Management and Outcomes of Neonatal Arteriovenous Brain Malformations with Cardiac Failure: A 17 Years' Experience in a Tertiary Referral Center

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Objectives To assess the management and outcomes of neonatal arteriovenous brain malformations (mostly vein of Galen malformations) complicated by cardiac failure in the era of prenatal diagnosis and endovascular treatment in a tertiary referral center.

Study design This observational study included 77 living newborn infants with arteriovenous brain malformations with cardiac failure, admitted to our referral center from 2001 to 2017. All infants underwent cardiovascular evaluation including echocardiogram and brain magnetic resonance imaging. Long-term survivors had standard neurocognitive assessments.

Results Infants were admitted to the neonatal intensive care unit at a median of 5 days of age (including 18 inborn patients since 2009). Sixty transarterial shunt embolizations were performed in 46 patients during their first month (at a median age of 7.5 days) or postponed beyond the first month in another 10 long-term survivors. Embolization was not performed in 21 infants, including 19 nonsurvivors with severe brain injury, uncontrolled cardiac failure, or multiple organ failure. Cardiac failure requiring vasopressor infusion occurred in 48 patients (64%) during the hospitalization. Infants who survived the first month underwent a median of 3 embolization sessions. Among the 51 survivors, 21 had a good outcome and 19 had a poor outcome at follow-up (median age, 5.3 years); 11 children were lost to follow-up.

Conclusions In the era of multidisciplinary prenatal diagnosis, using a standardized care protocol, 47% of liveborn infants with an arteriovenous shunt malformation with cardiac failure experienced a favorable outcome. *(J Pediatr 2019;■:1-7)*.

Vein of Galen aneurysmal malformation (VGAM) is a rare but potentially life-threatening and devastating cerebral arteriovenous shunt in newborn infants.[1] It was the first choroidal arteriovenous malformation recognized to be of embryonic origin.[2] These arteriovenous shunts are localized in the subarachnoid space and the choroidal fissure and are classified into 2 anatomic patterns, a mural form (direct fistula from vein of the prosencephalon) and a choroidal form.[3] The natural history of the disease, first described by Gold et al, may include high-output cardiac failure and encephalomalacia in neonates.[4] In older untreated children, increasing head circumference, hydrocephalus, seizures, headaches, or subarachnoid hemorrhage may occur.[5,6] Neurodevelopmental delay may occur at any age.[2]

Until recently, the overall prognosis of VGAM complicated by fetal or postnatal cardiac failure was considered poor (eg, death or severe brain damage) despite transarterial endovascular embolization.[7,8] Despite some controversy, the overall prognosis and survival rate has significantly improved over time.[3,9,10] Improvements in fetal and postnatal brain imaging have allowed a reliable diagnosis of VGAM and allowed obstetricians and neonatologists to refer infants to an interventional neuroradiology team earlier.[10] Our previous experience in a small group of newborns with VGAM complicated by severe cardiac failure showed a good neurodevelopment outcome in a quarter of long-term survivors.[11] However, there remains controversy about the ideal timing and the criteria for endovascular management as well.

MRI	Magnetic resonance imaging
NICU	Neonatal intensive care unit
SVC	Superior vena caval
VGAD	Vein of Galen dilatation
VGAM	Vein of Galen aneurysmal malformation

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This study aimed to describe the outcome of infants with cerebral arteriovenous shunt and cardiac failure (VGAM or dural or pial arteriovenous fistulae with vein of Galen dilatation [VGAD]) who were managed with a strategy of patient selection using fetal ultrasound examination and brain magnetic resonance imaging (MRI), prompt postnatal transfer, and echocardiogram-based hemodynamic management. We also evaluated prognostic factors for neurocognitive development.

Methods

Data on 440 patients (fetal or infant) admitted to our institution with VGAM or VGAD from January 2001 to December 2017 were collected prospectively using patient charts and a database system tool. The analysis was restricted to a subgroup of 77 newborn infants with proven true VGAM or VGAD (eg, pial or dural shunt with VGAD) cared for in the neonatal intensive care unit (NICU) of Bicêtre Hospital at <28 days of age for cardiorespiratory failure requiring respiratory support (**Figure**). We collected information about gestational age, clinical characteristics, antenatal or postnatal diagnostic modalities, and fetal and postnatal cardiac evaluations and severity scores (Pediatric Risk of Mortality Score II, Pediatric Logistic Organ Dysfunction-2 Score, and Bicêtre neonatal score at admission).[2,12] Cardiac failure was defined by the presence of tachycardia, respiratory distress with poor feeding, and hepatomegaly. Cardiogenic shock was diagnosed if the infant had poor peripheral perfusion, oliguria, or biochemical markers of organ failure requiring vasoactive drugs, irrespective of the arterial blood pressure.

Postnatal Hemodynamic and Neurologic Assessments

A cardiac ultrasound evaluation was performed at admission and repeated a few days after each endovascular procedure. It included measurement of the right and left end-diastolic diameters, the left ventricular ejection fraction, the left ventricular output, the superior vena caval (SVC) flow (as an indicator of the cerebral shunt output), and the systolic pulmonary arterial pressure, based on measurement of the tricuspid flow regurgitation or aortopulmonary transductal gradient. In the case of a patent ductus arteriosus, the ductal flow pattern was analyzed according to the pulsed Doppler sampled in the color area of the highest velocity and the estimate of the transductal gradient. End-diastolic retrograde flow in the descending aorta was quantified at the ductus arteriosus downstream insertion site. The shape of the interventricular septum was recorded.[11] For the most recent patients, we recorded the tricuspid annular plane systolic excursion, a well-accepted prognosis measure for right ventricular failure.

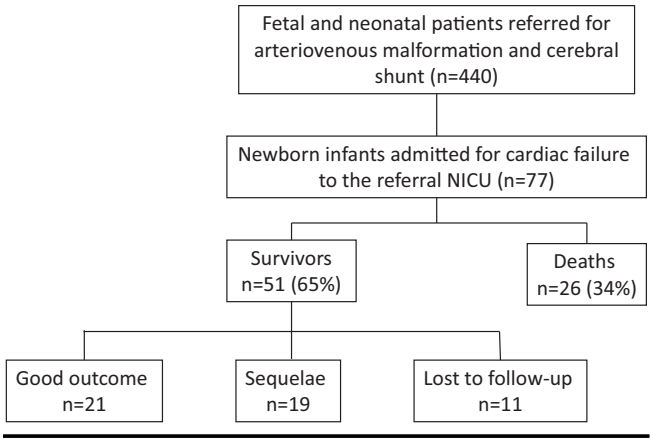

Figure. Flow chart summarizing the target population included in the study from 2001 to 2017 at the tertiary referral center of Bicêtre hospital.

The postnatal neurologic evaluation always included a physical examination, an electroencephalogram and postnatal brain MRI (including at least T1-and T2-weighted axial images, 5 mm thickness slices) to classify the shunt (VGAM, pial or dural sinus shunt with VGAD), and parenchymal features (normal, atrophy, or encephalomalacia). As a part of the neurologic management, an endovascular embolization was performed if the infant had persistent refractory cardiac failure. The presence of brain damage or encephalomalacia was considered to be a contraindication for the procedure.[2,7,12,13] Encephalomalacia was defined as a loss of brain parenchymal thickness (atrophy) combined with parenchymal hyperintensity on T1-weighted spin echo sequences (eg, laminar necrosis). In infants with improvement of cardiac function following medical care, embolization was postponed until the infants were 2-5 months old per our protocol, that was similar over the study period.[2]

Management

The endovascular procedure typically consisted of a catheterization of the femoral artery and a first transarterial embolization using *N*-butyl cyanoacrylate. The goal for the first session was to reduce the shunt by at least one-third, based on the size of the aneurysm, number of feeders, hemodynamic status, and previously published experience.[14]

Medical management consisted of early minimal enteral feeding, a loop diuretic (furosemide) to reduce preload, and invasive or noninvasive respiratory support. Hemodynamic management was based on echocardiogram findings as previously published.[10,15-17] Norepinephrine infusion was used routinely for hypotension to restore the right coronary and systemic perfusion gradient. Milrinone was added per protocol for right ventricular failure despite norepinephrine infusion. In some patients, prostaglandin E_2 infusions were added to maintain (or reopen) the ductus arteriosus, improve right ventricular failure, and prevent myocardial ischemia by reducing the transmural pressure gradient.[11,18]

Neurocognitive Assessment

The assessment was based on an adaptation of the milestones from the Denver Developmental Screening Test until 6 years of age (**Table I**; available at www.jpeds.com).[19] For children

>6 years of age, a school performance scale was used (Table II; available at www.jpeds.com). Information was obtained from families, close relatives, or attending physicians by phone, email, and/or medical visit reports. We also used the modified Rankin score, a rating scale measuring the degree of disability or daily dependency of patients with stroke that also has been used in children with arteriovenous brain malformations.[20,21]

For the global outcome assessment (Table III; available at www.jpeds.com), patients were classified into 3 groups based on a composite score that we built using the Bicêtre outcome score, the modified Rankin score and the adapted Denver score or the school scale.[2] Global outcomes were stratified into 3 groups (good outcome, sequelae, death). For the quality-of-life assessment, we used the Rivermead Post Concussion Symptoms Questionnaire that was previously developed in head trauma.[22] This questionnaire ranks symptoms (eg, headache, irritability, and agitation) on an increasing severity scale from 0 to 4.

Statistical Analyses

Continuous variables were tested for normality with Kolmogorov-Smirnov test and then compared with the Student *t*-test or Mann-Whitney *U* test. Noncontinuous variables were tested with χ^2 or Fisher exact tests, as appropriate. Data were described as frequencies and percentages, means and standard deviations or medians and IQRs. To identify factors of neurocognitive prognosis and death, we conducted a univariate analysis using the Bicêtre outcome score, walking delay or school education degree as a dependent variable. A *P* value of <.05 was considered statistically significant. Statistical analyses were carried out with GraphPad Prism (version 5.0a, GraphPad Soft, La Jolla, California).

The institutional review board approved the study and waived the need for individual consent.

Results

Demographic and Hemodynamic Features

Seventy-seven newborn infants were admitted to the NICU from January 2001 to October 2017 for cardiac failure owing to arteriovenous cerebral shunt (Table IV). A fetal cerebral shunt was shown with prenatal MRI in 53 infants. Infants developed heart failure at median age of 1 day (IQR, 0-4 days). The hemodynamic data are summarized in Table V. All infants showed clinical signs of heart failure at the time of admission and were treated with diuretics. Many of them had a "dancing" cervical carotid pulse and exhibited a peripheral spread precordial pulse owing to a hyperdynamic state and cardiac overload that was reflected on the echocardiogram and an elevated pro-brain natriuretic peptide plasma level. Postnatal cardiac ultrasound confirmed right ventricular overload or failure in a subgroup of patients assessed by overall inspection of the echocardiogram or a low median value of the tricuspid annular plane systolic excursion. The majority of patients had pulmonary arterial hypertension. The echocardiogram displayed an increased SVC return (median, 629 mL/kg/minute; IQR, 482-790 mL/kg/minute; normal range, 55-111 mL/kg/minute at term). The SVC-left ventricular output ratio ranged from 1.5 to 2.6, consistent with a large cerebral shunt. Almost 30% of electrocardiograms exhibited signs of myocardial ischemia, substantiated by an elevated median troponin plasma value.

Table IV. Demographic characteristics of the cohort (n = 77)

Characteristics	No. (%)	Median [IQR]
Female	35 (45)	
Gestational age (wk)		38.5 [37.0-40.0]
Birth weight (kg)		3.2 [2.8-3.5]
Head circumference (cm)		35 [34-36]*
Referred from abroad	29 (38)	
Inborn	18 (23)	
Prenatal diagnosis	53 (69)*	
Fetal cardiomegaly (by echocardiogram)	34/39 (87)	
Gestational age of antenatal MRI (wk)		34.0 [33.0-35.5]
Age at diagnosis of cardiorespiratory failure (d)		1 [0-4]*
Age at noninvasive ventilation (d)		1 [0-4]
Age at mechanical ventilation (d)		3.00 [0-5.75]
Age at admission, days		5 [0-11]
Admission Pediatric Risk of Mortality-II score		11.5 [5.0-17.0]
Admission Pediatric Logistic Organ Dysfunction-2 score		11 [2-12]
Admission neonatal Bicêtre score		10.5 [9-13]*
<8	13/72 (18)	
8-12	37/72 (51)	
>12	22/72 (31)	
Length of stay (d)		9 [5-15]
Endovascular treatment before day 30		
Yes/first session (days of life)	46 (60)	7.5 [5.0-13.0]
Yes/second session (days of life)	14/46 (30)	18 [12-25]
Yes/third session (days of life)	0/14	
No, contraindicated	21 (27)	
No, postponed beyond 2 months of age	10 (13)	
Complication after first embolization	13/46 (28)	
Complication after total embolization	20/51 (39)	

*$P < .05$ between survivors and nonsurvivors.

Neuroradiologic Features

A Vein of Galen malformation (true VGAM) was found in 71% of infants, either the choroidal or mural forms. Dural or pial arteriovenous fistulae with VGAD were documented in 13 infants (17%). The anatomic form was unknown in 8 nonsurvivors (12%) owing to the lack of arteriography (Table VI).

Forty-six infants (60%) underwent a first embolization session at <1 month of age (mean, 7.5 days; IQR, 5-13 days) (Table IV); 30% (14/46) needed a second embolization at a mean of days (IQR, 12-25 days) based on daily clinical and echocardiographic assessment or at the discretion of the neuroradiologist. Embolization was not performed in 21 infants (27%) owing to severe brain injury on postnatal MRI (n = 14) or concerns for severe cardiogenic shock or multiple organ failure (n = 5) or a weight of <3 kg (n = 2).

Table V. Hemodynamic data on admission

Characteristics	No. (%)	Median [IQR]
Vital signs		
Systolic blood pressure (mm Hg)		70 [60-76]*
Mean blood pressure (mm Hg)		47 [41-55]
Heart rate (bpm)		150 [142-163]
Biological measures		
pH		7.38 [7.31-7.44]
Blood Lactate (mg/dL)		32.4 [16.2-42.3]*,†
Creatinine (mg/dL)		0.78 [0.62-0.93]
NT Pro-B-type natriuretic peptide (pg/mL)		16 079 [8311-18 750]
Troponin T high-sensitive (ng/mL)		84 [29-183]
Cardiac ultrasound examination		
Left ventricular ejection fraction (%)		68.0 [65.0-72.5]
Left ventricular outflow (mL/kg/min)		322 [287-384]†
SVC flow return (mL/kg/min)		629 [482-790]
SVC-left ventricle ratio		2 [1.5-2.6]*
Pulmonary artery pressure (mm Hg)		68 [60-78]
Right ventricular end-diastolic diameter (mm)		16 [14-18]
Left ventricular end-diastolic diameter (mm)		19 [16-21]
Shape of interventricular septum,‡ pattern >2	54/73 (74)	
Patent ductus arteriosus, open or right-to-left shunting	45/74 (61)/25 (56)	
Tricuspid annular plane systolic excursion (mm)		9.0 [7.5-11.0]
Retrograde flow in the descending aortic (m/s^{-1})		0.30 [0.20-0.40]†
Cardiogenic shock	45/77 (59)	
Myocardial ischemia on electrocardiogram	14/47 (30)	
Medications		
Alprostadil	31 (42)†	
Sildenafil or bosentan	6 (8)	
Vasoactive drugs	48 (64)	

*$P < .05$ between Bicêtre outcome scores of <3 (death or sequelae) and Bicêtre outcome scores of 3-5 (good outcome).
†$P < .05$ between survivors and nonsurvivors.
‡The shape of the interventricular septum was based on the right-to-left side motion as follows: 1 = normal, 2 = intermediate, and 3 = complete right-to-left shift with left ventricular collapse.

Table VI. Neuroradiologic data and outcome in the 77 patients included in the study

Characteristics	No. (%)	Median [IQR]
Angioarchitectural form		
Choroidal VGAM	39/77 (50)	
Mural VGAM	16/77 (21)	
VGAD	13/77 (17)	
Unknown	8/77 (12)	
Postnatal MRI with encephalomalacia*	14/74 (19)	
Neonatal seizures	7/74 (9)	
Neonatal abnormal electroencephalogram	16/57 (28)†	
Global outcome score		
Death	26/77 (34)	
Sequelae	19/51 (37)	
Good	21/51 (41)	
Lost to follow-up	11/51 (21)	
Rivermead Post Concussion Symptoms Questionnaire Score of >4	24/37 (65)	7 [2-17]
Others		
Epilepsy	5/38 (13)	
Behavior disorders	12/38 (32)	
Autism spectrum disorder	3/38 (8)	
Visual impairment (strabismus, wear glass)	18/38 (49)	
Median age at follow-up in survivors (years)		5.3 [2.5-8.1]

*Postnatal brain MRI was performed at a median 4 days old.
†$P < .05$ between Bicêtre outcome scores of <3 and Bicêtre outcome scores of 3-5.

Finally, for 10 patients (13%), cardiac failure was controlled with diuretics and embolization was postponed to allow better timing in term of risks and benefits (4-6 months).

Twenty patients (39%) experienced adverse events during or after embolization, including parenchymal brain hemorrhages (n = 3), intraventricular bleeding (n = 5), ischemic stroke (n = 12), or thrombophlebitis (n = 3). These complications typically presented as seizures and led to the death of 5 infants.

Global and Neurocognitive Outcome

Twenty-six patients (33%) died because of encephalomalacia and uncontrolled circulatory failure. Embolization was deemed futile for 19 infants. Multiple organ failure or brain hemorrhage was the main reason for postembolization death for 7 patients. A child who was initially ineligible owing to encephalomalacia survived and was embolized at 4 months of age (sequelae group). Six of 7 infants with neonatal seizures died. One patient died at nearly 5 months of age owing to refractory intracranial hypertension despite 2 embolizations and ventricular shunt placement (subgaleal shunt, ventriculocisternostomy).

Fifty-one patients (66%) (Table VI) survived to NICU discharge. With a median follow-up of 5.3 years (IQR, 2.5-8.1 years), 21 of the 51 patients (41%) had a good outcome based on the global outcome score and 19 (37%) had sequelae. Eleven surviving children were lost to follow-up owing to relocation, living abroad, or lack of the family's response to contact.

The Modified Rankin Score, adapted Denver score, and the Bicêtre outcome score are shown in (Table VII; available at www.jpeds.com). Comorbidities, including Turner syndrome, encephalomalacia-cutaneous lipomatosis, and spinal lipoma occurred in 3 patients with developmental delay. Six children underwent a ventriculoperitoneal shunt for persistent hydrocephalus. Five patients developed epilepsy. All children with a good outcome had a normal postnatal brain MRI. The Bicêtre outcome score was 5 for 13 of the children (25%) with a range of 3-4 for 11 of the children (22%), meaning a normal or reasonable prognosis for 47% of surviving patients. Twenty-four (47%) children had a modified Rankin score range of 0-1.

Of the 18 school-age children >6 years of age, 61% attended a mainstream school and 39% need special classroom support. Fifty percent have learning difficulties. Among the 51 long-term survivors, 40 infants were tested using our adapted Denver test; 58% were without psychomotor developmental delay and 42% experienced cognitive impairment (Table VII). The quality of life was impaired in 37 survivors (65%) who were able to complete the Rivermead

Post Concussion Symptoms Questionnaire. The main symptoms were headache (38%), fatigue (39%), sleep disorders (31%), noise sensitivity (43%), irritability (34%), frustration intolerance (49%), restlessness (37%), speaking difficulty (31%), or concentrating difficulty (46%). The main sequelae were behavioral disorders (32%) and visual impairment (49%).

Fifty-five infants had true VGAM after excluding anatomic unknown form and VGAD (owing to pial or sinus dural malformation). After excluding those who died (n = 15), 16 of 40 patients (40%) had a good outcome, 17 (42%) had sequelae, and 7 (17%) were lost to follow-up.

Predictive Factors Associated with Death or Poor Outcome

In univariate analysis, the only significant differences in risk factors between survivors and nonsurvivors were head circumference, prenatal diagnosis, age of neonatal cardiorespiratory failure, neonatal Bicêtre score at admission, plasma lactate level, left ventricular output, and reversed flow in the descending aorta (**Table IV** and **Table V**). The results of the univariate analysis using the Bicêtre outcome score as dependent variable are shown in **Table VI** and **Table VII**. There were no differences for outcome between infants with the choroidal or mural form in VGAM subgroup.

Discussion

Our study assessed the clinical profile, hemodynamic findings, and neurologic outcome of a homogeneous cohort of 77 consecutively admitted liveborn infants with a cerebral arteriovenous shunt. The results affirm that symptomatic neonatal arteriovenous malformation remain a life-threatening disease as reflected by an early mortality rate of 34%. However, 41% of the long-term survivors (or 52% when excluding the lost to follow-up) were free from impaired global outcome. Fifty-eight percent had normal development or a moderate delay in psychomotor development (Denver score) and 61% of children >6 years of age were attending a regular school. Behavioral disorders jeopardized quality of life for two-thirds of children and may account for learning difficulties, indicating there is a broad spectrum of impairment. Only 13% of the children have developed epilepsy and 8% were ultimately diagnosed with autism spectrum disorder.

The early mortality of newborn infants with cerebral shunt-related cardiac failure varies from 20% to 50% and is a matter of debate owing to differences in case mix and inclusion criteria reported in the literature (ie, antenatal diagnosis, inhomogeneous criteria for heart failure, referral for assessment).[7,10,11,13,23] We aimed to include liveborn patients with cardiac failure only, as reflected by the mean severity scores and the higher proportion of infants treated with vasopressors and embolized before 28 days (60%). This early mortality is lower than previously observed and suggests improvement that may be related to protocol-guided management based on echocardiogram findings and interventional neuroradiology team involvement.[10,11] We did not find a prognostic impact of the requirement for vasopressors or the level of pulmonary arterial hypertension. However, our univariate analysis showed a poor prognostic value of SVC flow return, a strong reflection of the degree of cerebral shunt in VGAM or pial fistulae, also reported by others.[23] Moreover, the majority of deaths were related to encephalomalacia or critical illness, leading to withdrawal or withholding of ongoing treatment. However, only 5 newborns died owing to uncontrolled heart failure, suggesting an improvement in the hemodynamic management of these challenging situations.

The Bicêtre neonatal evaluation score that was historically developed as a decision tool in newborns (abstention, early treatment, or postponed beyond 2 months) seems no longer relevant. In recent studies, a score of <8 was not systematically associated with a poor prognosis as illustrated by a favorable outcome for 2 infants thanks to early aggressive treatment, including embolization.[2,3,24] The elevated complication rate observed after embolization (nearly 40%) was similar to the rates reported in recent studies and confirms that endovascular treatment is a challenging procedure in smaller patients.[9,25,26]

Only 41% of the survivors had a good global outcome, compared with other studies that found favorable outcome rate of 53%-88%.[1-3,9,24,27-29] In other studies, patients were more heterogeneous and widely distributed in regard to severity and age group, whereas in our study we only included severely ill newborns. A recent meta-analysis showed similar results, with a 49% rate of good outcome in newborns with cerebral shunt-related cardiac failure, and this was also very similar to the results of the national VGAM United Kingdom cohort.[3,25] However, our study provides long-term neurologic assessment with a longer median follow-up than previously published (median, 5.3 years).[3,24] The standardized neurocognitive evaluation carried out by our neuropediatric team is based on several tools, including the Bicêtre outcome score, Denver test, school performance, and quality-of-life scale.[1,29,30] This protocolized approach of neurocognitive assessment may have excess sensitivity, which may account for the higher sequelae rate observed. It is worth noting that autism spectrum behaviors affected 8%-12% of patients with neonatal VGAM, leading to concerns for a potential causal relationship between vascular/hydrodynamic disorders and autistic disorders.[25] Despite depicting step-by-step development milestones in infants and children, the Denver score is poorly predictive of risk for the academic difficulties that were seen in 50% of our patients.

Our study had several weaknesses. Because patients for this study were identified from a single institution, there may be a risk of inclusion bias over time. A tertiary maternity ward that opened in our institution has enabled us to care for infants after a prenatal diagnosis evaluation process. Termination of pregnancy in case of severe fetal abnormalities may decrease

the number of infants identified with severe brain injury. The recent identification of risk factors for poor prognosis (eg, mean cerebral artery pseudofeeder or severe tricuspid regurgitation) likely improved the fetal screening for encephalomalacia over time.[13,31] In contrast, earlier management may provide an opportunity to decrease the risk of refractory cardiac failure and to improve the neurocognitive outcome. For example, we have observed a reduction in the age of admission and treatment in our current cohort (median of 5.0 and 7.5 days old, respectively) compared with our previous experience (median of 12 and 21 days old, respectively).[11]

We also included newborns with pial and dural fistulas (VGAD), assuming that cerebral shunt-related systemic hemodynamic pattern is quite similar. This may have influenced the results. However, we also report the VGAM outcome results separately. Moreover, the anatomic morphology of the cerebral shunt remained unclear for 8 patients, mainly owing to early death; these infants did not undergo arteriography or brain MRI. Finally, we were not able to assess the complete outcome of 11 children who were lost to follow-up. ■

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Table I. Adapted Denver Milestone scores

Postures and gross motor skills		Language		Fine motor skills: Grasping (gripping objects, manipulation of cubes, embedding) Graphics for child >3 years old (line, round, man in 3 or 5 parts)		Social skill: Autonomy: Hygiene, food Social interactions	
0	Sitting posture before 9 months old	0	First words before 15 months old	0	No difficulty	0	No difficulty
1	Sitting posture after 9 months old	1	First words after 15 months old	1	Moderate difficulties	1	Moderate difficulties
0	Walking before 18 months old	0	First associations before 24 months or first sentences before 3 years old	2	Severe difficulties	2	Severe difficulties
1	Walking after 18 months old	1	First associations after 24 months or the first sentences after 3 years old				

Adapted Denver score 0-2: normal or borderline psychomotor development.
Adapted Denver score 3-8: psychomotor developmental delay.

Table II. Schooling score

School types		No. of repetitions		School learning	
0	Standard school	0	No grade repetition	0	Lack of academic difficulties
1	Standard school with a special education assistant	1	One to 2 repetitions	1	Moderate difficulties
2	Specialized school	2	More than 2 repetitions	2	Severe difficulties

Schooling score 0-2: normal or mild school difficulties (mainstream schooling).
Schooling score 3-6: severe learning disabilities.

Table III. Global Outcome score

Groups	Description
Good outcome	Bicêtre outcome score: 3-5 And modified Rankin scale: 0-1 And Schooling score range: 0-2 for children >6 years Or adapted Denver score: 0-2 for children ≤6 years
Sequalae	Bicêtre outcome score: 1-2 Or modified Rankin scale: 2-5 Or Schooling score ≥3 for children >6 years Or adapted Denver score ≥3 for children ≤6 years
Death	Bicêtre outcome score: 0 Or modified Rankin scale: 6

Table VII. Neurocognitive assessment and outcome of the 77 patients included in the study

	Survivors (n = 51 [65%])				
Assessments	Global outcome: Good (n = 21)	Global outcome: Sequelae (n = 19)	Lost to follow-up (n = 11)		Nonsurvivors (n = 26 [34%])
Antenatal					
Diagnosis	14	11	4		24
Fetal cardiac failure	8	8	–		18
Normal brain MRI	11	6	–		14
Inborn	6	4	0		8
Embolization					
Before day 30	18	12	9		7
Postponed	3	6	1		0
Contraindicated	0	1	1		19
Complicated	7	9	6		3
Outcome					
Bicêtre outcome score					
5	13	0	–	–	–
3-4	8	3	–	–	–
1-2	0	16	–	–	–
Modified Rankin scale					
0-1	21	3		–	–
2-5	0	16		–	–
Adapted Denver score					
0	10	0		–	–
1-2	9	4		–	–
≥3	2	15		–	–
Walking delay	3	14		–	–
Language delay	8	11		–	–
School Performance Scale					
0	4	0		–	– –
1-2	2	1		–	– –
≥3	0	11		–	– –
Regular school	6	5		–	– –
Specialized class	0	7		–	– –