Myelomeningocele: long-term neurosurgical treatment and follow-up in 202 patients

GIUSEPPE TALAMONTI, M.D., GIUSEPPE D’ALIBERTI, M.D., AND MASSIMO COLLICE, M.D.

Department of Neurosurgery, Niguarda Ca’Granda Hospital, Milan, Italy

Object. In this paper the authors focus on the long-term management of myelomeningocele (MMC) and its associated conditions.

Methods. During a 25-year period, 220 consecutive patients with MMC underwent surgical repair. There were 203 cases (92%) of enlarged ventricles, but only 171 cases (78%) of hydrocephalus. Seven infants (3%) presented with early brainstem dysfunction; two improved after ventricular drainage, whereas five required craniocervical decompression.

Results. Overall, five neonates (2%) died; 215 patients (98%) were eventually discharged from the hospital and of these, 202 (94%) remained in the authors’ outpatient program. During the follow-up (range 1–25 years, mean 9.3 years), 96 patients required shunt revision (63% of shunts); 16 patients (8%) experienced late brainstem dysfunction that was treated by shunt placement in eight and by craniocervical decompression in the other eight; 137 patients (68%) harbored hydroxy-syringomyelia, but only six required surgical treatment; 40 patients (20%) presented symptoms of tethered cord, but surgical detethering was indicated in just 22 patients (11%). There were five deaths (2%), and severe adjunctive neurological morbidity was reported in 18 patients (9%) (owing to various causes). “Social” results have been evaluated by extrapolating 38 patients older than 15 years of age whose initial lesions were below L-2; 37 (97%) of these patients were fully independent, had “social urinary continence,” and attended normal schools.

Conclusions. Currently, many patients with MMC reach adulthood and social continence; self-care may be expected in a large percentage of cases. Nevertheless, there are many associated neurological conditions that have to be faced, and a coordinated network of care remains necessary throughout the patient’s life. Moreover, these patients often present with so many peculiarities that indications for treatment, choice of proper techniques, and results are not always clear and evident. (DOI: 10.3171/PED-07/11/368)

KEY WORDS • Chiari malformation • hydrocephalus • myelomeningocele • pediatric neurosurgery • syringomyelia • tethered cord

Abbreviations used in this paper: CM = Chiari malformation; CM-II = CM Type II; CSF = cerebrospinal fluid; CT = computed tomography; ETV = endoscopic third ventriculostomy; FMD = foramen magnum decompression; ICP = intracranial pressure; MMC = myelomeningocele; MR = magnetic resonance; TCS = tethered cord syndrome; VP = ventriculoperitoneal.
Long-term treatment of myelomeningocele

Patient Population

There were 105 boys and 115 girls. The MMC was thoracic in nine cases, upper lumbar (above L-2) in 48, lower lumbar/upper sacral (between L-2 and S-1) in 128, and only sacral (below S-1) in 35. Of these patients, 198 were born at our hospital through an elective cesarean section, and the remaining 22 were referred to us after birth. One patient presented at the age of 2 years with a partially reepithelialized neural plaque and a history of numerous bouts of meningitis and presenting progressive TCS. Another baby was referred to us 3 weeks after birth for cord repair and management of ventriculitis following shunt placement at a local hospital. Orthopedic deformities were reported in 194 babies (88%). Other major congenital anomalies were observed in 17 patients (8%). All these malformations were studied and opportune managed by specialist consultants. The main associated malformations are listed in Table 1.

Repair of the MMC

Surgical repair was considered a priority and performed as soon as possible, so that preoperative MR imaging was not routinely performed. Patients requiring other surgeries (such as cardiac surgery) usually first underwent repair of the spinal cord. The MMC closure was performed within 24 hours in 142 newborns (64%), on the 2nd day in 64 patients (29%), and later than 48 hours in the remaining 14 patients (6%). A history of preoperative meningitis was reported in only two patients. One was a 19-day-old baby who arrived in a septic state at our emergency department after placement of a VP shunt at a local hospital, and the other was the aforementioned child who arrived at the age of 2 years.

Since 1998, all surgical procedures have been performed in a latex-free operating room. In 14 patients (6%), other spinal anomalies (split cord malformations, lipoma, hamartoma, and neuroenteric cyst) were found in or adjacent to the operating field and were surgically treated at the same time. In all cases, the first step of the surgical technique consisted of the microsurgical isolation of the neural plaque that was never resected. The terminal filum was sectioned if identified. In the early part of this experience, the isolated dural plaque was left open and simply replaced inside the reconstructed dural sac. Conversely, in the last 86 patients (39%), the neural plaque was gently folded up and pial microsutures were used to reconstruct a sort of neural tube (“tubing”). In the last 48 patients (22%), the intradural space was also perfused using a hyaluronic acid gel (Hyalobarrier, Fidia Advanced Biopolymers) in an attempt to prevent adhesions. In the vast majority of cases it was possible to reconstruct an adequately wide dural sac using direct watertight sutures, and only a few patients required dural grafts. The muscle layer was repaired in all cases. Finally, skin was repaired either by direct sutures or by flap mobilization.

Treatment of Hydrocephalus

Enlarged ventricles were evident in as many as 180 infants (82%) on the prenatal ultrasonography studies. Although in a very few cases the planned cesarean delivery had to be performed earlier than anticipated due to progressive ventricular enlargement, the enlarged ventricles tended to remain stable in the fetuses. Emergency drainage of severe fetal hydrocephalus was needed in just one case; a young woman arrived in our emergency department in an advanced stage of labor. Ultrasonography showed a fetus with severe hydrocephalus and MMC whose head was firmly stuck in the birth canal. During the cesarean section the head had to be freed by an ultrasonography-guided percutaneous tap of the right ventricle. The newborn rapidly recovered and was able to undergo MMC repair the following day and hydrocephalus shunt treatment 5 days later.

After birth, all infants were monitored by daily measurement of head circumference, palpation of the anterior fontanelle, and serial cerebral ultrasonography. Overall, 203 patients (92%) presented with enlarged ventricles, of whom 171 infants (78%) eventually required surgery for hydrocephalus. Treatment was considered to be indicated only in case of progressive ventricular dilation and signs of high ICP. Whenever it was possible, shunt placement was postponed for at least 1 week after MMC repair. In fact, just 21 (12%) of these 171 patients had to be treated within 1 week and contemporaneous treatment was very unusual. Accordingly, 122 (71%) of these patients underwent shunt insertion by 1 to 4 weeks and 28 (16%) by 1 to 6 months after cord repair. No patient in this series required treatment of hydrocephalus later than 6 months of age.

Treatment of hydrocephalus preferentially consisted of VP shunt placement (154 cases), whereas ventriculottrial shunt treatment and ETV were reserved for selected cases (13 and four cases, respectively). Indeed, a total of six patients with MMC underwent neuroendoscopic procedures, but ETV was performed only in four. In fact, in two patients the procedure was aborted because of the unexpected absence of clear anatomical landmarks on the floor of the third ventricle; these procedures were converted to shunt treatment. We no longer use ETV to manage hydrocephalus in patients with MMC.

Early Brainstem Dysfunction

Some respiratory and/or swallowing disturbances were relatively frequent, but these symptoms tended to be mild and to resolve on their own. Indeed, severe brainstem dysfunction was reported only in seven newborns (3%). This consisted mainly of central dyspnea, vocal cord palsy, severely altered swallow with nasal regurgitation, and generalized hypotonia. One patient was born with absent respiratory activity and required immediate nasotracheal intubation.

**TABLE 1**

Main associated malformations in 220 patients with MMC

<table>
<thead>
<tr>
<th>Malformation</th>
<th>No. of Patients (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>orthopedic</td>
<td>194 (88)</td>
</tr>
<tr>
<td>scoliosis, kyphosis, joint contracture, club foot, hip subluxation, other lower-limb anomalies</td>
<td></td>
</tr>
<tr>
<td>cranial</td>
<td>8 (4)</td>
</tr>
<tr>
<td>aplasia cutis membranosa, labiopalatoschisis occipital encephalcele</td>
<td></td>
</tr>
<tr>
<td>cardiac</td>
<td>5 (2)</td>
</tr>
<tr>
<td>patent Botallo duct, aortic coarctation, transposition of great vessels</td>
<td></td>
</tr>
<tr>
<td>urogenital</td>
<td>2 (1)</td>
</tr>
<tr>
<td>cryptorchidism, horseshoe-shaped kidneys</td>
<td></td>
</tr>
<tr>
<td>gastroenteric</td>
<td>2 (1)</td>
</tr>
<tr>
<td>esophageal atresia</td>
<td></td>
</tr>
</tbody>
</table>
and assisted ventilation. The other six infants progressively developed the brainstem syndrome within 30 days of birth. In all cases, a cerebral MR image revealed a very small posterior cranial fossa and severe CM-II. Hydrocephalus was always present, but there was no evidence of cervicobulbar syringomyelia. All patients were studied by direct laryngoscopy to assess vocal cord function. No barium study was performed in infants of this age.

Treatment first consisted of the management of hydrocephalus. The conditions of two patients markedly improved after VP shunt insertion, but five infants (2%) also required FMD (Fig. 1A–C). This consisted of a suboccipital craniectomy extending from the foramen magnum as far as the torcular herophili associated with a laminectomy adequate to expose the lower level of the cerebellar tonsils and vermis. The dural sac was widened as much as possible using a dural patch, but the arachnoid layer and the neural structures were left untouched. Treatment of brainstem dysfunction is summarized in Fig. 2.

Results

Discharge From the Hospital

Overall five patients (2%) died. All but one death occurred in the earliest phase of this experience (before 1988). Three patients died of general conditions (respiratory distress with secondary cerebral hemorrhage, necrotizing gastroenteritis, and complications of heart surgery), and two died of neurological conditions (ventriculitis and brainstem dysfunction). Severe adjunctive morbidity (not directly related to MMC) consisted of one case of severe brain damage due to prolonged fetal anoxia.

The MMC repair was responsible for no new neurological morbidity. There were seven cases (3%) of postoperative CSF fistula; this was conservatively treated in five patients, but two required reoperation and fistula repair.

Complications within the 1st month after CSF shunt treatment included five cases (2%) of ventriculitis and 19 cases (11%) of shunt failure. Ventriculitis always occurred in patients who underwent cord repair within 48 hours and shunt placement within 7 days. Management consisted of exteriorization of the shunt and general and intrathecal antibiotics. This treatment was effective in four patients; one infant died. In the cases of the 19 early shunt failures, three were due to system misplacement and 16 to system occlusion by debris or clot. Among these 16 patients, 10 had been treated by delayed MMC closure (after 48 hours of birth), and 14 had undergone VP shunt placement within 1 week of MMC repair. All of these patients were successfully treated by shunt revision or replacement.
As to the ETV procedure, there was no morbidity, but failure occurred in two of the four patients who required subsequent shunt treatment.

The FMD procedure was responsible for no morbidity, although it completely failed in the newborn who did not have respiratory activity and died within 1 month. Results of an autopsy showed severe brainstem derangement with immature cells and not securely recognizable nuclei. The conditions of the other four newborns progressively improved, although all of them had relatively eventful and long recovery courses with prolonged periods of tracheostomy and feeding through percutaneous endoscopic gastrostomy.

To sum up, 215 patients were eventually discharged from the hospital and underwent outpatient treatment at the Centro Spina Bifida of the Niguarda Ca’Granda Hospital. This program consisted of a multidisciplinary team approach with serial specialist controls and periodic examinations. Each patient underwent serial cerebral and spinal MR imaging. As a general rule, early MR imaging was recommended in all cases. Indeed, this modality became fully available at our hospital in 1990. Therefore, patients born in the early part of this study underwent their first MR imaging session at various ages. When a clinical problem was suspected, they were referred to a private radiological clinic where MR imaging was already available; otherwise after 1990 they were examined when they returned as outpatients. Moreover, after 1990 all patients underwent the first MR imaging study of the entire spinal cord and brain within 6 months of age. Afterward, patients whose conditions were stable without evidence of potentially deteriorating conditions (such as syringomyelia, dermoid cysts, and so on) were routinely reexamined at 3, 6, 10, and 15 years of age.

Serial neurourological examinations (including urogenital ultrasonography, cystometry, cystography, and so on) were performed. Consultations with members of the pediatric, physiatrist, orthopedic, urological, neuropsychological, and neurosurgical departments were periodically obtained.

Thirteen patients (6%) were lost to follow-up. The remaining 202 patients (92%) participated in our outpatient program for patients with spina bifida. Follow-up ranged from 12 months to 25 years (mean 9.3 years).

**Shunt Malfunction**

A total of 153 (92%) of 167 shunt-treated patients remained in our outpatient program and underwent follow-up. In all cases, a cerebral MR image was obtained earlier than 3 months of age. Ventricular size and morphology often revealed abnormalities even in the presence of a normally working shunt: colpocephaly was frequent as was ventricular asymmetry, which sometimes mimicked an isolated ventricle. These features were carefully noted on baseline MR images and recorded. In case of any future suspected shunt malfunction, this baseline assay was compared with repeated MR imaging or CT scanning to measure even minimal changes of the malformed ventricles (Fig. 1D–F).

In this paper, the generic term “shunt malfunction” often includes categories such as shunt obstruction, shunt infection, presence of loculate ventricles, overdrainage, and so on. Shunt malfunction was considered not only in cases with signs and symptoms of high ICP but also in the presence of asymptomatic progressive ventricular enlargement. Moreover, each patient with decreased ability in intellectual and/or physical performance was regarded as possibly having a malfunctioning shunt. Even in cases of suspected CM-II or TCS, a possible shunt malfunction was always ruled out (Fig. 1). Indeed, clinical manifestations of shunt malfunction were numerous and variable, ranging from subtle and nonspecific signs and symptoms to severe neurological conditions including comatose state. In this series, the more severe neurological conditions were always heralded by some manifestation of high ICP. Four patients were referred to our emergency department with a Glasgow Coma Scale score less than 8. In all cases, some symptoms had been present for some days but were not opportunistically recognized. All these patients underwent emergency shunt revision. Two recovered fully, one remained with permanent intelligence deficits, and one never recovered and ultimately died. We have information on another of our patients who died at a local hospital after he suffered headaches for a few days while he was waiting to undergo CT scanning.

This series also includes cases of very long shunt duration: there were 11 patients whose ages ranged from 18 to 26 years who had undergone shunt treatment when they were neonates and never experienced shunt malfunction. Nevertheless, 96 (63%) of 153 patients required reoperation for shunt malfunction during the follow-up. The causes, timing, complications, and final outcome of shunt malfunction are summarized in Table 2. The first revision procedure was mostly required either within 1 year (39 cases; 41%) or longer than 3 years (44 cases; 46%) after placement. The first shunt malfunction never occurred in patients older than 18 years of age and was not frequent even after 15 years (five patients). Conversely, repeated shunt failures occurred at any age. Of the 96 patients, 51 (53%) experienced more than one shunt malfunction, thus requiring multiple revision procedures (ranging from two–19 per patient, mean four).
The revision procedure was usually intended to identify and replace the obstructed shunt segment. However, when the shunt system was older than 5 years, usually a totally new system was implanted.

The most frequent cause of shunt malfunction was obstruction/misplacement (74 cases; 77%). Contamination of CSF was reported in 18 patients (19%) but cultures were not routinely obtained. Indeed, there were four patients (4%) who required revision due to clinically significant ventriculitis, whereas the revision procedure itself was responsible for four adjunctive cases of new CSF infections. In all cases, treatment consisted of shunt exteriorization, antibiotics, and final shunt replacement following sterilization of the CSF. One of the patients with ventriculitis eventually died and three had permanent intellectual deficits (severe in one case and moderate in two). The four patients with revision-related infection fully recovered. The shunt revision procedure was associated with two cases of cerebral hemorrhage with consequent hemiparesis in one case.

A total of eight patients with shunt malfunction were treated by ETV. This procedure effectively controlled the hydrocephalus only in four, whereas the other four required a subsequent shunt procedure. Conversely, endoscopy was highly effective in treating six patients with isolated entrapped ventricles: four patients with isolated lateral ventricle were successfully treated by septostomy, whereas two with an isolated fourth ventricle underwent aqueductoplasty and stenting (Fig. 3).

**Shunt Independence**

During the follow-up, 34 (22%) of 153 shunt-treated patients had imaging evidence of deconnection, fracture, or even migration of the shunt system, but were clinically com-

---

**TABLE 2**

Shunt malfunction during follow-up in 153 shunt-treated patients

<table>
<thead>
<tr>
<th>Shunt Malfunction</th>
<th>No. of Cases (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>total no.</td>
<td>96 (63)</td>
</tr>
<tr>
<td>causes</td>
<td></td>
</tr>
<tr>
<td>obstruction/misplacement</td>
<td>74 (77)</td>
</tr>
<tr>
<td>CSF contamination</td>
<td>18 (19)</td>
</tr>
<tr>
<td>ventriculitis</td>
<td>4 (4)</td>
</tr>
<tr>
<td>timing</td>
<td></td>
</tr>
<tr>
<td>w/in 1 yr</td>
<td>39 (41)</td>
</tr>
<tr>
<td>1–3 yrs</td>
<td>13 (13)</td>
</tr>
<tr>
<td>&gt;3 yrs</td>
<td>44 (46)</td>
</tr>
<tr>
<td>no. of multiple revisions</td>
<td>51 (53)</td>
</tr>
<tr>
<td>revision complications</td>
<td></td>
</tr>
<tr>
<td>postop infection</td>
<td>4 (4)</td>
</tr>
<tr>
<td>cerebral hemorrhage</td>
<td>2 (2)</td>
</tr>
<tr>
<td>outcome</td>
<td></td>
</tr>
<tr>
<td>death*</td>
<td>3 (3)</td>
</tr>
<tr>
<td>morbidity†</td>
<td>2 (2)</td>
</tr>
</tbody>
</table>

* Two patients had high ICP and one had ventriculitis.
† One patient had hemorrhage and one had ventriculitis.

---

*Fig. 3. A–C: Preoperative axial MR images showing an isolated fourth ventricle. Note the marked compression of the brainstem. This 4-year-old boy had undergone surgery for MMC and hydrocephalus in the neonatal period. He remained well for 4 years; later he presented with repeated headache, vomiting, and mild tetraparesis. The patient underwent shunt revision and endoscopic treatment consisting of aqueductoplasty, stenting of the aqueduct, and drainage of the fourth ventricle through the third ventricle. The preoperative syndrome completely resolved. D–F: Postoperative CT scans obtained 1 month later, showing the stent placed into the aqueduct and the fourth ventricle. Although it is still wide, the fourth ventricle is smaller, and the brainstem appears to have returned to its original size.*
Long-term treatment of myelomeningocele

 completamente asymptomatic. All these patients underwent MR imaging (which was compared with the baseline image) and were carefully studied for any possible subtle change in intellectual, behavioral, sensorimotor, and urological performance. Six (4%) of these 153 patients either presented with ventricular changes or did poorly on the neuropsychological tests and underwent revision of the shunt even if they appeared clinically asymptomatic.

There remained 28 patients in whom the imaging shunt anomaly noted on images did not cause any problems. These patients underwent conservative treatment and serial neuroradiological, neurological, neuropsychological, and urological assessments and were encouraged to opportunistically seek neurosurgical attention in case of any doubt. Repeated neuroradiological assessments (MR imaging or CT scanning) were planned at 1, 3, 6, and 12 months following the diagnosis of shunt anomaly. There were 16 boys and 12 girls. Age (at time of disconnection detection) ranged from 4 to 17 years (mean 7.5 years). These patients underwent follow-up lasting between 1 and 8 years (mean 5.4 years): 24 (86%) remained wholly asymptomatic and with unchanged ventricles and are still observed as outpatients, whereas four patients (14%) required a shunt revision.

In all 24 patients who did not require revision procedures, the initial cord lesion was below L-2. Moreover, none of these patients had required a shunt revision during the last 3 years (before detection of the shunt anomaly), and 18 had no history of any previous shunt malfunction. On the other hand, among the four patients (14%) who required a shunt revision, two were 5 years, one was 6 years, and one was 7 years old at the time of shunt revision. All four patients had a history of at least one shunt revision during the last 3 years. One patient arrived with a Glasgow Coma Scale score of 9 and sixth cranial nerve palsy, whereas the other three patients complained of a mild high ICP syndrome (headache in two patients and changes in repeated neuropsychological tests in one). On CT scans, the ventricle size was noted to be increased in three and unchanged in one. All four patients underwent shunt revision without any further delay. In all cases, recovery was complete, and there were no cases of morbidity.

Late Brainstem Dysfunction and Arnold–Chiari Malformation

The control MR image revealed CM-II and brainstem anomalies in 199 (98%) of 202 patients. A medullary kink in the upper cervical cord was reported in 111 (56%) of these cases. However, just 16 patients (8%) experienced brainstem dysfunction requiring surgical treatment. Age distribution and treatment of these patients are summarized in Fig. 2. Half the patients were younger than 3 years of age. Shunt-treated hydrocephalus was always present. In three patients, the symptoms of brainstem dysfunction were clearly triggered by shunt malfunction. In one of these cases, a clear high ICP–associated syndrome without any evident brainstem sign was initially brought on by shunt malfunction. However, after the ventricles were drained, headache and vomiting persisted and the brainstem dysfunction became evident only when tetraparesis, nuchal rigidity, and lower cranial nerve impairment occurred (Fig. 4). In the remaining 13 patients there was no clinical evidence of shunt malfunction. Classically, a slowly worsening syndrome developed with insidious onset. Two patients also complained of awake tachypnea and facial flushing associated with red spots on the skin of the neck and chest of probable vegetative (vasoactive) origin. Typically the spots presented acutely, often associated with the tachypnea, lasted for no more than 30 minutes, and vanished.

In all cases, the first treatment consisted of shunt revision even when no clear shunt malfunction was evident. This treatment completely resolved the symptoms in eight patients, whereas eight others required a subsequent FMD procedure. Five of these patients were younger than 3 years of age and three were older than 10 years (Fig. 2). The FMD procedure consisted of a suboccipital craniectomy with wide opening of the foramen magnum associated with laminectomy at the C-1 and C-2 levels (always) and at the C-3 and C-4 levels (when indicated). The dural sac was widened.

Fig. 4. A: Preoperative sagittal MR image obtained in a 15-year-old girl showing an enlarged fourth ventricle with the cerebellar tonsils that appeared lifted upward. This patient presented with headache and vomiting and no sign of brainstem dysfunction. She had undergone surgery for MMC and hydrocephalus in the neonatal period. A shunt revision was necessary when she was 5 years old. Another shunt malfunction was diagnosed, and the patient underwent shunt revision. B: Postoperative sagittal MR image showing proper drainage of the ventricles and descent of the cerebellar tonsils. Nevertheless, the patient’s headache and vomiting did not resolve but rather worsened. The shunt was exteriorized but the syndrome persisted. Eventually, the patient became tetraparetic and developed nuchal rigidity, dysphonia, and mild swallowing disturbance. Accordingly, the role played by CM became evident, and FMD was performed. C: Control sagittal MR image obtained 1 year later. The patient had fully recovered.
as much as possible using a dural graft. A cerebellar tonsillectomy was necessary only in one case due to accidental laceration during the approach. No patient died or suffered significant permanent morbidity. One patient required further shunt revision 4 days after the FMD. Another patient was found to have a postoperative occipitonuchal CSF collection that was successfully managed by serial lumbar taps. The FMD procedure allowed the complete resolution of the preoperative symptoms in five cases and marked improvement in three. Clinical improvement usually started immediately after surgery, even though the recovery from tetraparesis usually required some months.

Hydrosyringomyelic Cysts

The control MR image showed the presence of hydrosyringomyelic cavitations in 137 (68%) of 202 patients. All these patients also had a CM-II, but usually there was evidence of free CSF passage at the level of the foramen magnum. The hydrosyringomyelic cysts were variable for extension, size, morphology, concameration, and cord level. In 72 cases (53%) the cysts were single, well delimited, and appeared as quite circumscribed. In the remaining 65 patients (47%) the syringomyelia appeared more extended consisting of either multiple cysts or of a single large cyst affecting multiple levels. The cervical level was completely unaffected in 58 cases (43%). In 16 patients (11%), the MR imaging studies revealed intradural extramedullary fluid collections of unknown origin (Fig. 5). These collections were interpreted as a sort of communicating arachnoid cyst and were often associated with atrophic cord segments. In all cases, the hydrosyringomyelic cyst, as well as the extramedullary fluid collection and the cord atrophy, was completely asymptomatic (Fig. 5). Accordingly, the initial treatment was conservative in all cases, regardless of cyst extension and morphological features. Repeated MR imaging was planned between 6 and 12 months, then yearly for the first 3 years. Further MR imaging studies were obtained every 3 to 4 years until adulthood. All the cases of extramedullary fluid collection showed no tendency to increase and no treatment was needed. As to the hydrosyringomyelia, in 131 patients (96%) there was no clinical and/or imaging-documented progression throughout the entire follow-up period, and no treatment was necessary.

Conversely, there were six patients (4%) who required treatment due to either clinical progression or cyst enlargement. In one case the syringomyelia remained completely asymptomatic despite a marked progressive craniocaudal enlargement on repeated MR imaging. The remaining five patients presented with symptoms consisting of various combinations of classic symptoms of syringomyelia. In all cases bowel and bladder dysfunction remained relatively stable, thus helping to exclude a diagnosis of TCS. There was no case of progressive scoliosis. The MR images revealed cyst enlargement in all these six cases, whereas the cine-MR imaging studies showed hampered CSF–craniospinal communication in five patients. These five patients underwent FMD, and the dural sac was extensively widened by grafting. Plugging of the obex, fourth ventricle cannulation, and syringostomy were never performed. During the postoperative period (ranging from 3–16 years) good neurological improvement was achieved by three patients, clinical stabilization without further worsening was seen in one, and one patient obtained no definitive effect. This patient’s condition continued to deteriorate following a transient period of stability, and a reoperation in which widening of the dural sac with concomitant cystoperitoneal diversion was performed. Nevertheless, the neurological condition continued to worsen, and the patient underwent several further surgical procedures including cord detethering, extended laminoplasty, and even thecoperitoneal shunt treatment. All treatments were clinically ineffective; the patient progressively became tetraplegic and her condition is still worsening. Repeated MR imaging showed that the cyst was almost collapsed, but progressive atrophy of the cervical spinal cord had developed. In the other four patients, control MR images after FMD generally showed stable cysts without further progression. The one patient without CSF blockage at the foramen magnum harbored a cyst that extended to the
In this case, management consisted of the so-called terminal ventriculostomy with cyst marsupialization by the section of the terminal filum. Although the cyst size remained unchanged, this patient experienced a very good neurological recovery, which continues 11 years postsurgery.

**Tethered Cord Syndrome**

In this series, 199 patients (98.6%) had low-lying cord termini, and 130 (64%) had evident adhesions between the neural structures and the dural sac. These features were quite evident in all the 116 patients whose neural plaque had been left “open” at time of the MMC repair and in 14 (16%) of 86 patients whose neural tube had been reconstructed (“tubing”) (Fig. 6). These findings are reported in Table 3.

At each clinical examination, any new symptom or sign referable to a possible TCS was carefully recorded and analyzed. The TCS was suspected when one or more of the following signs were present: increased weakness and development of new neurological deficits, hypertonia and/or clonic movements, progressively worsening scoliosis and/or orthopedic anomalies (that is, high-arched feet), severe pain at the level of the back wound, and worsening of urinary function. In these cases, a multidisciplinary consultation was obtained involving various specialists from the Centro Spina Bifida. Every effort was taken to rule out any other possible causes of deterioration other than TCS.

In this series, a total of 75 (37%) of 202 patients presented with signs and symptoms of possible TCS. There was no patient whose condition rapidly deteriorated, and the syndrome always appeared as a very slowly progressive chronic condition. Table 3 summarizes the main features of these patients. Fourteen patients (7%) were identified with the so-called pseudo-TCS, in which the syndrome was mimicked by other conditions (that is, shunt malfunction or adolescence-related psychological malaise). These 14 patients were treated by tailoring the therapy to their specific conditions. In 21 patients, the syndrome consisted of very mild and stable symptoms without evidence of progression. These 21 patients did not undergo surgery, and no progression was observed during the subsequent follow-up period (range 1–7 years, mean 4.5 years). Accordingly, a “true TCS” was found in 40 of the initial 75 patients. An indication for surgical detethering was tailored based on the patient’s condition and quality of life. More aggressive indications were considered in patients who maintained the ability to walk, whereas nonambulatory patients were surgically treated only in cases in which their condition severely limited their quality of life.

![Fig. 6. Magnetic resonance images. Sagittal (A) and axial (B) control images obtained in a patient whose neural plaque was simply replaced inside the dural sac. The terminal cord appears adherent to the overlying dura over a considerable part of its length and is dorsally displaced. The unreconstructed and dorsally displaced plaque is clearly evident (left side in panel B). Sagittal (C) and axial (D) control images obtained in a patient whose neural tube had been reconstructed by pial microsutures (tubing). Although fewer adhesions are evident, the terminal filum still appears dorsally displaced. Sagittal (E) and axial (F) control images obtained in a patient whose neural tube had been reconstructed by pial microsutures (tubing). In this case, the cord does not appear dorsally displaced, and it appears well immersed in the CSF.](image-url)
Patients required detethering because of scoliosis progression, whereas the remaining 17 patients did not require such surgery even in paraplegic patients. Accordingly, 18 patients (9%) were treated nonoperatively. Subsequently, one of these patients is reported in Table 4.

TABLE 3

<table>
<thead>
<tr>
<th>Features</th>
<th>No. of Cases (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>neuroimaging</td>
<td></td>
</tr>
<tr>
<td>low-lying cord termination</td>
<td>199 (98.5)</td>
</tr>
<tr>
<td>extended neurodural adhesion &amp; dorsal cord</td>
<td>130 (64)</td>
</tr>
<tr>
<td>displacement</td>
<td></td>
</tr>
<tr>
<td>no tubing</td>
<td>116</td>
</tr>
<tr>
<td>only tubing</td>
<td>14</td>
</tr>
<tr>
<td>tubing &amp; intradural hyaluronic gel</td>
<td>0</td>
</tr>
<tr>
<td>limited adherences w/ terminal cord not dorsally displaced &amp; bathed into CSF</td>
<td>72 (36)</td>
</tr>
<tr>
<td>no tubing</td>
<td>0</td>
</tr>
<tr>
<td>only tubing</td>
<td>24</td>
</tr>
<tr>
<td>tubing &amp; intradural hyaluronic gel</td>
<td>48</td>
</tr>
</tbody>
</table>

clinical

| symptoms of TCS                              | 75 (37)          |
| pseudo-TCS                                    | 14 (7)           |
| mild & stable symptoms                        | 21 (10)          |
| true TCS                                      | 40 (20)          |

results in 40 true TCS

| conservative management                      | 18 (9)           |
| unchanged quality of life                    | 17               |
| failure (progression of scoliosis)          | 1                |
| surgical detethering                         | 22 (11)          |
| improved                                     | 11               |
| unchanged/stable                             | 6                |
| continued worsening                          | 5                |

* Tubing indicates neural tube reconstruction by pial microsutures.

For instance, in a nonambulatory patient, isolated progressive lower-limb weakness was not considered per se as an indication for surgery, whereas untreatable hypertonia, progressive scoliosis, and unresponsive back pain indicated surgery even in paraplegic patients. Accordingly, 18 patients (9%) were treated nonoperatively. Subsequently, one of these patients required detethering because of scoliosis progression, whereas the remaining 17 patients did not require such a procedure during a follow-up period ranging from 1 to 19 years (mean 7.5 years). On the other hand, surgical detethering was offered to 22 patients (11%), but one refused surgery; nevertheless a total of 22 patients underwent surgical detethering (21 with direct indication and one following initial nonoperative treatment). The main features of these 22 patients are reported in Table 4: the conditions of 11 patients improved, those of six remained unchanged but stable, and those of five worsened after a transitory period of stability. Typically, these five latter patients, following a few months of arrested progression, experienced recurrence of their preoperative symptoms (mainly progressive neurological deterioration). In four patients, a further detethering procedure was attempted. Again, following a transitory (shorter) period of stability, the syndrome recurred. Two of these patients underwent one and three further unsuccessful detethering procedures at other centers. These five patients with progressively deteriorating conditions underwent several other treatments including shunt revision, extended laminectomy, and physiotherapy. Unfortunately, all were ineffective and all five patients became severely disabled.

Postoperatively, the back wound pain resolved or markedly improved in all cases; the clonic contractions and hypertonia tended to improve, whereas the acquired neurological deficits and the urinary dysfunction usually remained unchanged; arched feet improved in all cases, whereas scoliosis remained unchanged. Follow-up after detethering ranged from 2 to 20 years (mean 9.2 years). The overall results of the detethering procedures in these 22 patients are reported in Table 3: the conditions of 11 patients improved, those of six remained unchanged but stable, and those of five worsened after a transitory period of stability. Typically, these five latter patients, following a few months of arrested progression, experienced recurrence of their preoperative symptoms (mainly progressive neurological deterioration). In four patients, a further detethering procedure was attempted. Again, following a transitory (shorter) period of stability, the syndrome recurred. Two of these patients underwent one and three further unsuccessful detethering procedures at other centers. These five patients with progressively deteriorating conditions underwent several other treatments including shunt revision, extended laminectomy, and physiotherapy. Unfortunately, all were ineffective and all five patients became severely disabled.

Curiously enough, the patient whose parents refused detethering experienced the spontaneous stabilization of his condition. He continued to experience slowly worsening of lower-extremity weakness and urinary function for some months; afterward he remained completely unchanged for 5 years. Presently, he is under observation.

**Overall Final and “Social” Results**

There were five deaths (2.4%) during the follow-up of these 202 patients. Three patients died of shunt malfunction/infection, one patient died of complications after orthopedic surgery, and one of renal failure and sepsis of urological origin. Presently, two patients are severely ill and with potentially lethal conditions: a 26-year-old woman with syringomyelia is complaining of upper cervical/bulbar dysfunction (after failure of FMD, syringoperitoneal shunt treatment, and various other procedures); and a 24-year-old woman is suffering from prion spongiform encephalopathy probably related to the use of bovine dural substitute at the time of the initial closure of the MMC.
Follow-up MR imaging studies revealed that three patients harbored cerebral cavernous angiomas. In two of these patients, the angiomas were asymptomatic, small, and deeply located so no treatment was considered. In the other, a 1.5-cm left parietal paraventricular angioma was uneventfully excised. Two adult patients required laminectomy and foraminotomy for low lumbar stenosis that was two and three levels above the MMC closure. Epileptic seizures were experienced by 56 (27%) of 202 patients. The seizures were well controlled in all cases, and only a few patients had true epileptic disease and had to commence chronic anti-epileptic therapy. Latex allergy was reported in a large number of patients, but life-threatening reactions occurred in only two (1%). Three patients required kyphectomy for progressively worsening kyphosis at the ages of 4, 6, and 12 years (Fig. 8). Many patients were afflicted by scoliosis, but only five required surgery.

Severe cerebral morbidity was reported in a total of 11 patients: one was hemiparetic due to hemorrhage during a shunt revision procedure, and 10 were severely mentally disabled because of ventriculitis, high ICP, or initial fetal distress. A thoroughly extended analysis of the cognitive level is beyond the purpose of this paper. However, significant cognitive impairments were evident only in these 10 patients, and the remaining 192 patients (95%) had normal or almost normal IQs.

Although a precise analysis was not done, in our material, we did not find a close correlation between IQ and shunt presence, the number of revision procedures, the initial ventricle size, the initial thickness of the cortical mantle, the amount of craniomegaly, the presence of midline brain malformations, and the level of the initial cord lesion (Fig. 9). Psychological troubles were very frequent and mainly consisted of signs of inhibition, slackness, passivism, “cocktail party personality” (chattering speech with limited content), and exaggerated dependence on adults’ help. However, true depression and somatization (such as in the cases of pseudo-TCS) were relatively unusual.

Long-term functional results have been retrospectively evaluated by extrapolating 38 consecutive patients older than 15 years whose initial lesions were below the L-2 level. The mean age was 18.3 years, and the male/female ratio was 1. There were 28 patients with shunt-treated hydrocephalus, and 26 had experienced at least one revision procedure. None had a history of ventriculitis, symptomatic CM-II, or syringomyelia, whereas one had required a detethering procedure. The social outcomes of these 38 patients are reported in Table 5.

Discussion

The Center for Spina Bifida is the operative arm of the Associazione Spina Bifida e Idrocefalo di Niguarda. This is a nonprofit association that coordinates all specialists involved in MMC management and tracks patients with MMC from the prenatal diagnosis to adult life. A significant number of teenagers and young adults are still under observation by our center. Unfortunately, just a few centers continue to
observe these patients after 18 years of age. Recently, Mattsson et al.\textsuperscript{31} pointed out that, after the age of 18 years, medical responsibility is discontinued, often with less readiness in adult medicine to meet adolescents with spina bifida and their special needs. Of course, this is a problem of paramount importance, because patients with MMC require multidisciplinary, specialized care virtually throughout life.

### Timing of MMC Repair

Although the superiority of cesarean section over vaginal delivery has not been proven,\textsuperscript{10,22,23} the efficacy of a scheduled cesarean section in the prelabour period has been reported in selected cases.\textsuperscript{10,22,23} We believe that this policy may have some advantages. Parents are usually more relaxed, the newborn is less stressed, and few lesions are ulcerated. Furthermore, to plan the cesarean section means also to plan the subsequent MMC repair and, in a busy neurosurgical unit, this allows the operation to be performed electively by a specialized surgeon. Despite the fact that we usually cooperate with highly qualified obstetricians from other hospitals, we always strongly recommend that the cesarean section be performed at our hospital so that the neural defect may be repaired without any delay and both parents may remain close to their newborn.

There is no consensus about the timing of MMC repair: either no significant difference is reported between early and delayed repair, or surgery within the first 48 to 72 hours is recommended to prevent CSF infection and further neurological deterioration.\textsuperscript{10,37} An increased risk of shunt malfunction has been reported following delayed MMC repair because of increased CSF proteins and debris, which may lead to shunt occlusion even without infection.\textsuperscript{14} In our series, all patients who underwent MMC repair after 2 days experienced shunt malfunction; likewise, early shunt failure (not related to misplacement) was almost exclusive to patients with delayed repair. We favor a policy of “as soon as possible repair” and delayed repair was only due to delayed referral. This probably accounts for our relatively low rate of ventriculitis. Infections occurring before MMC repair were very rare and occurred only in two patients with delayed referral. Also postoperative ventriculitis was quite rare, occurring in patients with early cord repair and early shunt placement. Given that early MMC repair was used in the vast majority of our patients, we think these infections are to be correlated to early shunt treatment.

### Techniques of MMC Repair

As to the surgical procedure, we used well-known traditional techniques,\textsuperscript{10,22,23} which deserve just a few comments. In no case have we performed intentional rhizotomy or distal cordectomy or excised the plaque, given that some neurological function could be maintained.\textsuperscript{33} Even when the plaque was very large, it was always possible to reconstruct adequately wide dural sacs without any deliberate sacrifice of neural elements. A firmly scarred and reepithelized neural plaque had to be partially resected in the one patient who underwent surgery at 2 years of age. The only deliberate sacrifice was that of the terminal filum,\textsuperscript{36} but often we were not able to recognize the filum despite meticulous microsurgical inspection and intraoperative electrophysiology. In our opinion, the fact that stimulation of a neural root elicits no reaction does not mean it is not functional and may be sacrificed. It could be just “stressed” or traumatized by exposure to the amniotic liquid and air, as well as by nursing and surgical manipulation, so that it could maintain potential for a subsequent recovery. McLone\textsuperscript{34} has reported that one third of infants have postoperative sensorimotor functions that were not initially observed at birth.

The technique of reapproximating the lateral edges of the placode (tubing) has been proposed to minimize scar adhesion between the placode and the overlying dura.\textsuperscript{23} Despite the fact that TCS prevention has not been achieved and there is risk of placode damage,\textsuperscript{10,22,23} this technique undoubtedly triggers less scarring, thus making possible future detethering procedures easier.\textsuperscript{10,37} Since the mid1990s, we have systematically used the tubing technique and have found no re-
Long-term treatment of myelomeningocele

Fig. 9. Magnetic resonance images. Preoperative axial (A) and coronal (B) images obtained in a 10 day-old newborn showing massive hydrocephalus with very thin cortical mantle. This patient underwent VP shunt placement within 2 weeks of birth. Control axial (C) and coronal (D) images obtained 6 years later when the patient presented with normal intelligence and was attending elementary school without any particular problems.

...lated morbidity. Using this technique, on control MR images the reconstructed cord often appeared well immersed in CSF (that is, an almost-normal condition has been recreated) and with limited scarring, although TCS was not always prevented. Besides the tubing procedure, we have treated more recent patients by perfusion of the intradural space by hyaluronic acid gel (Hyalobarrier). This product is widely used in abdominopelvic surgical procedures to prevent adhesion formation. It forms a barrier against contact between adjacent tissues during the repair phase subsequent to a surgical procedure. It is obtained by the condensation of hyaluronic acid, one of the main components of human connective tissue and is completely resorbed 7 days after its application. We do not know of other uses of this product in neurosurgery. We observed no side effects, complications, or morbidity. To date, none of these patients has had to undergo reoperation, so we cannot confirm that there are no adhesions. Needless to say that the number of patients and follow-up duration (range 1–6 years, mean 4.1 years) are not adequate to give information about the efficacy of this product. However, the absence of side effects and complications encourages us to continue this experimentation.

Although some debate exists about the reconstruction of the lumbodorsal fascia, we think that the myofascial plane provides an additional protective layer and may be useful in preventing postoperative CSF fistulas. Moreover, the paravertebral muscles may be medially mobilized as a single bloc with the overlying subcutaneous tissues, thus avoiding wound tension and allowing an easier skin repair. Even in cases of significant kyphosis, an extended myofascial dissection and mobilization usually makes it possible to cover the dural sac with adequately thick tissue. In these cases, kyphectomy at the time of the initial closure has been advised to prevent interference with wound closure. However, the possible advantages of immediate correction at birth are counterbalanced by the more appropriate vertebral somectomy with instrumentation and stabilization that are possible at more advanced ages. Accordingly, we try to postpone the kyphectomy as long as possible. Regardless, only a few patients (1.4%) required this procedure because of progressively worsening spinal deformity, neurological deficit, or decubitus ulcers (Fig. 8).

**Hydrocephalus and MMC**

Hydrocephalus in MMC may be present at birth and sometimes subsequently develops. The timing of shunt insertion should depend on both the severity and the rate of progression of the hydrocephalus, but complete agreement does not exist. On the one hand, several authors have reported no significant increase in complications following coincident MMC closure and shunt placement. Indeed, this could facilitate healing of the back without CSF leakage and could protect the brain from the effects of progressive ventricular dilation. On the other hand, hydrocephalus is immediately evident at birth in approximately 25% of newborns, which means that most infants with MMC do not require simultaneous MMC repair and shunt insertion. Other authors have listed the risks of simultaneous MMC repair and shunt treatment as follows: compromised immune function of the newborn, catabolic response with prolonged wound healing, CSF exposure to organisms from the open sac, transient bacteremia during surgical manipulation for back closure, and unrecognized urinary tract infections. In our practice, we try to postpone shunt treatment as much as possible. Nevertheless, postoperative CSF leakage from the back did not represent a major problem even in cases of gross hydro-

<table>
<thead>
<tr>
<th>Variable</th>
<th>No. of Patients (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>fully independent in daily activities</td>
<td>37 (97.3)</td>
</tr>
<tr>
<td>able to walk with orthoses</td>
<td>30 (78.9)</td>
</tr>
<tr>
<td>useful “community ambulation”</td>
<td>18 (47.3)</td>
</tr>
<tr>
<td>“social urinary continence”*</td>
<td>37 (97.3)</td>
</tr>
<tr>
<td>completed “normal” primary school</td>
<td>37 (97.3)</td>
</tr>
<tr>
<td>completed “normal” secondary school</td>
<td>36 (94.7)</td>
</tr>
<tr>
<td>entered 3rd level schools†</td>
<td>31 (81.5)</td>
</tr>
<tr>
<td>completion of individual education course</td>
<td>16 (42.1)</td>
</tr>
<tr>
<td>have a job</td>
<td>11</td>
</tr>
<tr>
<td>unemployed but looking for a job</td>
<td>4</td>
</tr>
<tr>
<td>in the care of parents &amp; social services</td>
<td>1</td>
</tr>
</tbody>
</table>

* Clean intermittent autocalization regimens.
† Presently, 18 have obtained the Advanced Level Certificate of Education, 11 are university students, and two have graduated.
cerebrospinal fluid pressure was normal. In most cases, careful dural and muscular closure should result in a dry wound.

In our hands, patients who underwent shunt treatment soon after MMC repair were at a higher risk for early shunt failure and infection. On the other hand, we found a relatively close correlation between delayed cord repair and incidence of early shunt malfunction.

It is now recognized that patients with MMC and non-progressive ventricular enlargement may develop completely normally. Rekate described a series of criteria (including age and mantle thickness) to help in deciding which children should not undergo shunt placement. In our series, ventricular enlargement was evident in the vast majority of newborns, but treatment of hydrocephalus was required by only 78% of patients, numbers that are comparable with the reported rates of 80 to 90%. It is interesting to note that shunt treatment was usually required within the 1st month of life. Only a few patients had to be treated with a shunt after 1 month of age, and none after 6 months. Similar findings were also found by Rekate.

The recent development of endoscopic techniques has led some to attempt ETV in cases of hydrocephalus due to MMC. However, one should be ready to convert an ETV to a shunt if unexpected local anomalies are found. Apart from some initial enthusiasm, it is now recognized that ETV merely transforms the hydrocephalus from obstructive to communicating, thus leading to reductions in the shunt revision rate and the probability of massive and acute high ICP. To date, there is increasing evidence that the failure rate of ETV is so high in infants with MMC that the procedure should be reserved for older children. In our practice, ETV is no longer offered to newborns with MMC.

Shunt Malfunction

Despite the modern progress in shunt system manufacturing and surgical techniques, the rate of shunt malfunction remains high. Symptoms and signs of shunt malfunction in patients with MMC may be numerous, subtle, extremely variable, and very difficult to recognize. Even neuroimaging studies may be not helpful given that high ICP syndrome may coincide with unchanged or even slit ventricles.

In our practice, we always obtain a baseline MR image when the shunt is working properly. Repeated assessments compared with the baseline images may be useful to reveal the malfunction in patients with malformed and enlarged ventricles. Nevertheless, the diagnosis of shunt malfunction often remains mainly clinical; 52 to 64% of shunt-treated patients with MMC have been reported to experience shunt failure. This occurs mainly within 1 year of placement and is often due to infection. Within 6 years, 20% of patients require multiple revision procedures and 40% have persistent ventricular enlargement, whereas normal and slit ventricles account for 20 and 40% of cases, respectively.

With 20 to 25 years of follow-up, 95% of patients undergo at least one shunt revision. Indeed, our rate of infection may appear lower, but we realize it could be underestimated given that we do not routinely perform CSF assays.

We have relatively aggressive indications for shunt revision. On the one hand, the shunt revision procedure carries relatively low risks (≈ 0.5% of both mortality and morbidity rates in our series); on the other hand, death and severe morbidity due to delayed shunt malfunction are not unusual (≈ 1% mortality and 0.5% morbidity rates in our experience). In the present series we have included patients with headache and vomiting of unexplained origin, but with normal neurological examination and unchanged ventricles. Following a period of in-hospital observation, we generally favored the shunt revision that usually abated the preoperative syndrome. We investigate any new clinical manifestation even those not typical for shunt malfunction. Chiari malformation Type II, syringomyelia, and/or TCS may be exacerbated and even mimicked by hydrocephalus and may be resolved by correctly draining the ventricles.

We have found two peaks for the incidence of the first shunt malfunction: the vast majority of patients required reoperation—either within 1 year or after 3 years. This means that our shunts either required early revision or were likely to last longer than 3 years and often 7 years (mean duration 7.1 years). Curiously enough, patients who reached 15 to 18 years of age without any shunt malfunction seemed to have a good chance of not experiencing shunt malfunction during adulthood. Our series includes a small group of patients who underwent shunt treatment in the neonatal period and who reached adulthood without any shunt revision. Indeed, the duration of a shunt system is absolutely unpredictable. Our rate of multiple procedures (53%) was comparable with those reported in the literature. Conversely, in our series, following the first malfunction, the risk of further malfunctions appeared relatively high. This was probably related to the fact that the first shunt placement in a newborn was considered an elective surgery, whereas shunt revision was often performed on an emergency basis by the neurosurgeon on duty, who was not necessarily the most experienced one.

Teo and Jones recently reported an 80% success rate managing shunt malfunction by using ETV in children with MMC and identified the criteria to predict the effectiveness of the procedure: older age, triventricular hydrocephalus, and scarcely represented subarachnoid space. Unfortunately, we cannot confirm these good results. We do not know the reasons for our high rate of failures. Recently, however, Marlin has produced arguments against ETV; he found a 20 to 30% failure rate and difficult assessment of ETV failure even using MR imaging to assess stoma patency and cine–MR imaging to evaluate flow. Although outcomes of ETV in MMC were unsatisfactory, other endoscopic techniques proved highly effective in the treatment of shunt-treated patients with MMC who had entrapped ventricles. Isolated lateral ventricles were resolved by fenestration of the septum pellucidum, whereas isolated fourth ventricles were successfully managed by aqueductoplasty and stent placement.

Shunt Independence

An old principle long adhered to in neurosurgery states “once a shunt, always a shunt.” However, this cannot be accepted as an absolute rule. In a recent retrospective analysis of 850 children affected by nontumoral hydrocephalus, obvious shunt independence could be demonstrated in 3.2% of patients and 25% had MMC. Humphrey stated that as many as 50% of patients with MMC may outgrow the need for the shunt system by their 7th birthday. This becomes manifest when the tubing fractures, becomes too short, or appears clearly obstructed on routine examination while the patient remains completely neurologically asymptomatic.
tomatic with unchanged psychometric evaluations and unchanged ventricular sizes. In these circumstances, observation rather than shunt revision may be reasonable.\textsuperscript{11,22} and protocols or trials have been proposed for conservative management or even shunt removal.\textsuperscript{24,61} On the other hand, Rekate\textsuperscript{47} presented a paper partially titled “the erroneous concept of shunt independence in spina bifida patients,” and even Humphrey,\textsuperscript{23} in a subsequent paper, reported that follow-up MR imaging may reveal “a galaxy” of changes about the brain base and the spinal cord, which would be related to the faulty CSF circulation and which would eventually lead to neurological signs. In our practice, such MR imaging changes are usually not asymptomatic and clearly represent per se an indication for shunt revision. Nevertheless, our series also included entirely asymptomatic patients in whom no changes were noted on follow-up MR images.

Sudden respiratory or cardiac arrest has been reported due to the exhausting of the physiological mechanism of compensation.\textsuperscript{30,47,51} Nevertheless, if the patient is previously thoroughly asymptomatic, we think that a risk of truly sudden death does not exist. In our experience, some subtle sign or symptom was invariably present in the history of patients who experienced rapid deterioration, but the signs were not promptly recognized and the patients did not receive timely neurosurgical attention. In our mind, shunt malfunction is not a sort of unpredictable ictus cerebri, and we maintain the opinion that patients who present with imaging-documented shunt anomalies should be strictly monitored by a protocol of accurate, regular, and close controls, provided that they are really neurologically, psychometrically, and radiologically asymptomatic. By this policy, most of our patients with imaging-documented shunt anomalies could avoid shunt revision, and there were neither deaths nor permanent morbidity. Patients older than 4 or 5 years of age, with very low cord lesions, who underwent shunt treatment within a few weeks of birth, and without a recent history of shunt revision seemed to have higher chances of becoming independent of the shunt. Of course, we cannot be sure they are really and definitively shunt independent, but we can at least affirm that our protocol of conservative management is not burdened by high neurological risks. Nonetheless, these risks must be compared with the risks of an unnecessary revision procedure. Finally, our protocol of strict and close controls undoubtedly carries economic and psychological costs. However, patients with MMC are so used to undergoing so many assessments that the global cost of their care is not greatly affected and they do not seem upset by these adjunctive examinations.

Early and Late Brainstem Dysfunction and CM

Chiari malformation Type II is practically exclusive to patients with MMC and is present in all or almost all cases.\textsuperscript{52} It is now believed that the malformation is due to chronic CSF leakage during the fetal stage,\textsuperscript{39} a hypothesis that is also supported by the decreased incidence of CM-II that follows fetal repair of the MMC.\textsuperscript{46} Hydrocephalus most likely plays no role in the genesis of the malformation, but it is important for the development of clinical manifestations.\textsuperscript{10,58} In fact, in our experience, hydrocephalus was present in all symptomatic cases; moreover, it is known that ventricular drainage may sometimes completely reverse the CM-II symptomatology.\textsuperscript{10,38,52} Symptomatic patients frequently had a medullary kink (as in our series), and 75% of patients with a kink below C-4 would be symptomatic.\textsuperscript{7} From a schematic point of view, the CM-II clinical syndrome would be related to either intrinsic brainstem malformation\textsuperscript{44} or brainstem compression.\textsuperscript{43,52}

The CM-II syndrome has been defined as the main determinant of the quality of life of individuals with MMC, given that it more than anything else would determine the outcome for survival and independence in these children.\textsuperscript{25,38} However, it is clinically relevant in 20 to 30% of cases,\textsuperscript{34,58} and most patients with initially mild or moderate symptoms may spontaneously improve.\textsuperscript{10} In our series, relevant CM-II syndromes were observed in 10% of cases, but we are considering only the most severe cases (those requiring surgical treatment). Some authors\textsuperscript{43,58} have advocated early and aggressive treatment even for children with moderate types of the syndrome; others\textsuperscript{10} have advised surgery only in children with progressive or severe signs and symptoms. The first surgical treatment usually consists of shunt placement or revision.\textsuperscript{38,52} Patients whose conditions are not cured by shunt treatment must undergo an FMD procedure. This should be performed without any delay. The mortality rate has been reported to decrease from 70% to 15 to 20% after a more urgent surgical course has been taken, thus suggesting that brainstem compression plays a reversible role in the production of life-threatening symptoms.\textsuperscript{52} In our experience, the necessity of FMD was clearly age-related. Although FMD was required by a few adolescents, the vast majority of patients undergoing this treatment were either newborns or infants younger than 3 years of age (Fig. 2). It may be interesting to observe that patients between 3 and 10 years as well as those older than 14 years of age rarely experienced the syndrome and never required FMD.

Generally, younger patients are more likely to present with rapid deterioration and more severe symptoms and have the worst prognoses even following FMD, thus suggesting a prominent role for intrinsic brainstem malformations.\textsuperscript{10,52} Conversely, older patients usually have a chronic brainstem–upper cord syndrome, which is commonly improved by FMD, thus suggesting a compressive pathogenesis.\textsuperscript{43,52} Indeed, intrinsic structural brainstem changes have been reported in a total of 76% of patients regardless of age,\textsuperscript{18} which probably means that both pathogenetic mechanisms are possible but their respective risk may be different according to age. In our series, the newborns’ syndrome was really more severe and was lethal in one case. The surviving newborns required prolonged assistance in breathing and feeding postoperatively, but all eventually improved. Despite their intrinsic malformations, FMD probably provided the time to allow maturation of the brainstem. Cases of late death due to prolonged apnea have been reported during infancy,\textsuperscript{52} but we did not observe any fatal case during the follow-up. In our older patients, the CM-II syndrome actually was less severe and was invariably slowly progressive. Manifestations of CM-II have been carefully reported\textsuperscript{44} and were relatively typical in our series. Nevertheless, we also observed two cases of unusual vegetative disturbances consisting of tachypnea with red spots on the skin (of presumed vascular origin), which rapidly appeared and disappeared. We are not even sure that these manifestations were a result of brainstem dysfunction, but they completely resolved and never recurred following FMD.

As to FMD, we do realize this term is probably not com-
completely correct. McLone and Dias prefer the term posterior or cervical decompression. In fact, these patients may have a large foramen magnum, and the operation mainly consists of widening the dural sac by multilevel laminectomy, whereas the suboccipital craniectomy is limited by a low-lying torcular herophili. However, the term FMD is popular and remains in the clinical jargon. Apart from the terminology, following this procedure, some authors have reported such a high rate of complications that surgical results were not significantly better than the natural history of the disorder. We never intentionally penetrated the arachnoid space, never intentionally excised cerebellar tissue, and never cannulated the fourth ventricle. This probably accounts for our virtually absent mortality and morbidity rates. Moreover, we extended the laminectomy laterally as far as possible, but the articularizations were always preserved, and we rarely had to remove more than three levels. Nonetheless, none of our patients required reoperation to provide adequate CSF outflow from the fourth ventricle, and we observed neither bone regrowth nor cervical instability.

A final consideration concerns the comparison between patients with and without MMC. In general, in most patients with MMC, the CM is asymptomatic, not progressive, and requires no treatment. Conversely, in our experience, in patients without MMC, the CM is often responsible for craniospinal dissociation, brainstem dysfunction, and alteration of CSF dynamics, which frequently leads to progressive syringomyelic cavitations, so that a more aggressive surgical approach may be considered.

Hydrosyringomyelia and MMC

Hydrosyringomyelia is very frequent in our study and others concerning MMC. In general, the role played by the CM in the development of syringomyelia is well known and is described by the term foraminal syringomyelia. However, other causes are also possible, including tumors, arachnoiditis, injuries, and cranio-cervical junction malformation. Given that CM-II is invariably present in MMC, one might think that it is responsible for all the syringomyelic cysts occurring in patients with MMC. Indeed, it is our opinion that most of the intramedullary cysts in patients with MMC are not directly related to the CM-II and could be merely the further expression of the malformation of the neural tube. In our series, these cysts were usually present from the time the first MR imaging studies were obtained (within a few months of birth), thus supporting the malformative origin. Even when the cysts were shown only on repeated MR imaging studies, the retrospective reanalysis of the initial MR image usually led to the reappraisal of previously underestimated features due to the difficulty (especially in the past) of obtaining good quality images in small infants. Moreover, these cysts almost always affected the lumbar or thoracolumbar levels, thus sparing the cervical segment in almost half of our cases. In our series and those of other authors, most cysts were completely asymptomatic, and we observed even asymptomatic cysts occupying almost all the cord diameter. These cysts were conservatively managed and underwent long periods of observation, and they usually remained unchanged and asymptomatic. We do realize that syringomyelia may remain quiescent for very long periods, but, usually, large classic CM-related cysts are not completely asymptomatic and subtle varying and vanishing symptoms do exist. Of course, we are not denying the possible role of CM-II in the development of syringomyelia in patients with MMC, but we think there are also other types of cysts that are not actively supplied, unlike the so-called foraminal syringomyelia. In our series, we observed a few cysts (4%) that behaved as typical foraminal syringomyelia: they were progressive, the cervical level was always affected, and the cine–MR imaging studies showed CSF flow alteration at the level of the foramen magnum. These cases were obviously managed by FMD. On the other hand, there was only one isolated lumbar cyst that was progressive; the findings were normal on cine–MR images and the patient responded favorably to cyst marsupialization. We think that the CM played no role in this case, which was the only case of a progressive malformative cyst requiring surgery. Accordingly, in our series, there were cysts of probable malformative origin that were relatively frequent but required treatment very rarely. Conversely, there were a few properly termed foraminal syringomyelias that obviously required FMD.

As to the treatment modality, we agree with Oldfield et al. that the best treatment for foraminal syringomyelia is simple osteodural decompression with dural sac widening without any cannulation of the cyst or ventricles. When this FMD is ineffective, other treatment modalities, such as cyst marsupialization, cyst derivation, or thecoperitoneal shunt treatment, must be considered but, in these cases, the results are often unsatisfactory. On the other hand, cyst marsupialization may be effective in the rare cases of progressive malformative cysts.

Tethered Cord Syndrome

Each structure lacking viscoelasticity, such as a postoperative scar, has the potential for determining tight fixation of the spinal cord and TCS. Virtually all children with repaired MMC have a scarred and a low-lying spinal cord, but only 10 to 30% will develop TCS. Therefore, MR images showing low-lying cord and scarring do not dictate per se a detethering procedure. Magnetic resonance images obtained in the prone position and ultrasonography studies of the spinal cord motion have been proposed to help in the diagnosis of TCS but proved to be of poor practical utility. Accordingly, despite modern imaging progress, the TCS must still be diagnosed mainly on the basis of clinical criteria. Of course, MR imaging maintains its importance to preoperatively identify possible associated lesions such as lipoma and syringomyelia and to provide information about the relationships between the cord and the dural plane. In the present series, most patients had extended adhesions between the repaired cord and the dura, and the cord appeared dorsally displaced (Table 3). Of course, these features did not imply the development of TCS, but they were present in all patients with TCS, whereas we never had to perform detethering procedures in patients whose terminal cord was well immersed in the CSF. Although techniques exist to try to achieve such a favorable condition, indeed we completely agree with Hudgins and Gilreath and Zide et al. that presently no technique of cord repair can reliably prevent subsequent TCS. In particular, the tubing technique (that is the reconstruction of the neural tube) has not proved efficacious, but it limits scar adhesions and dorsal cord displacement (Fig. 6) so that a possible future detethering pro-
In our series, this technique was not associated with increased morbidity but was unable to prevent all cases of TCS. Nonetheless, TCS occurred in 16% of patients without tubing and in 3% of those with tubing. Moreover, no patient undergoing tubing plus intradural perfusion by Hyalobarrier developed the TCS. Although these results may seem encouraging, indeed we cannot draw any reliable conclusions because the follow-up periods are very different—tubing has been routinely performed only during the last 10 years and Hyalobarrier has been used just in the last few years.

Two peaks of incidence for TCS have been reported. The mean age for TCS was 7.8 years, but we had to perform surgery even in adult patients, and the possibility that even adults may require detethering is increasingly reported in recent papers. The clinical manifestations of TCS have been carefully described. The syndrome may be subtle and involve nonneurological conditions so that the importance of a real multidisciplinary approach cannot be overemphasized. In our series, the TCS was never acute or rapidly worsening. Moreover, we found some patients with pseudo-TCS in whom the syndrome was mimicked by other conditions. Apart from shunt malfunction (“always check the shunt first”), an important role was played by the psychological condition. A worsened ability to walk could be caused by bulimia with obesity and apathy, as well as true somatization with conversion of psychological disturbances into physical symptoms. It could even represent an attempt for more parents to seek medical attention for their children by reporting progressive lower-extremity weakness.

As to the treatment, we do not believe that all cases of TCS should be surgically managed. The progression of TCS depends on chronic repeated microinjuries to the spinal cord during normal daily activities, so that a regimen of bed rest without stressful spinal movement may lead to clinical improvement. Surgery should be tailored to the severity of clinical signs and symptoms, the original neurological status, and the quality of life. Yamada et al. reported that patients more severely afflicted with MMC invariably present with no neurological improvement following detethering. Nonambulatory patients with isolated increased lower-extremity weakness may be (at least initially) conservatively treated. These patients should undergo detethering only when pain, spasticity, and/or scoliosis are expected to lead to loss of their ability to sit. Conversely, the least afflicted children are the most vulnerable, as they have more function that may be further impaired, so they must have more aggressive indications. We opted to perform surgical detethering only in patients with documented clinical progression and expected worsening of quality of life. Accordingly, most patients who underwent detethering procedures were ambulatory, whereas relatively few paraplegic patients underwent surgery. Patients who did not undergo surgery were strictly observed, and we had to reconsider the decision in only one. Nonetheless, the diagnosis of TCS is often difficult and the indications for detethering may remain doubtful. Therefore, we recommend that patients more severely afflicted with MMC invariably present with no neurological improvement following detethering can be considered for surgery. These patients should undergo detethering only when pain, spasticity, and/or scoliosis are expected to lead to loss of their ability to sit. Conversely, the least afflicted children are the most vulnerable, as they have more function that may be further impaired, so they must have more aggressive indications. We opted to perform surgical detethering only in patients with documented clinical progression and expected worsening of quality of life. Accordingly, most patients who underwent detethering procedures were ambulatory, whereas relatively few paraplegic patients underwent surgery. Patients who did not undergo surgery were strictly observed, and we had to reconsider the decision in only one. Nonetheless, the diagnosis of TCS is often difficult and the indications for detethering may remain doubtful. Therefore, we recommend that patients more severely afflicted with MMC invariably present with no neurological improvement following detethering can be considered for surgery. These patients should undergo detethering only when pain, spasticity, and/or scoliosis are expected to lead to loss of their ability to sit. Conversely, the least afflicted children are the most vulnerable, as they have more function that may be further impaired, so they must have more aggressive indications. We opted to perform surgical detethering only in patients with documented clinical progression and expected worsening of quality of life. Accordingly, most patients who underwent detethering procedures were ambulatory, whereas relatively few paraplegic patients underwent surgery. Patients who did not undergo surgery were strictly observed, and we had to reconsider the decision in only one. Nonetheless, the diagnosis of TCS is often difficult and the indications for detethering may remain doubtful. Therefore, we recommend that patients more severely afflicted with MMC invariably present with no neurological improvement following detethering can be considered for surgery. These patients should undergo detethering only when pain, spasticity, and/or scoliosis are expected to lead to loss of their ability to sit. Conversely, the least afflicted children are the most vulnerable, as they have more function that may be further impaired, so they must have more aggressive indications. We opted to perform surgical detethering only in patients with documented clinical progression and expected worsening of quality of life. Accordingly, most patients who underwent detethering procedures were ambulatory, whereas relatively few paraplegic patients underwent surgery. Patients who did not undergo surgery were strictly observed, and we had to reconsider the decision in only one. Nonetheless, the diagnosis of TCS is often difficult and the indications for detethering may remain doubtful. Therefore, we recommend that patients more severely afflicted with MMC invariably present with no neurological improvement following detethering can be considered for surgery. These patients should undergo detethering only when pain, spasticity, and/or scoliosis are expected to lead to loss of their ability to sit. Conversely, the least afflicted children are the most vulnerable, as they have more function that may be further impaired, so they must have more aggressive indications. We opted to perform surgical detethering only in patients with documented clinical progression and expected worsening of quality of life. Accordingly, most patients who underwent detethering procedures were ambulatory, whereas relatively few paraplegic patients underwent surgery. Patients who did not undergo surgery were strictly observed, and we had to reconsider the decision in only one. Nonetheless, the diagnosis of TCS is often difficult and the indications for detethering may remain doubtful. Therefore, we recommend that patients more severely afflicted with MMC invariably present with no neurological improvement following detethering can be considered for surgery. These patients should undergo detethering only when pain, spasticity, and/or scoliosis are expected to lead to loss of their ability to sit. Conversely, the least afflicted children are the most vulnerable, as they have more function that may be further impaired, so they must have more aggressive indications. We opted to perform surgical detethering only in patients with documented clinical progression and expected worsening of quality of life. Accordingly, most patients who underwent detethering procedures were ambulatory, whereas relatively few paraplegic patients underwent surgery. Patients who did not undergo surgery were strictly observed, and we had to reconsider the decision in only one. Nonetheless, the diagnosis of TCS is often difficult and the indications for detethering may remain doubtful. Therefore, we recommend that patients more severely afflicted with MMC invariably present with no neurological improvement following detethering can be considered for surgery. These patients should undergo detethering only when pain, spasticity, and/or scoliosis are expected to lead to loss of their ability to sit.

Overall Final and Social Results

Despite the fact that the survival of children with spina bifida has dramatically increased during the last 30 years, a mortality rate of up to 24% has been reported to continue in patients reaching young adulthood. This would be mainly related to hydrocephalus and shunt malfunction/infection. Shunt-treated patients with MMC have been said to have higher mortality rates in comparison with other causes of hydrocephalus. We are reporting a considerably lower mortality rate. This was probably due to our meticulous attention to hydrocephalus and shunt malfunction and the fact that we examine all outpatients with MMC repeatedly, frequently, and serially. Shunt-treated adults with MMC have been recently recognized as being at risk for shorter life spans. This is probably because these adults do not usually undergo medical observation.

Latex allergy has been reported in approximately 33 to 50% of patients, with 8% of patients experiencing a life-threatening reaction. This depends on the high degree of
exposure to latex products as a consequence of repeated surgical procedures, implantation of latex-containing materials, and catheterization.9 We have been aware of latex sensitization since the 1990s and have used latex-free operating rooms in all cases and all types of pediatric neurosurgical procedures. Perhaps this does not completely provide a latex-free environment, but at least serious allergic reactions may be avoided.40

As to mental development and ability, no differences in intelligence have been reported in patients with and those without shunts, provided that the cortical mantle is at least 2.8-cm thick.39 Shunt malfunctions and shunt infections remain the main determinants for mental development, but a role is played also by the neonatal condition after delivery,44 the lesion level, the presence of cerebral malformation, and the family and social environment of the patient.13 In our and others’ experiences,3,9,62 the intelligence of patients with MMC is usually considered almost normal, although it has been reported that, as the patients age, these children fall behind peers on arithmetic and visual-motor performance tests; however, they keep pace on reading and spelling tests.62 Despite this normal or near-normal mental situation and although patients with MMC are generally able to perform activities of daily living independently, indeed there are still low levels of independence and probability of work participation.5 Too many patients with MMC do not engage in the full range of adolescent activities (decision making, relationships with peers, and household responsibilities) and do not achieve positive outcomes (self-management and employment) necessary to make a successful transition to adulthood.5

A lesion below L-2 is theoretically compatible with ambulation although the number of ambulatory patients is usually less than expected. In the study by Davis et al.,9 76% of patients had lesions below L-2, but just 24% were ambulatory. Apart from late deterioration due to conditions such as tethered cord and scoliosis, adolescents with MMC may simply prefer a wheelchair to be more mobile and so accepted (sometimes tolerated) by their peers and teachers. Complete wheelchair dependence may develop, but careful reflection must be made based on the child’s health and quality of life with and without a wheelchair. Ambulation in adolescents with MMC may also be limited by cardiopulmonary problems and obesity, which may be relatively frequent.5 Ambulation in adolescents with MMC and well depicted by MR imaging, but their presence does not represent per se a surgical indication; thus, again, the decision for surgery must be clinically based. An old medical proverb advises, “Let’s treat the patients, not their radiograms.” Patients with MMC must present frequently to physicians and hospitals. This cannot be avoided, but it is necessary to prevent exaggerations and aberrations. In fact, another proverb states, “People should be treated to live, but should not live to be treated.” One of the greatest challenges in medicine today is establishing a network of care for these patients.3

Acknowledgments

This experience would have been impossible without the invaluable and indefatigable work of Professor Vito Console, Dr. Tiziana Redaelli, Dr. Francesca Schioppa, and Dr. Maria Pia Onofri from the Centro Spina Bifida of the Niguarda Ca’Granda Hospital and from the Associazione Spina Bifida e Idrocefalo, Niguarda.

The first author wishes to especially thank Dr. Pietro Versari, the man who started this experience. He is not a teacher: he is a friend!

References

Long-term treatment of myelomeningocele


11. Epstein F: Diagnosis and management of arrested hydrocephalus. Monogr Neural Sci 8:105–107, 1982


385

Accepted July 12, 2007.
Address correspondence to: Giuseppe Talamonti, M.D., Via Accademia 23, 20131 Milan, Italy. email: tala_nch@yahoo.it.