

THE MANAGEMENT OF VEIN OF GALEN ANEURYSMAL MALFORMATIONS

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OBJECTIVE: The vein of Galen aneurysmal malformation (VGAM) is a choroidal type of arteriovenous malformation involving the vein of Galen forerunner. This is distinct from an arteriovenous malformation with venous drainage into a dilated, but already formed, vein of Galen. Reports of endovascular treatment of VGAM in the literature approach the disease from a purely technical viewpoint and often fail to provide satisfactory midterm results. To focus the therapeutic challenge to a strictly morphological goal overlooks the fundamental aspects of neonatal and infant anatomy and fluid physiology. During the past 20 years, our approach to VGAM has remained the same. Our experience, based on 317 patients with VGAM who were studied in Hospital Bicêtre between October 1981 and October 2002, allows us to describe the angioarchitecture, natural history, and management of VGAM in neonates, infants, and children.

METHODS: Of our cohort of 317 patients, 233 patients were treated with endovascular embolization; of these, 216 patients were treated in our hospital. The treatment method of choice was a transfemoral arterial approach to deliver glue at the fistulous zone.

RESULTS: Of 216 patients, 23 died despite or because of the embolization (10.6%). Twenty out of the 193 (10.4%) surviving patients were severely retarded, 30 (15.6%) were moderately retarded, and 143 (74%) were neurologically normal on follow-up.

CONCLUSION: Our data demonstrate that most treated children survive and undergo normal neurological development; an understanding of the clinical, anatomical, and pathophysiological features of VGAM has, therefore, reversed the former poor prognosis. Our level of understanding about the lesion allows us to predict most situations and remedy them by applying a strict evaluation protocol and working within an optimal therapeutic window. Patient selection and timing remain the keys in the management of this condition. It is more important to restore normal growth conditions than a normal morphological appearance, with the primary therapeutic objective being normal development in a child without neurological deficit.

KEY WORDS: Cardiac failure, Clinical outcome, Glue, Hydrovenous disorders, Transarterial embolization, Vein of Galen malformation

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During the past 20 years, written contributions on cerebral arteriovenous malformations (AVMs) in children have evolved from anecdotal case reports to short series, offering a better understanding of the disease, the therapeutic strategies, and results of various managements. Historical contributions from the neurosurgical point of view have demonstrated limitations in the management of these difficult lesions and relinquished them to interventional neuroradiology.

The vein of Galen aneurysmal malformation (VGAM) is an AVM of the choroidal sys-

tem draining into the vein of Galen forerunner. This is distinct from an AVM with venous drainage into a dilated, but already formed, vein of Galen. The first description of a possible VGAM was reported by Steinhel in 1895, cited by Dandy (8); this was, in fact, a cerebral AVM of the diencephalon draining into a dilated vein of Galen. Today, it would be described as a false vein of Galen malformation (18). The first therapeutic attempts were recorded at the beginning of this century and describe an infant with intracranial hypertension who subsequently underwent bilateral

internal carotid ligation. In 1946, Jeager reported bilateral arteriovenous (AV) communications draining into an aneurysmally dilated vein of Galen (15). Boldrey et al. (2) treated two similar patients with arterial ligation in 1949. Only the last patient seems to correspond to a VGAM. Most subsequent authors used the same generic name, VGAM, for very different entities. Failure to recognize the true nature of the lesion resulted in imprecise anatomical and natural history descriptions.

Raybaud et al. (23) were the first to recognize that the ectatic vein in VGAM was, in fact, the median vein of the prosencephalon, the embryonic precursor of the vein of Galen itself. A complete pathological specimen of a neonatal case of true VGAM was analyzed and illustrated by Landrieu in the late 1980s (15), supporting the findings of Raybaud et al. We appreciated the dural sinus abnormalities (17) and persistent alternative embryonic routes of the deep venous drainage in this condition (16). From then on, the vein of Galen malformation was recognized as an embryonic choroid plexus vascular malformation.

Reports of endovascular treatment of VGAM in the literature, although emphasizing technical solutions, often failed to provide satisfactory midterm results (7, 9, 14, 20); mental retardation in these patients was seldom mentioned or tested. Unnecessary premature interventions have also interfered with the quality of the results. Instead of dealing with the difficulty of establishing satisfactory patient selection criteria, these reports merely approached the disease from a purely technical viewpoint. In certain reports, anatomic exclusion of lesions was considered a technical success, even when the child died shortly after treatment. To focus the therapeutic challenge on a strictly morphological goal overlooks the fundamental aspects of neonatal and infant anatomy and fluid physiology (1, 12, 26).

During the past 20 years, our approach to VGAM has been a different one, which we outline in this article and which is based on our experience with 317 patients with VGAM who were studied in the Bicêtre Hospital between October 1981 and October 2002 (Table 1). Of these, a total of 233 patients were treated with endovascular embolization; 216 patients were treated in Bicêtre, whereas 17 were embolized elsewhere by other teams after consultation (Table 2). The decision for therapeutic abstention was made in 67 patients for a variety of

TABLE 2. Therapeutic decision and proposed treatment for patients with vein of Galen aneurysmal malformation

| | Embolization | Abstention | Lost to follow-up | Total |
|----------|----------------|------------|-------------------|-------|
| Neonates | 88 (5) | 45 | 7 | 140 |
| Infants | 103 (8) | 16 | 6 | 125 |
| Children | 42 (4) | 6 | 4 | 52 |
| Total | 233 (17) 73.5% | 67 (21.1%) | 17 (5.4%) | 317 |

reasons (Table 3). We consider our group of patients to be homogeneous because the neuroradiological assessment, technical principles, and perioperative clinical management have been similar during the past 20 years and were carried out by the same group of physicians. Our primary therapeutic objective is to preserve normal development without neurological deficit. To achieve these clinical objectives, we have chosen, since 1981, transarterial embolization using glue (*n*-butylcyanoacrylate) as the embolic agent. The following observations were derived from this experience.

ANGIOARCHITECTURE OF VGAM

The VGAM involves the choroidal fissure and extends from the interventricular foramen rostrally to the atrium laterally (18). The arterial supply involves the choroidal arteries; it may also receive a significant contribution from the subependymal network originating from the posterior circle of Willis. These arteries should be differentiated from transmesencephalic ones (their involvement, in fact, would exclude the diagnosis

TABLE 3. Reasons for therapeutic abstention

| Reason | No. (%) |
|---------------------------------------|----------|
| Neonates | |
| Therapeutic abstention | 45 |
| Encephalomalacia | 25 (56%) |
| Neonatal score < 8 ^a | 17 (38%) |
| Therapeutic interruption of pregnancy | 3 (6%) |
| Infants | |
| Therapeutic abstention | 16 |
| Encephalomalacia | 9 (56%) |
| Technical failure | 1 (6%) |
| Spontaneous occlusion | 6 (38%) |
| Children | |
| Therapeutic abstention | 6 |
| Bicêtre admission Score 1 | 3 (50%) |
| Surgery | 1 (17%) |
| Spontaneous occlusion | 2 (33%) |

Score 8, four patients; Score 7, six patients; Score 6, three patients; Score 5, four patients. For further description of the neonatal score, refer to Table 4.

TABLE 1. Characteristics of patients with vein of Galen aneurysmal malformation, 1981–2002

| Age | At diagnosis (mo) | At first consultation (mo) |
|---------------------------|-------------------|----------------------------|
| Fetus | 93 (29.3%) | 18 (5.7%) |
| Neonates (<1 mo) | 119 (37.5%) | 122 (38.5%) |
| Infants (>1 mo and <2 yr) | 82 (25.9%) | 125 (39.4%) |
| Children (2–16 yr) | 23 (7.3%) | 52 (16.4%) |
| Total | 317 | 317 |

of VGAM and indicate a tectal AVM). Very rarely, thalamoperforating arteries are recruited. Subependymal and trans-cerebral contributions are accessory in the supply to the shunt, possibly created by the sump effect of the venous drainage. They usually disappear after occlusion of the most prominent shunts. The persistent limbic arterial arch, which bridges the cortical branch of the anterior choroidal artery initially and the posterior cerebral artery secondarily with the pericallosal artery, is seen in nearly half of the neonatal patients (Fig. 1). The limbic arterial arch on each side can anastomose and may fuse on the midline in the supracallosal region. The circle regresses after obliteration of the VGAM by embolization.

The nidus of the lesion is located in the midline and often receives a bilateral, and usually symmetrical, supply. In general terms, two types of angioarchitecture are encountered: choroidal and mural. The former corresponds to a very primitive condition, with contribution from all the choroidal arteries and an interposed network before opening into the large venous pouch (Fig. 2). This type is encountered in most neonates with low clinical scores. The latter type corresponds to direct AV fistulas within the wall of the median vein of the prosencephalon (Fig. 3). These fistulas can be single or, more often, multiple. The mural form is better tolerated, is, therefore, encountered more often in infants who do not experience cardiac symptoms and who feature higher clinical scores, as outlined below.

The venous drainage of the VGAM is toward the dilated median vein of the prosencephalon. No communication exists with the deep venous system. Thalamostriate veins open into the posterior and inferior thalamic veins, as occurs normally during the third month in utero. They secondarily join either the anterior confluence or, more often, a subtemporal vein or lateral mesencephalic vein, demonstrating a typical ϵ -shape on the lateral angiogram (Fig. 4). The straight sinus is absent in almost all patients. Falcine dural channels drain the pouch toward the posterior third of the superior sagittal sinus, which also happens to be where granulations are expected to appear

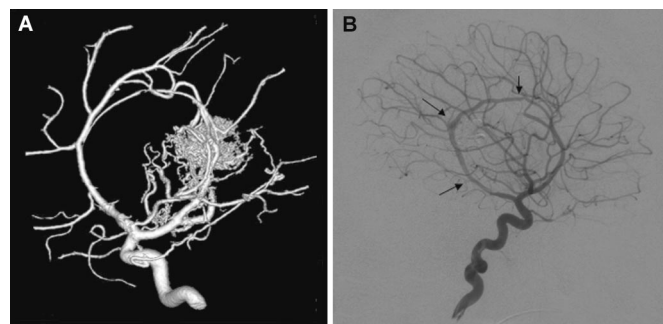


FIGURE 1. Persistent limbic arch. A, three-dimensional aspect of a persistent limbic arch in a lateral and slightly anterior oblique view. Note the choroidal and subependymal feeders of the VGAM. B, carotid injection lateral projection after complete exclusion using glue embolization. The limbic arch can be well perceived with a communication between the posterior cerebral artery and the anterior cerebral artery via the pericallosal artery (arrows).

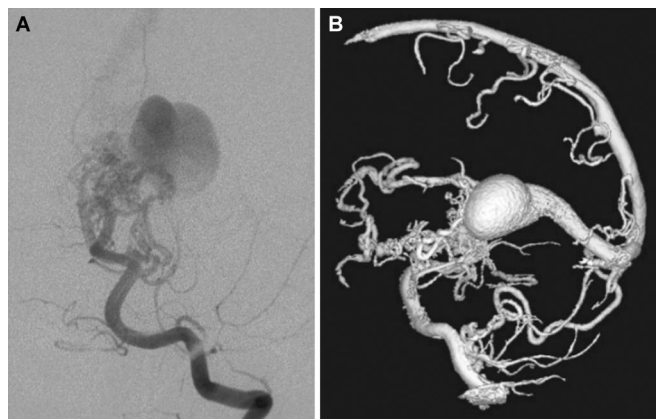


FIGURE 2. Choroidal VGAM. Vertebral injection in frontal projection (A) and three-dimensional reconstructed image (B) demonstrating multiple choroidal feeders forming a nidus anterior to the venous pouch. This venous pouch corresponds to the dilated median vein of the prosencephalon, which is the precursor of the vein of Galen.



FIGURE 3. Mural VGAM. Vertebral injections in lateral (A) and frontal (B) projections. In comparison with choroidal VGAMs, there is a direct arteriovenous fistula within the wall of the venous pouch.

first. Other embryonic sinuses persist, such as the occipital and marginal sinuses. The appearance of the remainder of the venous system is difficult to predict. The torcular is often dilated in relation to the flow and turbulence exiting from the falcine or straight sinus. A few months after birth, the cavernous sinus matures and captures the sylvian veins to offer the brain a potential route of drainage through the orbit, pterygoid plexus, or inferior petrosal sinus (Fig. 5). Drainage of the cerebral veins into unusual channels may take place, apparently without significant functional implications. The plasticity of the venous system in these instances is remarkable. It changes with the spontaneous modification of the hemodynamics and the influence on growth and maturation induced by the disease, and, eventually, treatment undertaken. It is clear that the timing of interference with the anatomic continuum is as important as the extent of the corrections proposed in the treatment of these lesions (22).

NATURAL HISTORY OF VGAM

The natural history of VGAM is difficult to discern from reports documented in the literature (13). Much of the so-

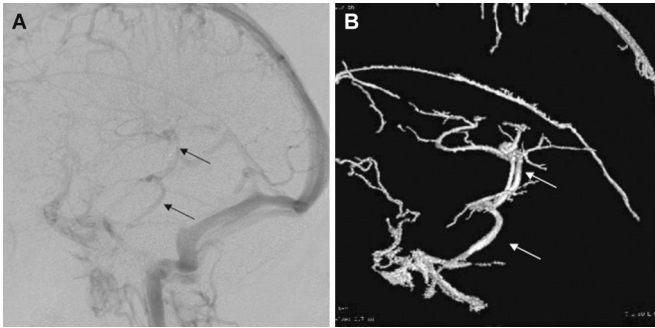


FIGURE 4. Late venous phase of vertebral angiogram (A) and three-dimensional angiographic (B) aspect demonstrating the ϵ -shaped deep venous drainage into the superior petrosal sinus (arrows). Because there is no vein of Galen, the deep venous system has to find an alternate route to drain. Thalamostriate veins open into the posterior and inferior thalamic veins, which secondarily join a subtemporal or lateral mesencephalic vein, which then join the superior petrosal sinus, demonstrating a typical epsilon shape on the lateral angiogram.

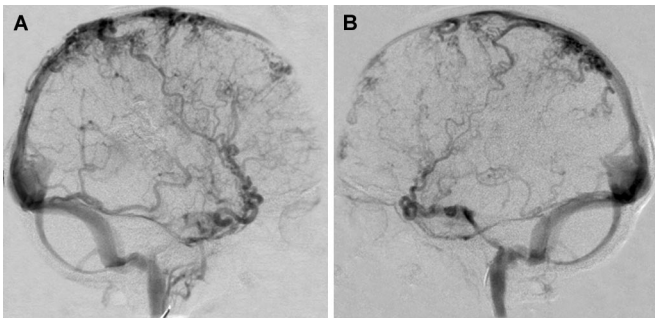


FIGURE 5. A and B, angiograms showing bilateral carotid injections in the lateral projection. There is bilateral cavernous sinus drainage and a phlebotic aspect of the cortical veins, despite complete exclusion of the VGAM.

called natural history of surviving children comes from case series that include patients who had undergone shunting procedures. The onset of seizures traditionally described in the late phase of VGAM reflects this evolution in babies who underwent shunting. Most neurological symptoms and hemorrhages reported in the literature were mistakenly diagnosed VGAM or are the result of changes in angioarchitecture, which, in turn, altered the consequences of the initial lesion. Endovascular management of this population has given us a chance to observe the anatomical and clinical evolution under nonsurgical circumstances.

Through our management of VGAM patients, the predictability of certain evolutions and the various clinical tools developed over the years have helped us to determine the optimal timing for treatment (therapeutic window). We have chosen a diagrammatic presentation of the natural history of VGAM to highlight the path followed by each individual (Fig. 6). As soon as previous stages have been identified, the subsequent ones are more easily anticipated. The therapeutic window outlines the optimal moment for the endovascular

approach. It has become the objective of our decision regarding therapeutic timing and points to the therapeutic goals to be achieved. To achieve normal cerebral development does not require, in all cases, rapid morphological disappearance of the AV shunt or rapid shrinkage of the ectasia. To reach our objectives, we chose transarterial embolization using the femoral approach with glue (*n*-butylcyanoacrylate) as the primary embolic agent. This method has proven to offer reliable and predictable results. In the following paragraphs, we first focus on the management of VGAM in the neonate, followed by the management of this disease in infants and children, because the specific complications are different for these age groups, as outlined below.

MANAGEMENT OF VGAM

Neonates

Antenatal diagnosis is not, by itself, an indication for termination of pregnancy, early delivery, or Caesarian delivery at term. There are only two antenatal manifestations that have shown prognostic value and represent an indication for abortion: in utero cardiac failure and cerebral damage. These findings are associated with severe, irreversible multiorgan failure at birth (11, 24).

The idea that a neonate with severe multiorgan failure would do well if the VGAM was to be excluded is wrong; there is evidence in the literature that, in neonates who have undergone properly performed emergency embolization, the neurological outcome was disastrous despite apparently normal pretherapeutic brain imaging. This emphasizes the importance of a thorough analysis to best predict the degree of cerebral tissue impairment not evident on imaging. We are aware of the difficulty in making these decisions, and this represents the basis and purpose of our VGAM neonatal score (Table 4).

When the diagnosis of VGAM is suspected clinically, a pretherapeutic evaluation should include the following information: 1) clinical evaluation of the baby, including the weight and head circumference; 2) evaluation of renal and liver function; 3) transfontanelar ultrasound to evaluate for encephalomalacia; 4) cardiac ultrasound to assess cardiac tolerance and any associated cardiac malformation that may require specific treatment; 5) magnetic resonance imaging to provide information on lesion morphological features (the diagnosis of a cerebral AVM at this age would have completely different therapeutic consequences) and the status of myelination; and 6) electroencephalogram only if the baby is in an intensive care unit (ICU), intubated, and sedated. Angiography in the neonatal workup is not indicated. Only if embolization is contemplated should angiography be performed at the same time. Management decisions follow a strict protocol based on the neonatal score derived from the above information. The specific neonatal score documents the significant nonneurological manifestations in this age group in addition to assessing the gross neurological status. According to our experience, a score

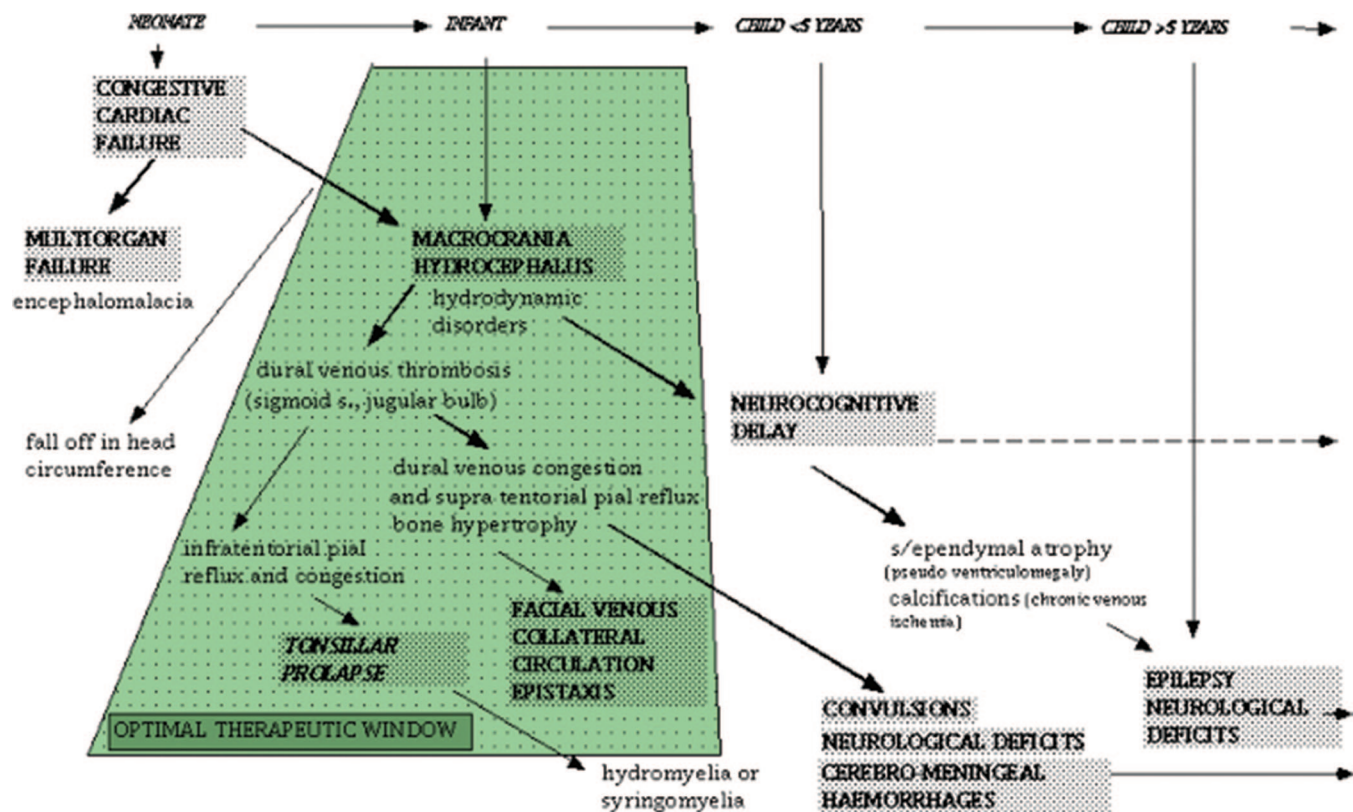


FIGURE 6. Diagram illustrating the natural history of VGAMs over time. Note that the optimal therapeutic window is in infancy, typically at approximately 5 months of age (from, Lasjaunias P: *Vascular diseases in*

neonates, infants and children. Interventional Neuroradiology Management. Berlin, Springer, 1997 [15]).

of less than eight out of 21 results in a decision not to treat; a score of between eight and 12 out of 21 entails emergency endovascular intervention; a score of more than 12 out of 21 leads to the decision for medical management until the child is at least 5 months of age, providing there is no failure to thrive. At such a time, a decision is made to proceed with endovascular treatment no matter what the symptoms are. In our experience, angiography and treatment at 5 months has proven to balance best the maximum efficacy of embolization against the minimum risk of cerebral maturation delay.

In neonates, the immediate goal is not only to restore a satisfactory systemic physiology and to gain time, but also to recreate the conditions enabling further maturation of the vascular systems. It is apparent that the score used during the first few days of life varies from one day to the next, depending on the response to medical treatment. Failure to observe a response to ICU management (or stagnation) leads to early embolization at neonatal age. The end point of partial embolization is usually the reduction of one-third to half of the AV shunt to expect a significant systemic impact. The role of the pediatric intensive care physician is crucial at the neonatal age in the management of VGAM. We rely heavily on their analysis of the clinical situation and their therapeutic choices.

Infants and Children

In infants and children, the immediate goal is to preserve the hydrovenous equilibrium, as will be outlined later, to preserve the normal brain development, and to exclude the lesion. Our concern in patients of this age is to anticipate the natural history to avoid ventricular shunting. Premature attempts to exclude an asymptomatic lesion or taking significant technical risks to exclude, in one session, a VGAM that presents no immediate cerebral danger should not be encouraged. Conversely, a decision not to treat on the assumption that an asymptomatic lesion is well tolerated is dangerous. In children referred late with already impaired functions or severe retardation, we have attempted to improve their quality of life. Under these circumstances, endovascular treatment has proven to achieve satisfactory results, even with incomplete exclusion of the lesion. Endovascular end points are directed to the draining pattern of the brain.

Spontaneous thrombosis of the VGAM, although often referred to by those who oppose interventional treatment, is, in fact, rare. In our series, eight out of 317 patients (2.5%) experienced spontaneous thrombosis, but only half of them were neurologically normal. This is below what proper treatment can now accomplish. In addition, thrombosis is mostly unpredictable and tends to occur late, when cerebral damage may

TABLE 4. Bicêtre neonatal evaluation score^a

| Points | Cardiac function | Cerebral function | Respiratory function | Hepatic function | Renal function |
|--------|--|---|--|---|----------------------------------|
| 5 | Normal | Normal | Normal | — | — |
| 4 | Overload, no medical treatment | Subclinical, isolated EEG abnormalities | Tachypnea, finishes bottle | — | — |
| 3 | Failure; stable with medical treatment | Nonconvulsive intermittent neurologic signs | Tachypnea, does not finish bottle | No hepatomegaly, normal hepatic function | Normal |
| 2 | Failure; not stable with medical treatment | Isolated convulsion | Assisted ventilation, normal saturation FIO ₂ < 25% | Hepatomegaly, normal hepatic function | Transient anuria |
| 1 | Ventilation necessary | Seizures | Assisted ventilation, normal saturation FIO ₂ > 25% | Moderate or transient hepatic insufficiency | Unstable diuresis with treatment |
| 0 | Resistant to medical therapy | Permanent neurological signs | Assisted ventilation, desaturation | Abnormal coagulation, elevated enzymes | Anuria |

^a EEG, electroencephalogram; FIO₂, fractional inspired oxygen. Maximal score = 5 (cardiac) + 5 (cerebral) + 5 (respiratory) + 3 (hepatic) + 3 (renal) = 21.

already be irreversible. Spontaneous thrombosis should not be considered a favorable outcome. Expecting it to occur does not represent a therapeutic strategy and now constitutes an unacceptable choice.

Developmental delay is part of the natural history of untreated VGAM. Careful evaluation of neurocognitive performances shows that most children with macrocrania present some degree of mental retardation. In view of the poor prognosis of the disease, specialists and parents tend to accept as normal a child with mild retardation (up to 20% of normal for the chronological age). Such delay allows the child to attend a normal school, albeit with support. To measure the neurocognitive status during the follow-up period, the pediatric neurologists in Bicêtre have recommended the Denver test and the Brunet-Lezine test, which are easy to perform and are reproducible (10). However, one should interpret the developmental status of a child at one point in time with caution. It is more important to look at the rate of development over time and to interpret the results together with what is known about the child's background.

The specific evaluation score in neonates cannot be used for clinical follow-up in infants. We have chosen a more global clinical initial outcome assessment (Table 5). Although this

score may lack certain details, it has been sufficient to observe the evolution in a given child. With this score, we have been able to rationalize and compare our decisions and to verify their stability over the past 20 years.

PROBLEMS IN THE MANAGEMENT OF VGAM

Cardiac Manifestations

Cardiac manifestations have been reviewed for neonates (11) and antenatally diagnosed VGAM (24). In contrast to the cardiac failure observed in large hemangiomas, where they occur at infancy at the proliferative stage of the disease, the congestive cardiac failure (CCF) in VGAM can be present during the neonatal period.

In most cases, there is a brief period of stabilization, after which the CCF worsens during the first 3 days of life, then stabilizes again and improves with appropriate medical management. Severe CCF in neonates requiring mechanical ventilation usually is associated with poor outcome (6). None of the babies referred to us developed de novo cardiac failure after the third week of life. However, cardiac function can decom-

TABLE 5. Bicêtre admission and outcome score^a

| Score | Condition |
|-------|--|
| 5 | Normal (N) |
| 4 | Minimal nonneurological symptoms, not treated (MS), and/or asymptomatic enlargement of the cardiac silhouette |
| 3 | Transient neurological symptoms, not treated (TNS), and/or asymptomatic cardiac overload under treatment |
| 2 | Permanent minor neurological symptoms, mental retardation of up to 20%, nonpermanent neurological symptoms under treatment (MNS), normal school with support, and/or cardiac failure stabilized with treatment |
| 1 | Severe neurological symptoms, mental retardation of more than 20% (SNS), specialized school and/or cardiac failure unstable despite treatment |
| 0 | Death (D) |

^a Does not apply to neonates.

pensate at 3 weeks or can recur later after lung infections or other concurrent diseases. CCF never constitutes the presenting symptom in infants, nor does it worsen at that age if already present. The degree of failure is variable from one child to another, but seems to be independent of the characteristics of the shunt. Some high-flow lesions are well tolerated, whereas apparently small shunts may lead to multiorgan failure.

Renal and hepatic damage may aggravate CCF further, and their function can be impaired transiently or can become rapidly unstable despite intensive medical care. Severe forms of CCF are associated with persistence of the fetal type of circulation. Septal defects and patent ductus arteriosus often are noted during cardiac ultrasound; they should not be considered associated cardiac malformations. Like most of the disorders encountered under these circumstances, they usually resolve spontaneously or after endovascular management of the AV shunt itself. They should be followed with special attention if embolization is not performed early, because they may induce a failure to thrive condition. Coagulation disorders have not been noted unless there is associated hepatic failure.

Macrocrania and Hydrocephalus

After CCF, the next phase in the evolution of the disease is marked by hydrovenous disorders. As opposed to CCF, hydrodynamic disorders can manifest themselves in fetuses, neonates, and infants. They constitute the primary revealing factor at infant age if the diagnosis has not been made previously. They result from the abnormal hemodynamic conditions present at the torcular venous sinus confluence, the posterior convergence of the venous drainage of the brain, and the immaturity of the granulation system (25). Hydrocephalus and intracranial hypertension occur. During infancy, persistence of the situation leads to clinical manifestations including irritability, alteration of the conscious level and neurological status, stagnation of the head circumference, decrease in brain volume, and developmental delay.

For many years and even now, the mechanical compression of the mesencephalic aqueduct was and is sometimes still considered to be the primary cause of the hydrodynamic disorders at this age. In reality, the aqueduct is patent in almost all patients (26). The water dysfunction combines an intracerebral (intrinsic) retention with an increase in the cerebrospinal fluid (extrinsic) volume. In VGAM, the venous pressure is often very high. Mickle and Quisling (20) reported that pressures were more than 30 ml H₂O, and Quisling and Mickle (21) reported that pressures were more than 50 ml H₂O with a 1:5 ratio between the intraventricular pressure and superior sagittal sinus pressure. This explains the difficulty of the cerebrospinal fluid in entering the dural sinus compartment from the subarachnoid space. Ventricular shunting does not deal with the problem, but only transiently resolves an emergency situation at the ventricular level. It creates a cerebripetal flow along the medullary veins opposite the natural and necessary cerebri-fugal one. Deficits, seizures, or

hemorrhages after ventricular shunting have been well documented.

Endovascular management of the same situations today has shown that, even with partial treatment of the AV shunt, these hydrovenous disorders do not occur unless additional factors intervene to change the angioarchitecture of the lesion. At the infant stage, we recommend careful clinical assessment for the development of macrocrania before endovascular treatment. If the increase in head circumference seems too rapid, if the clinical follow-up period demonstrates a significant developmental delay, or if there is preclinical magnetic resonance imaging evidence of intraventricular hyperpressure, urgent embolization should be carried out and ventricular shunting should be avoided. If, however, the child is referred too late with clinically detectable increased intracranial pressure and ventricular enlargement, clinical improvement after emergency embolization is usually insufficient even if the hemodynamic result is excellent, and surgical ventricular drainage may have to be performed. With such a treatment sequence, morbidity from the shunting procedure is lower. In our experience, after additional embolization and clamp tests, the ventricular drain can often be removed after a few months. Today, endoscopic ventriculostomy offers an acceptable alternative to ventricular drainage after embolization in patients with symptomatic hydrodynamic disorders. The reversed strategy, shunting followed by embolization is, without doubt, the worst option, unless endovascular treatment is not available.

Dural Sinus Occlusion and Supratentorial and Infratentorial Pial Reflux

Dural sinus occlusion and supratentorial and infratentorial pial reflux correspond to a dysmaturation of the jugular bulbs. With persistence of the occipital and marginal sinuses in VGAM, most of the efferent torcular flow is directed medially and does not trigger development of the sigmoid sinuses, which remain distally thin. When the embryonic sinuses finally disappear, the sigmoid sinuses will have occluded fully distally, even though the extracranial jugular veins are still patent and receive the inferior petrosal sinuses.

Thrombosis is usually progressive and may develop without symptoms over a long period. The development of jugular bulb stenosis protects the heart, but exposes the brain. Not only does it interfere with water resorption, it also creates congestion within the cerebral veins. Symptoms will depend on the timing between the upstream effects of the stenosis and the capture of the sylvian veins by the cavernous sinus. The overall prognosis of an untreated VGAM is, therefore, largely

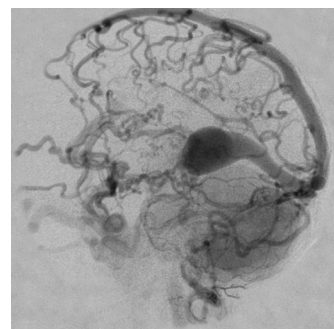


FIGURE 7. Angiogram showing vertebral injection in the venous phase. There is reflux into the superior sagittal sinus and extensive pial venous reflux.

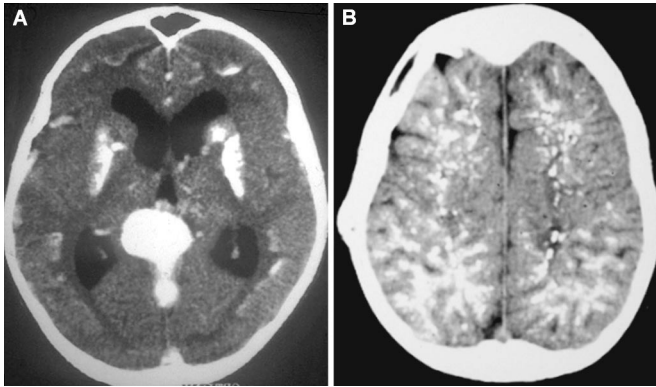


FIGURE 8. A and B, axial computed tomographic scans showing diffuse intracranial calcifications in two patients with VGAM who were referred late for treatment. These calcifications are the results of a longstanding hydrovenous disorder.

dependent on the patency of the jugular bulbs. The situation is particularly unstable if the stenosis is complete and bilateral. The risk of hemorrhage and venous infarction is high because there is significant pial reflux and the VGAM has become an AVM draining into the pial venous system (Fig. 7). Under these circumstances, emergency endovascular management should aim to balance the flow of the AV shunt to the capacity of the posterior outlets and functionally to disconnect the VGAM drainage from the normal cerebral one.

The infratentorial consequence of dural sinus occlusion is tonsillar prolapse. It develops secondary to congestion of the cerebellar pial veins and does not occur in the neonate. It may disappear with correction of the AV shunt, provided that the prolapse has not existed for a long time. The prolapse is not

related to global intracranial hypertension. Therefore, its presence does not call for emergency ventricular shunting, but rather embolization to diminish the drainage of the VGAM into the overall venous pathways.

Late Sequelae

Seizures and mental retardation are the main symptoms seen if the correction of the AV shunt was not carried out in time, and they often occur in children who were referred late or after ventricular shunting. Cerebral morphological sequelae include calcifications (Fig. 8), subependymal atrophy (pseudovertriculomegaly), and the stigmata of previous acute accidents with cortical and subcortical atrophy. It should be noted that in VGAM with patent sinuses, as opposed to cerebral AVMs, local or regional melting-brain phenomena are not encountered, because pial and, therefore, subpial reflux does not occur (15). The insult to the brain is, therefore, a slow and permanent one, as testified by the calcifications. The calcifications, however, do not have a predictive value for neurological outcome in a treated VGAM. They rarely produce abnormal movement disorders that are seen most often with more posteriorly located damage. There is no real link between the images and the clinical evolution of the child. This highlights the inability of imaging methods to appreciate the true substrate of neurological handicap in all instances.

It is important to note that the clinical outcome of children with patent sinuses is relatively good compared with those with secondarily occluded sinuses. This is probably the single most clinically relevant observation to be derived from angio-architectural analysis at infant age.

TABLE 6. Technical aspects of vein of Galen aneurysmal malformation embolization at Bicêtre

| |
|--|
| General anesthesia |
| Femoral puncture with 20-gauge Teflon needle; 4-French sheath |
| 6 ml/kg contrast (diluted at 50% for fluoroscopic control) |
| 4-French diagnostic catheters |
| One to three angiographic runs in neonates, 3 ml/s, total 6 ml (vertebral Towne's projection or biplane if possible), followed by bilateral internal carotid artery lateral projection. If one posterior cerebral artery is not seen on the first run, choose the corresponding internal carotid artery side as second run, and the opposite one for expected cerebral venous information. |
| Microcatheters: Baltaci P. 1.8 (Balt, Montmorency, France); if slow flow feeders, Magic 1.8 (Balt, Montmorency, France) |
| Guidewires (if necessary): 0.012 (Terumo, Tokyo, Japan); Mirage 0.008 (MTI, Irvine, CA) |
| Pure <i>n</i> -butylcyanoacrylate + Tantalum powder + Lipiodol (in slow flow shunts) |
| Intraoperative blood pressure: 70 mm Hg systolic if possible during high flow fistula embolization |
| No additional arterial line |
| No heparin |
| Alternate side for femoral puncture at each session |
| Usual length of procedure, 45 min; maximum length of procedure, 2 h |
| Bladder evacuation (if necessary) after the procedure before removing the sheath |
| Recovery room after procedure (few h) |
| Pediatric neurology ward (after recovery room) |
| Pediatric intensive care unit (24 h asleep) if occlusion complete or almost complete (secondary thrombosis expected) |
| No low blood pressure in intensive care unit, but controlled blood pressure |

TABLE 7. Therapeutic results in the embolized group, 1981–2002^a

| | Neonates | Infants | Children | Total |
|--|--------------|-----------------|---------------|----------------|
| Neurologically normal (BOS 3–5) | 36.4% (4/11) | 78.9% (112/142) | 67.5% (27/40) | 74% (143/193) |
| Moderate retardation (BOS 2) | 54.5% (6/11) | 11.3% (16/142) | 20% (8/40) | 15.6% (30/193) |
| Severe retardation (BOS 1) | 9.1% (1/11) | 9.8% (14/142) | 12.5% (5/40) | 10.4% (20/193) |
| Death despite or because of embolization | 52% (12/23) | 7.2% (11/153) | 0% (0/40) | 10.6% (23/216) |

^a BOS, Bicêtre outcome score. Total of 216 patients, 193 surviving. Note that nearly 50% of neonates referred for management died. Many of these represent earlier cases that today would be scored below eight and, thus, would fall into the nontreatment group.

TABLE 8. Complications of embolization procedures, 1981–2002

| Complication | No. of complications/total ^a (%) |
|---|---|
| Transient neurological disability | 3/193 (1.6%) |
| Permanent neurological disability | 4/193 (2.1%) |
| Nonneurological complication (nondisabling) | 13/193 (6.7%) |
| Death related to embolization ^b | 3/196 (1.5%) |
| Hemorrhage ^c | 11/196 (5.6%) |

^a One hundred ninety-three surviving patients.

^b Three out of 196 patients.

^c During or within 2 weeks after embolization. Clinical eloquence included.

RESULTS

Technical Remarks

The technical aspects of VGAM embolization at Bicêtre are outlined in *Table 6*. We use the transarterial femoral approach to deliver glue in situ as the first treatment method in every case. In rare cases, we have had to perform femoral puncture with the aid of Doppler ultrasound. The smallest baby who was embolized weighed 2.3 kg. No surgical exposure of the femoral artery or umbilical vein approach has been necessary in our experience. We try to obtain complete exclusion in the fewest numbers of sessions, but this goal is primarily guided by the clinical stability observed in the infant and the angioarchitecture of the cerebral vasculature.

In our series of embolized patients, with a total of 502 sessions (an average of 2.4 sessions per child, ranging from one to five sessions), the venous route was used in only eight patients when it became impossible to achieve effective embolization by the arterial route, or specifically to disconnect a sinus reflux to protect the brain. In each case, the children were in a clinical condition that necessitated immediate treatment; no attempt was made to exclude the VGAM completely considering the hemorrhagic risk related to the sudden congestion of nonvisualized subependymal anastomoses.

Whenever the occlusion of the VGAM is complete or almost complete, neonates and infants are kept under general anesthesia for the next 24 hours in the ICU. This protocol has been followed since the beginning of our experience to avoid the unnecessary agitation of a baby awakening in the immediate postembolization

period. Heparin and steroids are not used, and blood pressure is kept normal while the child is asleep in the ICU. Endovascular treatment sessions are arranged every 3 to 6 months, depending on the clinical status and response to the embolization.

Follow-up

We have not observed revascularization at later follow-up when angiographic evaluation results at 6 months to 1 year were completely normal. When slight hyperemia is demonstrated at 6 months, even without evidence of AV shunting, additional control angiograms are obtained 1 and 2 years later.

Total or nearly total obliteration (90–100% occlusion) of the lesion has been obtained in 55% of the children who were embolized in our series and a 50 to 90% occlusion rate has

been obtained in 38.5% of patients, whereas only 6.2% of patients had an occlusion rate of less than 50%. In many instances, complete disappearance of the shunt is not achieved at the end of embolization. Some slow flow can still be demonstrated, but the remaining shunt represents less of a risk in comparison with the technical difficulty in completely obliterating it. We have not seen rupture of the VGAM under these circumstances.

During the follow-up period, all children are evaluated clinically by the referring physicians or the pediatric neurologists. Clinical assessment is based on neurocognitive examination using the Denver and Brunet-Leizine test. After treatment is completed, children are followed up with a clinical examination every year and magnetic resonance imaging every 2 years, because we have created a population of children who did not exist 20 years ago. This ongoing clinical follow-up period is mandatory in the pediatric population, because therapeutic success can be evaluated truly only when brain maturation is complete and functionally evaluated over time.

Clinical Results

In our series, 143 out of 193 surviving patients (74%) were neurologically normal on follow-up after embolization (*Table 7*). There were non-neurological complications related to the embolization procedure and the technical difficulty of injecting pure bucrylate glue in 13 out of 193 patients (6.7%). In this same group of treated patients, 2.1% experienced permanent neurological disability (*Table 8*).

Two children treated by the transvenous route after failure to achieve further embolization by the transarterial approach

sustained an intracerebral hemorrhage within a few hours after embolization. In both patients, occlusion of the venous outlet was complete and the remaining flow into the VGAM was reduced insufficiently. From the literature and in our own limited experience with the transtorcular approach, hemorrhage occurred in more than 10% of patients during the venous approach after coil deposition.

The mortality rate in our group of children was 10.6% (23 out of 216 patients). Many of these, especially the neonates, represent earlier cases that today would be scored below eight and, thus, would fall into the nontreatment group.

OTHER TECHNIQUES

Transvenous treatment of VGAM has been described (19). Reduction in arteriovenous shunting is achieved by packing the venous pouch with a variety of materials, including coils, balloons (19), and nylon (3). Transvenous dural sinus angioplasty and stenting have also been performed (4) in patients with progressive sigmoid sinus-jugular occlusion. The long-term results of these anecdotal dural sinus stenting procedures are unknown at this point. Transvenous occlusion of the venous pouch carries the risk of venous infarction and hemorrhage. Consumptive coagulopathy after transvenous treatment has also been reported (5). A number of centers use a combination of both transarterial and transvenous approaches, tailoring the technique according to the angioarchitecture of the lesion and response to previous treatment attempts.

Stereotactic radiotherapy has a limited role in the treatment of VGAM. The effectiveness is uncertain and the time required to achieve results is unacceptably long for the developing brain.

Arterial coiling has been performed in some rare favorable cases with single high-flow mural types. The fistulous point had been reached either through arterial or venous approach retrogradely. Transarterial balloon occlusion of the fistula's feeder was also advocated in the past; however, the lack of long-term clinical results, unreported failures, and complications supported our technical choices. The introduction of large coils in the venous pouch to slow down the flow so that glue may be used has also been proposed by others. However, series and clinical outcome are still missing.

It is likely that many technical approaches are applicable in the various situations faced in VGAM management. The purpose of this review, however, is to share the features interfering with the therapeutic goals per age group, the clinical challenges, as well as the results of these clinical decisions in a large personal series.

CONCLUSION

An understanding of the clinical and the anatomical and pathophysiological features of VGAM has reversed the former poor prognosis, as was indicated by Johnston et al. in 1987 (13); our data demonstrate that a majority of treated children survive and have a normal neurological development. Our level of understanding about the lesion allows us to predict most situations and remedy them by applying a strict evaluation protocol and working within the therapeutic window. Management of the

patient is best adapted to the malformation itself. In this environment, pediatricians assist us with neurological assessment in neonates and young infants, whereas the neurosurgical and ICU team provide support whenever needed.

At the present time, patient selection remains the key in the management of this condition. Clinical outcome is of paramount importance. It is more important to restore normal growth conditions than a normal appearance, with our primary therapeutic objective being normal development in a child without neurological deficit. Our purpose in this review is to share 20 years of experience in the management of VGAM in Bicêtre. The main emphasis is on the clinical decision making and results obtained with the technique we use. The technical challenges faced and choices made to overcome them are secondary in the discussion. Most likely, different technical solutions can be brought to the treatment of this disease to ensure a normally growing child.

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