
Endovascular tr. + surgery	4	4	–	–	–
Surgery + radiosurgery	1	–	1	–	–
Radiosurgery	3	2	1	–	–
Endovascular tr. + radiosurgery	2	2	–	–	–
No treatment	4	1	–	1	2

were relatively frequent, accounting for 24.3% of the cases (9/37 cases). However we did not observe a particularly unfavourable prognosis. Five of our nine patients with a posterior fossa AVM presented with an AVM bleeding. In spite of this, only one patient died; three patients are currently in excellent clinical condition and the last survivor suffers from only minor neurological sequelae. A relatively limited bleeding in two of the five patients we observed for a haemorrhagic posterior fossa AVM, as well as an early surgical removal of the clot in two out of the three remaining children presenting with a cerebellar haematoma may account, at least in part, to the more rewarding outcomes we observed in our patients as compared to other series.

Management Strategies

The management strategies of AVMs in childhood have been and still are a matter for debate. Adult series have documented a high long-term risk of death and disability in unoperated patients, advising AVM treatment whenever feasible [15, 23, 34, 47]. In contrast to this, several studies supported non-operative management in selected paediatric cases. For example, So [38] reserved surgery only for patients presenting with intracranial haemorrhage; neverthless 8 out of 19 (42.1%) children who were treated conservatively in his series died; furthermore 10 out of 14 (71.4%) patients originally presenting with seizures in his series suffered a late intracranial AVM bleeding. Kelly *et al.* [27] confirmed the indication for surgical treatment in children with extensive haematomas, but they suggested this type of treatment also in infants with large AVMs and in patients with refractory seizure disorders.

Since the early eighties the indication for the operative treatment of AVMs in children has been extended. Gerosa *et al.* [14] confirmed the poor prognosis of AVMs treated conservatively and indicated surgical treatment as the primary therapeutic choice both for AVMs which have or have not bled. Humphreys *et al.* [21], reviewed 105 paediatric AVM cases and reported a bleeding risk of 32% in a ten year observation period, with a mortality rate from a single haemorrhage of 24%. Operative mortality rate was significantly lower (8%) in their experience than that depending on the natural haemorrhagic risk; consequently the authors favoured the surgical option also in cases of non bleeding lesions.

Lussenhop and Rosa [31] proposed an anatomical grading to compare operative and natural history risk in AVM patients. They concluded that in the first three decades the surgical risk is less than the natural one for all patients in grade I and II and for more than half of those in grade III. A more recent study on paediatric AVMs [22] supported these findings, but recognized a percentage of about a 10% of patients who cannot be helped by surgery or any other interventional therapy. These are children presenting with symptoms other than haemorrhage, whose AVMs are large, situated in eloquent regions of the brain and/or with difficult vascular access. Four patients in the present series were not treated ($4/37 = 10.8\%$); two harboured large sized basal ganglia AVMs, one a left choroideal AVM and the fourth a huge left hemispheric vascular malformation fed both by the left anterior and middle cerebral arteries. Grading according to Spetzler and Martin was 3 in 2 cases, 4 in one case and 5 in the last one, respectively. Surgical and endovascular treatment were considered to bear an unacceptable high risk, whereas the large size of the lesions prevented the utilization of radiosurgery. Children with cerebral AVMs which can not undergo any kind of treatment carry a grim prognosis in the majority of instances, related to the long-term natural risk of intracranial haemorrhage [17, 23]. Indeed two of our four children regarded as untreatable died a short time after diagnosis because of massive intracranial bleeding; of the remaining two patients, one is in poor clinical condition 31 months after a huge basal ganglia haemorrhage, whereas the second is in good clinical condition without neurological sequelae 12 months after an intraventricular bleeding from his choroidal AVM.

The Role of Surgical Treatment

Surgical management is still the treatment of choice for parenchymal AVMs [4, 9, 13, 19, 21, 22, 31, 32, 50,

51]. Surgery as a single procedure allows AVM total removal in 70–90% of paediatric patients [9]. Fifty-two to 75% of these cases do not have neurological deficits at the postoperative follow-up. Severe complications after the operation have been reported in about 10% of patients. The reported mortality rate ranges between 0 and 8% [9, 13, 21, 22]. Twelve of the 23 (52.2%) patients who were treated by surgery alone in our Section are currently in excellent clinical condition without neurological deficits; 6 out of the 23 patients suffer minor neurological sequelae (26.1%) whereas severe post-operative complications were observed in 1 patient (4.3%). Four deaths were recorded in the immediate post-operative period: in all cases the surgical treatment had been carried out as an extreme therapeutic attempt in patients in extremely compromised clinical condition.

Endovascular Treatment

Endovascular treatment has mainly an adjuvant role [10, 45, 46, 48]. Wisoff and Berenstein [48], in reviewing their experience with this technique in paediatric AVM patients stated that the complete endovascular obliteration of AVMs is seldom obtained with embolization alone. Partial obliteration of the AVM can be obtained in 54 to 90% of the cases, but there is no evidence that it will protect against haemorrhage [16, 48]. Most series report a cure rate of 7 to 14% with a mortality rate of 1 to 6% and permanent deficits in 7–10% of the cases [45]. In a recent study Frizzel *et al.* [10] analyzed 1246 patients from the literature and found a cure rate of only 5%. Wickolm *et al.* [45], in a series of 192 AVM cases treated by endovascular embolization observed that most of their patients had a high Spetzler and Martin grade (84% > grade 3) and had been regarded as unsuitable for surgical resection. They concluded that the large size, the high number of feeders and the large percentage of patients with perforating arteries feeding the AVMs influenced the low rate of success (cure rate: 13%) and predicted subsequent complications.

A significant improvement in results has been obtained with the combination of endovascular treatment and surgery [18, 44]. Westphal *et al.* [44] reported a cure rate of 95.8% in a series of 72 patients who underwent one stage AVM embolization and surgical resection. This result compared well with the 92% rate of success in a group of 25 cases with lower grade AVMs treated by surgery alone. Four children in the present study underwent a combined endovascular and surgical treatment with an uneventful AVM total removal in all the cases.

Radiosurgery

Stereotactic radiosurgery has been estabilished as a successful treatment in small or moderate sized AVMs (< 3 cm.) [1, 8, 30, 49]. Most recent studies report a 3 year obliteration rate of 80–95%; severe complications are described in 2.5–4.5% of patients and transient neurological deficits in about 3% of cases [8, 49]. A progressive reduction in the success rate is observed with increasing size and volume of the AVM. Engenhart *et al.* [8], with a mean dose of 23.6 Gy, reported a 3 year obliteration rate of 83% with volumes less than 4.2 cc., and of only 50% with volumes of 70–113 cc. Higher treatment doses (25–45 Gy) significantly increased the risks of neurological sequelae, with both transient and permanent deficits observed in up to 50% of patients. Most authors consider 2 to 3 years as the time required to assess the results of radiosurgical treatment [8, 30]. During this period radiosurgery has no protective effect against the possibility of AVM bleeding. The calculated annual risk of intracranial haemorrhage is 1.6–8%, in fact not different from the natural history of AVM bleeding [8, 30, 49].

Encouraging results have been obtained with radiosurgery in selected paediatric series. Levy *et al.* [30], utilizing Bragg peak radiosurgery in 25 children and adolescents, stated that 14 of 18 (77.7%) had experienced total obliteration of their AVM two years after treatment. Yamamoto *et al.* [49], in a series of nine patients with small size AVMs (< 3 cm), observed a cure rate of 66.6% (mean dose: 23 Gy) after 5 years and no differences in pretreatment and posttreatment neurological conditions. Similar results were reported by Riva *et al.* [37] on cognitive and psychological performances in 8 children six years after gamma unit radiosurgical treatment.

Six children in the present study were referred for stereotactic radiosurgery. In three cases this was the only treatment given. In spite of the small size of the AVM (< 3 cm. in all cases) only a reduction in size has been obtained in these patients (mean follow-up observation: 6 years); a similar result was observed in the two children in whom radiosurgery was combined with endovascular treatment (mean follow-up observation: 19.5 months). A complete obliteration was instead documented in the patient who received radiosurgery

after a subtotal surgical resection of a posterior fossa AVM.

Factors Influencing Outcome

Previous studies have defined the Spetzler and Martin scale as the most reliable method to describe AVM complexity and found it to be highly predictive of patients outcome [19, 39, 40]. Heros *et al.* [19], by reviewing a series of 153 personal cases, described excellent or good results in all patients with grade I and in 94.3% of patients with grade II AVMs, but only in 28.6% of patients with grade V AVMs. Mortality and late morbidity rates were 1.1% in grade I to III AVM patients, 12.2% in the group with grade IV AVMs and 38.4% in patients with grade V AVMs. Steinberg *et al.* [40] confirmed these findings in a series of 33 patients treated by a combination of surgical treatment and radiosurgery. The only two deaths were observed in patients harbouring respectively a grade IV and a grade V AVM. A less direct correlation was observed in the present study. Indeed, in spite of a worsening in the outcome of patients with grade I to III AVMs (patients in excellent or good conditions: grade I = 100%; grade II = 84.6%; grade III = 71.4%; patients who died: grade I = 0%; grade II = 7.7%; grade III = 28.6%), no patient with a grade IV AVM died and only one out of 6 of these children (16.6%) is actually in fair clinical condition.

In our experience the factors which were more strictly predictive of the patients outcome were the occurrence of AVM bleeding and the neurological status on admission. All the patients who did not present an intracranial haemorrhage are actually in excellent (9/11) or good (2/11) clinical condition, compared to 18/26 (69.2%) of the children who suffered AVM bleeding.

All the patients who had suffered an intracranial haemorrhage, but presented on admission without any alteration of consciousness (9/26), or with a minor impairment (coma grade I or II) (7/26) are actually in excellent (11/16) or good (5/16) clinical condition. Six of the ten patients (60%) in coma grade III or IV on admission died and another two patients (20%) have severe neurological sequelae. These findings are not in agreement with previous reports. Indeed, in spite of the fact that most authors consider a posthaemorrhagic high grade comatose state as a controindication for surgical treatment in adults [13, 24], encouraging results have been obtained in paediatric patients operated on in comparable clinical conditions [4, 9, 21]. Such a fact has been emphasized by Humphreys *et al.* [21] who concluded that "the child's biologic plasticity is such that the degree of postoperative recovery can be as complete and gratifying as the preoperative deterioration was rapid and dramatic".

Finally the analysis of the outcome, with reference to the different types of treatment we utilized in our series of children is not possible, because of the low number of cases in the single subsets of patients. Endovascular treatment and radiosurgery appeared in our series to have a significant adjuvant role, and to improve surgical results (Table 6). All the patients who could profit of pre-operative endovascular embolization of their AVM or of postoperative radiosurgery are currently in excellent or good clinical condition, compared to a percentage of 78.2% of favourable results in children who underwent surgery as the only treatment modality.

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Comments

The authors present a series of 37 AVM observed in patients under the age of 15. The authors study carefully the clinical symptomatology on admission and compare the therapeutic options in a paediatric population.

Despite the small number of patients this paediatric series is interesting for several reasons.

- AVM are uncommon lesions in children (0.014–0.028%).
- Explanation for late clinical presentation are suggested and raise some controversial opinions.
- The annual risk of haemorrhage is higher in children (3,2%) than in adults (2.2%). This fact must be considered at the time of initial management.
- The authors confirm a well known datum in adult population: small and deeply located AVM; in the basal ganglia and the thalamus, have a higher risk of rebleeding.
- The high mortality rate in children is confirmed in this series (20–24%) as it exists in other series in the literature, compared with adults (6–10%). This mortality is due mainly to massive intracranial haemorrhage.
- The different therapeutic strategies are analyzed and compared. Initial surgical management remains the treatment of choice for peripheral AVM. Endovascular treatment has an adjuvant role. Embolisation alone is insufficient (5% of good results). Combined endovascular and surgical treatment give comparable results to surgery alone. Stereotactic radiosurgery is indicated in small and more deeply situated AVM. Two or three years are needed to assess the final results of radiosurgical treatment. During this interval the calculated annual risk of intracranial haemorrhage remains the same as that of the natural history of AVM bleeding.
- For the authors good correlation between Spetzler scale and the outcome doesn't exist. The most predictive factors for a favourable outcome are the occurrence of AVM bleeding and the initial neurological outcome.

In conclusion the authors emphazise the sentence of R. Humphreys: «The Child's biologic plasticity is such that the degree of postoperative recovery can be as complete and gratifying as the preoperative deterioration was rapid and dramatic».

M. Choux

The Cerebral Arteriovenous Malformations in Children, the Bicêtre Experience

The management of cerebral arteriovenous malformation in children has undergone several significant changes in the past 20 years. From neurosurgical to Interventional Neuroradiology therapeutic strategy has evolved. As an example, between 1984 to 1999 our group in Bicêtre has been involved in the therapeutic discussion of 213 cerebral AVMs in paediatric cases (< 16), in addition to 242 Vein of Galen malformations. The age at first consultation was the following: neonates 7.5%, infants 14.1%, and children 78.4%. Several particularities were noted in our group with 47% of haemorrhage at presentation and several complex arteriovenous diseases. Multifocal AVMs were noted in 8.4% and in addition 7% of children had a Rendu Osler Weber disease; 3.7% were diagnosed as Wyburn Mason AVM. Only 8% of children presented micro-AVM. In 73.2% of cases embolisation was proposed, 6.6% of cases were felt to be therapeutic contra-indications because of brain damage, 4.7% (opted for no treatment). Fourteen of these children were lost to follow up and 8.4 were proposed for direct surgery or radiosurgery. The usual male dominance in several other paediatric vascular cases was not noted in our group of paediatric AVMs, where female and male were equally seen.

These numbers and decisions are very different from the series reported by the group of Concezio Di Rocco. These differences lean obviously on the fact that our referral pattern is geographically spread over a large population. All the patients seen or referred to Bicêtre are already seen by other specialists: neurosurgeons and paediatric neurosurgeons, paediatric neurologists, neonatalogists or paediatric cardiologists. Many of them represented poor indications for surgery. The treatment has been undertaken at various ages: 0.8% of the embolisations have been performed at neonatal age; 18.4 at infancy and 80,8 in children. Four percent among these children embolised have been lost to follow up.

Permanent neurological deficits have been noted in 6.9%, most of them related to visual field problems or worsening of pre-existing deficits. Six percent of the children embolised died: 1 despite embolisation, 1 five hours after embolisation with haemorrhage, 1 following secondary surgery, 5 patients rebleed 4 months to 2 years after the last embolisation. Although, most of the cases actually embolised had previously bled, 7% of haemorrhagic recurrences were noted during the follow up period. Total morphological exclusion by embolisation alone was achieved in 31.5%. In the other cases the treatment is partial.

These numbers presented at several meetings and previously published in part in many papers illustrate the place that endovascular approaches have taken in the technical discussion of these diseases.

The interventional neuroradiology contribution extends the understanding of the disease, and raises several questions, some of which remain unanswered. The discussion around the congenital nature of brain AVM must be touched upon. There are several arguments suggesting that the AVMs are not present as such at birth in most of the cases. The dormant lesion is triggered secondarily, postnatally, most probably after infancy at least when the granulations are fully matured. Therefore the natural history of the lesion can only start when the AVM has been formally diagnosed. We have seen several lesion "appear" accounting for that pseudo-acquired nature. However AVMs will not grow in size and small lesions will not become large ones over time. The specific angiogenetic capacities in children should also be taken into consideration when surgical removal is organised and haemorrhage has occurred. The observations made about recurrence or regrowth, point to the specificities of the paediatric population with this high percentage of multifocal lesions.

The specificity of the children AVMs leans both on the angioarchitecture lacking flow related aneurysms and presenting a high degree of single hole arteriovenous fistulae with large venous pouches, and a specific natural evolution that includes hydrovenous disorders related to post natal jugular bulb and granulation dysmaturations. In addition the focal atrophy response frequently noted in the vicinity of the AVM is specific to the infant population. Multiple imprecisions occur in the recognition of associated arterial aneurysms in paediatric AVMs, they are certainly extremely rare albeit the highest flow lesions are seen in that population group. Most of the confusion is related to the presence of arterial pouches at the acute stage of haemorrhage in relation to a false arterial aneurysm.

We have already discussed the limitation of the Spetzler grading in this population:

The deep venous drainage is often involved because of the high flow characteristics of these lesions,

The cerebral eloquence is often difficult to assess particularly in view of the plasticity of the brain functions in the youngest ages.
The size can be spectacular due to the venous compartment of these lesions, in relation to a very focal shunt easily treated by its local exclusion.

From our earliest involvement in these treatment managements we placed as the ultimate therapeutic goal: the normal growth and life of the child who presented with a brain AVM. Such an ambitious objective implies

To know the spontaneous risk of the disease if the patients referred are left untreated
The level of morbidity and mortality involved in the proposed treatment
The clinical results over time in relation to the technique used (provided that it remained stable and was not changed every 2 or 3 years)

There is no statistical evidence that complete exclusion (by any means) is the best choice and thus the primary goal to reach in any of these difficult lesions. It is certainly a crude approach to the question: risk of the disease-risk of the treatment. On the contrary the long term results of our series of Vein of Galen malformations (that are excluded from the numbers and discussion started above) show the quality of the clinical results when the goal of treatment is a normally growing child. From our experience, the value of partial targeted treatment of cerebral AVMs by embolisation has shown its capacity to significantly reduce the risk of haemorrhage. This embolisation is carried on with glue and targeted on the weak or active features of the angio-architecture. This statistically validated observation cannot be confused with the results of partial treatment regardless of the modality as it is often referred to. The classic comment about the size and risk of bleeding is an erroneous extrapolation of a retrospective manifestation at presentation. There is no statistical evidence that a micro-lesion will bleed more than a large one over time in adults and certainly not in children.

The management of neonates and infants is based on our capacity to understand the interference of the AVMs with the post natal maturation processes and to reduce them below the level of interference. In fact the basis for an aggressive management is the postulated morbidity of a future haemorrhagic episode. From a recent publication concerning the morbidity of haemorrhage (although in adults) shows that the residual morbidity is lower than usually estimated. This paper raises several questions when observed therapeutic morbidity/mortality is higher. It also shows that the assessment of the risk of haemorrhage is insufficient to justify a hazardous approach if the morbidity of future bleeding episodes is not truly appreciated. It is likely that post haemorrhagic morbidity is overestimated even in children.

Such discussion is crucial to choose for a given case the best technique among the available ones in a given place.

Finally, identification of various sub-groups as for example: single hole arteriovenous fistulae, multifocal nidus, Rendu Osler Weber, Wyburn Mason, proliferative angiopathy are certainly representing different diseases with a natural history requiring different management and distinct acceptable therapeutic morbidity. Applying adult observations to children can only be done with extreme caution, children are certainly not small adults and their AVMs have not the same consequences. Neonates and infants also represent a distinct population with its specific pathophysiology and vulnerability; in this group lack of results can sometimes be due to inappropriate therapeutic decisions. The quality of that result depends on the accurate definition of the treatment target and the choice of the optimal moment to perform it. In addition correct training and sufficient critical mass are mandatory to offer updated treatment of paediatric cerebral AVMs. Homogeneously high quality studies and analysis of the angio-architecture are also expected.

Fully evaluated children by a specialised paediatric neurosurgical group in association with paediatric interventional and paediatric neurology support are today expected standards in Europe. There is a need to accurately and permanently study (evaluate) the clinical presentation, post therapeutic outcome, and follow up of treated and untreated cases in order to assess the natural history and results of practices in a given place. Significant differences in referral populations may lead to apparent contradictions in decisions made.

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