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Chapter 102

Spinal cord malformations

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INTRODUCTION

Malformations of the spinal cord are one of the most frequent malformations in the embryo. They have been described as long as man has walked on the planet and many anthropological excavations have uncovered spines with typical stigmata seen in children with spinal dysraphism, most of which were myelomeningocele (MMC). As there were no treatments for these malformations, we can assume that most did not survive. However, many ancient sculptures and drawings provide evidence of adults with such spinal deformities or lesions which can be related to open or, more often, occult dysraphisms. These spinal dysraphisms belong to the family of malformations called neural tube defects (NTDs), which includes anencephaly, exencephaly, encephaloceles, and meningoceles.

Ancient medical care for these children was virtually nonexistent and even Aristotle recommended infanticide for these children, starting an on going ethical debate regarding the antenatal diagnosis and management of the most severe cases of MMC. Early attempts at treatment included unsuccessful ligation of the sac and application of sclerosing solutions. Only the two last centuries have seen progressive improvement in treatment, including surgery for closure of the sac and the effective treatment of hydrocephalus.

CLASSIFICATIONS

These malformations must be clearly divided into two different families of malformations.

Open dysraphism

This consists mostly of MMC. It is a frequent, very severe malformation in which the spinal canal is open to the external surface with its external edge attached to the edges of a skin defect (Fig. 102.1). The muscles are absent or pushed laterally and the posterior elements of the vertebral column are absent or open (spina bifida).

Occult dysraphism

This is a heterogeneous group of malformations including lipomas of the filum and the conus, diastematomyelias, neurenteric cysts, dermal sinuses, and more complex conditions, often associated with malformative syndromes.

The caudal regression syndrome is probably distinct from the previous malformations and will be treated separately.

EMBRYOLOGY

The term spina bifida was suggested by Nicolas Tulp in his first description of MMC in 1651. It was proposed solely to describe a duplication of the spinous process of the vertebra. This term, as incorrect as it might be, is still used to describe any malformation occurring in the lower spine (Afonso and Catala, 2003).

Gastrulation

After fertilization and approximately five rounds of cell division, the human embryo comprises a spherical blastocele (the future placenta) and an eccentrically placed cluster of cells, the inner cell mass (the future embryo).

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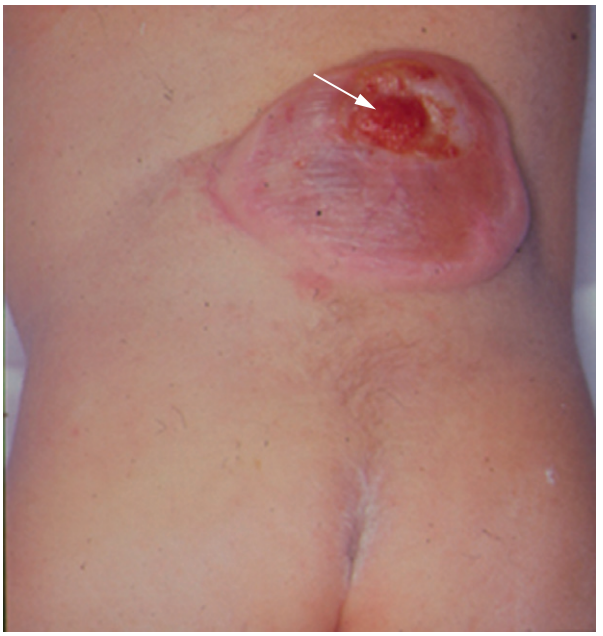

Fig. 102.1. Myelomeningocele at birth. Arrow: the neural placode.

By the end of the first embryonic week, it will be composed of two layers, the epiblast and the hypoblast. This establishes a ventrodorsal axis.

During the second week a rostocaudal axis develops and the epiblast cells in the caudal region of the embryo migrate toward the midline to form the primitive streak. At the cranial end of the primitive streak lies the primitive knot or Hensen's node. Cells from the primitive streak and Hensen's node invaginate beneath the epiblast in a process known as gastrulation. This invagination creates a three-layered embryo (endoderm, mesoderm, and ectoderm). The ectodermal cells give rise to the surface ectoderm and the neuroectoderm or neuroepithelium. The regression of the primitive streak, the primitive pit, the notocordal canal, and the notocordal plate has been described in the avian embryo but is still debated in more evolved species (there is no evidence of neurenteric canal in mammals, for example). Some complex dysraphisms (myelomeningocele, split cord malformations) are related to this period of embryogenesis.

Primary neurulation

During the third embryonic week, the ectoderm forms two morphologically distinct tissues: the centrally located neuroectoderm and the more peripherally located cutaneous ectoderm (Catala et al., 1996). The neuroectoderm is visible on embryonic day 16. Between day 16 and day 28, the neuroectoderm undergoes a number of morphological changes, referred to as neurulation, to form the neural tube. A midline neural groove develops. Elevation, growing, and medial convergence of the neural folds brings the neuroectoderm together in the midline to form the neural tube. Fusion of the neural folds and separation from the overlying cutaneous ectoderm completes the process. This process starts at the middle part of the embryo and progresses rostrally to close at day 24–26 at the level of the anterior neuropore (future commissural plate lamina terminalis) and caudally to close 2 days later (caudal neuropore) at the level of the second sacral segment where it joins the process of secondary neurulation.

This entire primary neurulation is finished at the end of the 4th week.

Secondary neurulation

This involves a mechanism entirely different from primary neurulation. The most caudal part of the neural tube develops from a pluripotent group of cells. Secondary neurulation involves the independent formation and canalization of multiple secondary tubules from the caudal cell mass and subsequent fusion of adjacent tubules to form a secondary neural tube. It will eventually fuse with the primary neural tube (Catala, 1999).

Spinal occlusion

This begins at the time of the anterior neuropore closure (D24) and ends a week later. This begins the rapid growth of the neural tube and the dilatation of the ventricular system. Failure to maintain this spinal and spinal cord occlusion may produce myelomeningocele, and mesenchymal and brain anomalies referred to as the Chiari 2 malformation.

Ascent of the conus medularis

By approximately day 45 of gestation, the caudal end of the neural tube extends to the coccygeal spinal level. Thereafter, the caudal end of the neural tube begins to ascend to more cranial spinal levels. This involves two mechanisms: retrogressive differentiation and, more importantly, the differential growth between the spine and the spinal cord during embryonic and fetal life. By 1 or 2 months after birth, the conus medularis lies at its final location, opposite the L1–L2 disk space. Any problems during this relative ascent (i.e., secondary neurulation) can lead to a low and tethered spinal cord.

Embryology of myelomeningocele

Many theories have been discussed (nonclosure, reopening, overgrowth, overdistension) (Till, 1969; Lemire, 1983). The nonclosure theory has gained almost universal acceptance but there is no definitive evidence to refute the other theories. Numerous teratogenic agents and

genetic disorders (trisomy 13 or 18, CHILD, Frazer, Waardenburg, Meckel–Gruber syndromes) have been identified that act on specific parts of the neurulation sequence to produce neural tube defects. Folate deficiency has also been identified as one of the main causes of open dysraphism and can be largely prevented by folate supplementation before conception and during the early stages of pregnancy.

Embryology of the occult dysraphisms

While it remains mostly unknown in humans, occult dysraphism involves a mechanism clearly different from that which causes MMC (Till, 1969; Lemire, 1983; Belzberg et al., 1991; Catala, 1998, 2002; Tortori-Donati et al., 2000; Li et al., 2001; Afonso and Catala, 2003; Finn and Walker, 2007; Muthukumar, 2009).

OPEN DYSRAPHISM: MYELOMENINGOCELE

Epidemiology

Myelomeningocele is one of the most frequent human malformations. Its mean incidence is 1/1000 live births with a wide variation based on ethnicity, race, geography, and temporal trends. In Europe the highest rates are found in Ireland and Wales (5/1000 live births) compared to the southeast part of Europe (0.1–0.6 per 1000 live births) (Group, 1991). In Canada and in the USA a higher incidence has been reported along the East Coast. In China the incidence rates north of the Yang Tze river are six times those of the southern province. Pockets of higher incidence have also been seen in India without any clear geographic pattern (Frey and Hauser, 2003).

Ethnicity also has an effect on the rates of spina bifida. In the United States, the Hispanic population has the highest risk compared to African-Americans and Asians. This risk remains among Hispanics even after controlling for other factors. When a low prevalence ethnic group migrates to a region of high incidence, they tend to maintain their low rates or at least a rate lower than that of the native population. When a high prevalence ethnic group migrates to a region of low incidence, they maintain a higher rate than the native population, but there is always a significant reduction of the risk. These geographical and ethnic considerations have led to a search for environmental factors and nutritional factors, specifically the folates (Canfield et al., 1996a, b, 2009).

Observations in the mid-1970s in the UK that lower red cell folate levels in women of lower socioeconomic status were associated with a higher prevalence of NTDs implicated folate deficiency as an etiological factor (Rosano et al., 1999). In the early 1980s, initial randomized trials in the UK were strongly suggestive of a role for folate supplements in preventing NTDs. From 1988 to 1995 a number of case–control studies indicated a risk reduction of 30–75% in those who received folic acid supplements. The Medical Research Council Vitamin Study Group (UK) in 1991 reported the results of a double-blind randomized controlled study (33 centers, 7 countries) which showed that periconceptional folic acid supplementation (4 mg/day in mothers with a previous history of NTDs) was associated with a risk reduction of 72% (Smithells et al., 1976, 1983; Laurence et al., 1980, 1981). In 1991 the US Center of Disease Control (CDC) therefore recommended 4 mg/day supplementation for those mothers with a high risk of MMC by virtue of a previously affected pregnancy (Pitkin, 2007). In 1992, a randomized study of 4156 low-risk Hungarian women found a statistically significant reduction of NTDs with folic acid supplementation (800 μg/day). This led to the further recommendation by the CDC that all women of reproductive age should take 400 μg folic acid daily in addition to a folate-rich diet (Czeizel and Dudas, 1992; Czeizel et al., 1992; Dudas and Czeizel, 1992).

Prevention

Since folic acid supplementation has been shown to reduce the risk of NTDs, the mainstay of prevention is now aimed at increasing the intake of folic acid in the target population of women. This can be achieved in three ways:

1. Increasing folate-rich foods in the diet. Even if foods high in folate are numerous (broccoli, spinach, green salad, etc.), it is difficult to get enough folate from natural sources alone to reduce the risk of NTDs. Therefore, recommendations to increase folate intake via food are not an adequate measure on their own.
2. Folic acid supplementation. Since 1993, public health strategies in many countries have aimed to promote the taking of folic acid by women of child-bearing age. The recommended dose is 400 μg daily (McNulty et al., 2000). Women who have had a previous NTD-affected pregnancy and are otherwise high risk (close relative who has a NTD, type 1 diabetes mellitus, seizure disorders treated with valproic acid or carbamazepine) are recommended 4 mg per day. This needs to be taken at least 1 month prior to conception and continued throughout the first trimester of pregnancy. However, these have generally not been successful in reducing the number of affected births. The likely reason is that up to 50% of all pregnancies are

unplanned and folate must be taken prior to conception to have an effect.

3. Fortification of foods with folic acid. Because the above measures are often unsuccessful, food fortification policies (UK, Australia, Mongolia) have instead been used to provide a more widespread and reliable intake of folic acid. Since 1998, mandatory fortification of flour has been introduced in Canada, Indonesia, and some South American and Asian countries. Recent data have confirmed that rates of NTDs dropped in the USA and Canada by 26% and 46% compared to prefortification rates. In Chile, where the fortification was introduced in 2000, there has been a 40% drop (Lopez-Camelo et al., 2000, 2005; Hertrampf and Cortes, 2004; Llanos et al., 2007; Nazer et al., 2007). In Europe (i.e., France) there has been a reluctance to follow such policies. The most recent results were published in 2009, after Brazil introduced fortification of flours made of corn and wheat in the state of Rio Grande do Norte in 2002. Only an insignificant decrease in the incidence of myelomeningocele was found, probably related to the poor consumption of flour produced in factories by poor families.

Antenatal diagnosis and management

Until a few decades ago, the prenatal detection rate was relatively low and mostly occurred in developed countries. Serum screening (alpha-fetoprotein, acetylcholinesterase) (Wald and Cuckle, 1980) was used in conjunction with ultrasound. Using this type of approach, detection rates as high as 80% had been reached. Over the past 20 years, the detection rate has dramatically increased to nearly 100%, following the recognition that indirect cerebral signs were present in the overwhelming majority of cases of myelomeningocele (Fig. 102.2). These cerebral signs include ventriculomegaly, the lemon sign (frontal bossing), the banana sign (deformation of the cerebellum), and obliteration of the cisterna magna. Direct signs best

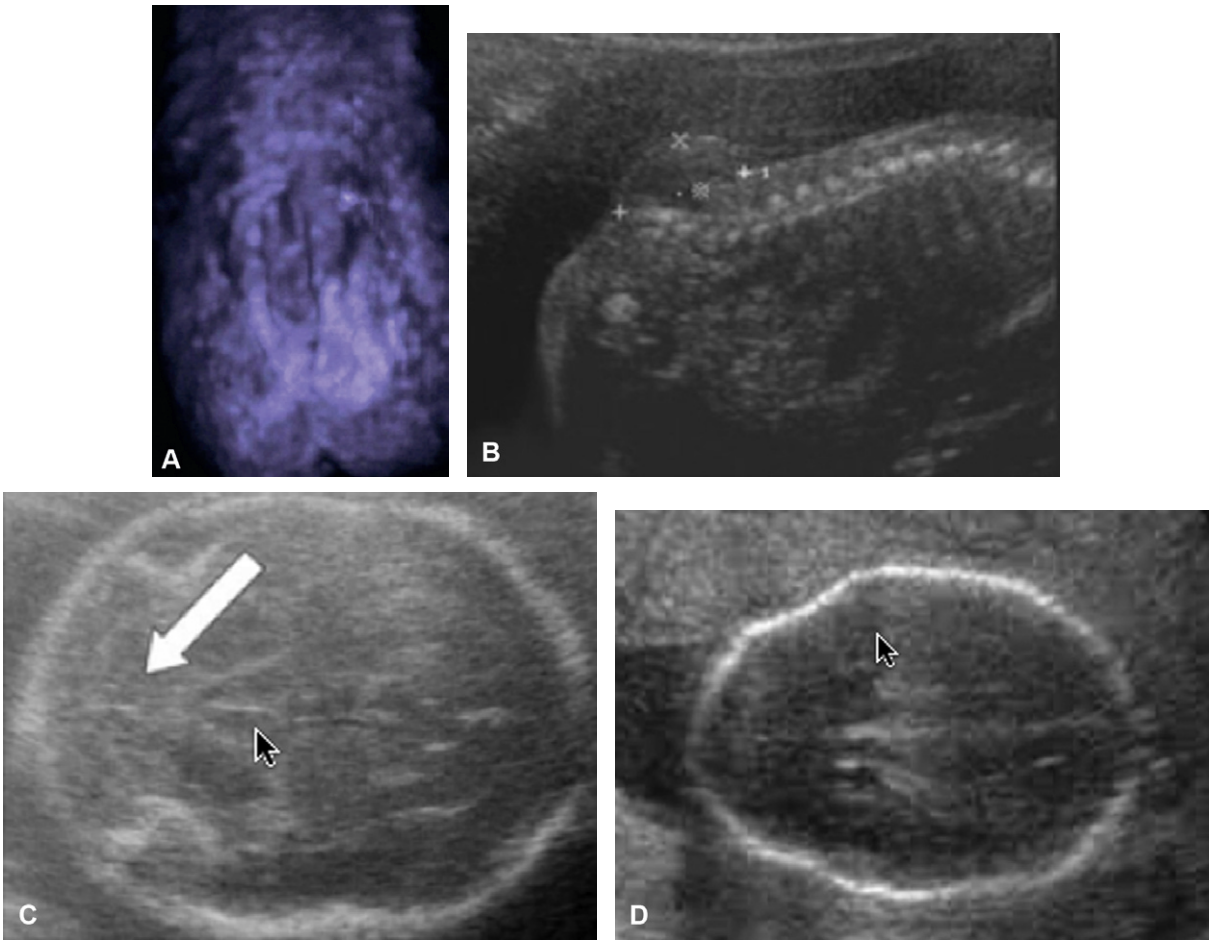

Fig. 102.2. Myelomeningocele–antenatal diagnosis. **(A)** 3D ultrasound; **(B)** 2D ultrasound; **(C)** Chiari malformation (banana sign); **(D)** frontal narrowing (lemon sign).

detectable on axial planes are a C or U shape of the affected vertebra, interruption of the skin contour with or without a meningocele, and splaying of the lateral process. This diagnosis can be achieved progressively earlier (10th or 12th week in some cases, 18th to 24th in the large majority of cases) (Nicolaides et al., 1986; Filly, 1989a, b; Van den Hof et al., 1990; Sebire et al., 1997; Monteagudo et al., 2000; Rossi et al., 2004a, b; Ghi et al., 2006). MR scan and fetal karyotyping are not routinely recommended. These can, however, reveal chromosomal anomalies (8–16%) or other associated malformations.

Once the diagnosis has been made, the weight of ethical and moral decisions falls squarely onto the shoulders of the parents and physicians as they consider which course to follow. The termination of the fetus has always been at the center of the moral debate about the right to live and hinges on the status of the fetus. In many countries termination remains illegal even in cases of severe malformation. In most countries where termination is allowed, the period of legal termination is no later than the 18th to 28th week of gestation. In very few countries, such as France, termination remains legal for lethal or very severe malformation, such as MMC, until the last day of pregnancy. The termination rate is 23% in the USA and 78% in Europe (Czeizel et al., 1979; Dommergues et al., 1999, 2006; Koszutski et al., 2009).

In utero treatment of myelomeningocele has been proposed (Bruner et al., 2000, 2004; Walsh et al., 2001; Hirose et al., 2003; Tubbs et al., 2003; Tulipan et al., 2003; Hamdan et al., 2004; Tulipan, 2004; Johnson et al., 2006; Sutton, 2008; Hirose and Farmer, 2009). It remains very controversial and is done in very few centers in the world. Preliminary reports show no improvement in limb deficits or in sphincter dysfunction, but possibly a reduction in the rate of Chiari malformation and hydrocephalus (90 to 50%). A strictly controlled prospective clinical trial (MOMS) began in 2003 involving three major centers in the USA. The final results of this study are not yet published.

In case of the decision to continue the pregnancy, early consultation should be organized with a neurosurgeon to explain to the future parents the initial postnatal care and the short- and long-term follow-up.

Initial management at birth

Delivery by cesarean section is recommended by many authors to avoid any trauma to and possible infection of the myelomeningocele during transit through the birth canal, though this indication is still controversial and not evidence-based (Cochrane et al., 1991; Merrill et al., 1998; Lewis et al., 2004; Hamrick, 2008).

Even if it remains nonaccessible in many countries for the majority of children, early surgery is the gold standard treatment for MMC. If surgery is not done during the first few days, most of the children will die from early infection or later (sometimes after several months) from chronic hydrocephaly.

In addition to supplies routinely needed in the delivery room, sterile gauze, warm saline, and nonpermeable coverings for the dressing should be provided. Infants with open dysraphism are at high risk of latex allergy. In a recent study, 48% of patients with myelomeningocele showed a biological (specific IgE > 0.7 kU/L) latex sensitization and 15% were allergic to latex with clinical manifestations. These results underline the importance of avoiding latex exposure from the beginning. All diagnostic and therapeutical procedures should therefore be conducted in a latex-free environment (Buck et al., 2000; Niggemann et al., 2000; Rendeli et al., 2006; Woodhouse, 2008; Majed et al., 2009).

The neonatal pediatric and neurosurgical assessment is the first step prior to any surgical procedure planning. Other than determining the lesion's level, the evaluation aims to identify the site, extension, and characteristics of the spinal malformation along with ruling out any other linked spine deformity (scoliosis, severe kyphosis, split cord malformation, etc.) that may have an impact on the surgery. Ascertaining the presence of hydrocephalus (rarely present at birth) is crucial for ensuring the correct management of surgical interventions. Closure of MMC within 24-48 hours is customary. The role of surgery is to place the spinal cord back within the spinal canal and to close dura, fascia, muscle, and skin in separate layers. In some large defects, the plastic surgery closure techniques can be useful. Early postoperative mortality is near zero. However, the morbidity due to complications of the repair (wound healing problems, CSF leak, meningitis) can be significant. They may affect the patient's quality of life and are usually due to faulty techniques that are by and large preventable.

As many as 90% of infants with open dysraphism develop hydrocephalus before the end of the second week (Chakraborty et al., 2008). It can be detected by clinical examination and ultrasound and treated by ventriculoperitoneal shunt. The vast majority of babies with MMC exhibit some degree of Chiari II malformation. The exact number of those who will develop clinical signs and need surgery remains controversial (5 to 30%). The need for surgery during the first day of life is exceptional (Pollack et al., 1996).

Parents of babies with myelomeningocele may experience feelings of crisis, stress, anxiety, helplessness, denial, or lowered self-esteem. The initial approach by the pediatric team is extremely important. As should be done during the prenatal clinics, in the preoperative period, the pediatric neurosurgeon should spend adequate time with the family explaining the diagnosis, treatment, complications,

and outcome expectations. Overly optimistic or pessimist explanations should be avoided.

Late complications

Vertebral problems and deformities

Children with myelomeningocele have a high incidence of vertebral deformities (scoliosis, kyphosis, or lordosis). The deformities are either congenital or the result of the paralysis. They are often progressive and bracing can be ineffective, leading to surgical treatment in most cases.

Neuropathic bladder

This is the most frequent complication of myelomeningocele and needs to be closely followed from birth in order to minimize the risk of urological deterioration (chronic infections, urinary incontinence, vesicouretral reflux). All children with myelomeningocele should be followed regularly by kidney and bladder ultrasound and urodynamic studies.

Chiari II malformation and syringomyelia

The Chiari II malformation is specific to myelomeningocele (La Marca et al., 1997; Caldarelli et al., 1998). It occurs in more than 90% of the cases but is rarely symptomatic. The brainstem has abnormal disposition and angulation. The posterior fossa is smaller than normal. The fourth ventricle is caudally displaced and elongated. The foramen magnum is large, there is significant prolapse of the vermis, and the lower part of the tonsils is low or very low (lower cervical or even upper thoracic spine). It is very often associated with brain and ventricular malformations (dysgenesis or agenesis of septum pellucidum, colpocephaly, enlarged mass intermedia, malformation of the floor of the third ventricle). Clinical manifestations of the Chiari II malformation can be related to brainstem compression, usually seen during the first weeks of life (poor feeding, recurrent vomiting, high-pitched cry or stridor due to vocal cord paralysis, episodes of apnea, nystagmus, or bradycardia, torticollis, opisthotonus, lower cranial nerves dysfunction). The incidence of these symptoms is estimated at 5–10%. The indications for early craniovertebral junction surgical decompression are controversial, but this can sometimes be associated with good clinical results. Problems related to the hindbrain hernia can also be seen later in life, in childhood or in adulthood. Syringomyelia is very frequent but remains, in most of the cases, asymptomatic. However, it can worsen the neurological, orthopedic, or urological status of the child. In these situations, craniovertebral decompression is also controversial and must not be performed until cord retethering and, most importantly, shunt malfunction has been ruled out.

Tethered cord

This occurs in about 20% of initially operated myelomeningocele (Hoffman et al., 1976; Yamada et al., 1981; Pierz et al., 2000; Phuong et al., 2002; Hertzler et al., 2010; Mehta et al., 2010; Vandertop, 2010). The clinical diagnosis is difficult, but decline in lower extremity strength, urinary changes, rapid worsening of the scoliosis, gait change, spasticity, and pain are the most frequent symptoms. MR scan, unfortunately, is of little help in making the diagnosis.

One must keep in mind that by far the most common cause of neurological change in myelomeningocele is shunt malfunction. It can mimic any of the symptoms of the above complications, and, therefore, shunt function must always be confirmed prior to any surgical treatment (craniovertebral junction decompression or untethering). Even in cases of severe shunt malfunction the ventricular size may remain small or unchanged, and so many neurosurgeons recommend a surgical shunt exploration in all cases of unclear clinical deterioration, regardless of imaging results.

OCCULT DYSRAPHISM

The cutaneous syndrome

Cutaneous anomalies are present in 90% of cases (Guggisberg et al., 2004). These skin anomalies have considerable diagnostic value. Their absence is often responsible for delayed diagnosis. These anomalies (Fig. 102.3) are often in the midline (72% in our series) but when lateral they are predominantly on the left side (75%, $p < 0.01$). In all series the most common of these anomalies was a subcutaneous lump indicating the subjacent presence of a lipoma or a meningocele. When the subcutaneous lipoma is caudally situated, the lump is associated with a gluteal fold deviation. The diagnostic value of these lumbosacral cutaneous lesions in asymptomatic children to detect occult spinal dysraphism is variable. In a previous study we retrospectively reviewed 54 children referred to the department of pediatric dermatology in our hospital. Occult spinal dysraphism was detected in three of 36 patients with an isolated midline lesion and in 11 of 38 patients with the combination of two or more different skin lesions. These skin anomalies can be divided into three groups of varying risk:

- Group 1 (high risk): two or more lesions (whatever they are), subcutaneous lipoma, tail, dermal sinus, “queue de faune”.
- Group 2 (low risk): atypical dimple, aplasia cutis, deviation of the gluteal furrow.
- Group 3 (very low risk): hemangioma, port-wine stain, hypertrichosis, fibroma pendulum, pigmentary nevus, coccygeal dimple.

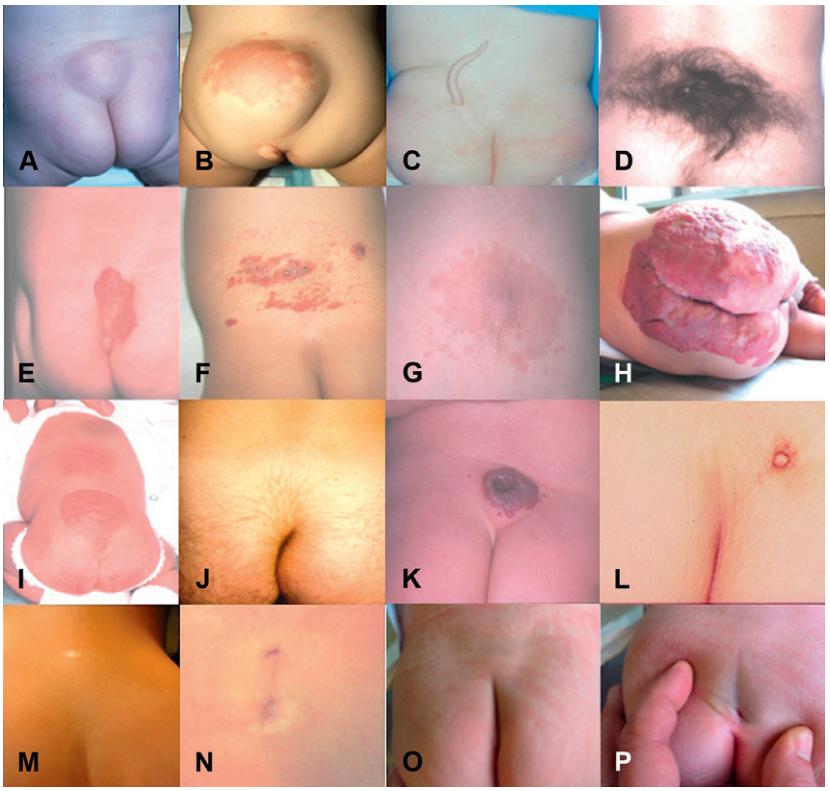

Fig. 102.3. The cutaneous syndrome. **(A)** Lipoma; **(B)** lipoma associated with an angioma and a lump; **(C)** tail; **(D)** queue de faune; **(E,F,G,H)** different types of cutaneous angiomas; **(I)** skin hamartomas; **(J)** deviation of the gluteal fold; **(K)** meningocele manqué; **(L)** dimple; **(M)** aplasia cutis; **(N)** dermal sinus; **(O,P)** sacrococcygeal fossette.

Lipoma

Congenital lumbosacral lipomas are the most common form of closed neural tube defect. In most cases, they are now diagnosed prenatally or at birth. They may lead to progressive neuro-orthopedic and urinary deterioration. However, their natural history is poorly understood. Prophylactic surgery has been the gold standard of treatment, but considering the deterioration after prophylactic detethering over time, especially in case of lipoma of the conus, the performance of systematic prophylactic surgery has been questioned.

General considerations

Among more than 2500 cases reported in the literature, there is a significant female predominance (F:M, 1.2:1, $p < 0.0001$). This contrasts with the equal sex ratio generally found in myelomeningocele and the male predominance in isolated osseous spina bifida occulta or neurenteric cysts.

The real incidence of this malformation is uncertain. In a previous paper, we attempted to approach the epidemiology of this malformation in two French regional registries. A minimal incidence of 4–8 per 100 000 was found. Routine autopsy has provided a prevalence of incidental lipomas ranging from 0% to 6% (average of 0.003%). Recent MR studies of adults investigated for suspected disk diseases or lumbar stenosis have revealed an incidence of 1.5–5%. All of these studies, however, were of small size and restricted to the filum.

These lipomas are essentially mature teratomas (and not tumors) (Pierre-Kahn et al., 1997). They typically consist of normal mature adipocytes separated into clusters by numerous collagen bands. In our series, 77% included, in addition, a wide variety of ectodermal, endodermal, or mesodermal tissues. The most frequent were from mesodermal origin (nerves and striated muscle fibers). The metabolic activity in the lipoma was similar to that observed in the normal adipose tissue. Consequently, adipocytes from congenital lipomas are capable of growth or regression commensurate with increase or decrease in the rest of the body's fat, with consequent clinical deterioration or improvement.

Lipoma of the filum

This is the simplest malformation (Pierre-Kahn et al., 1997). The fatty infiltration of the filum may involve the whole length of the filum or only a part of it (Fig. 102.4).

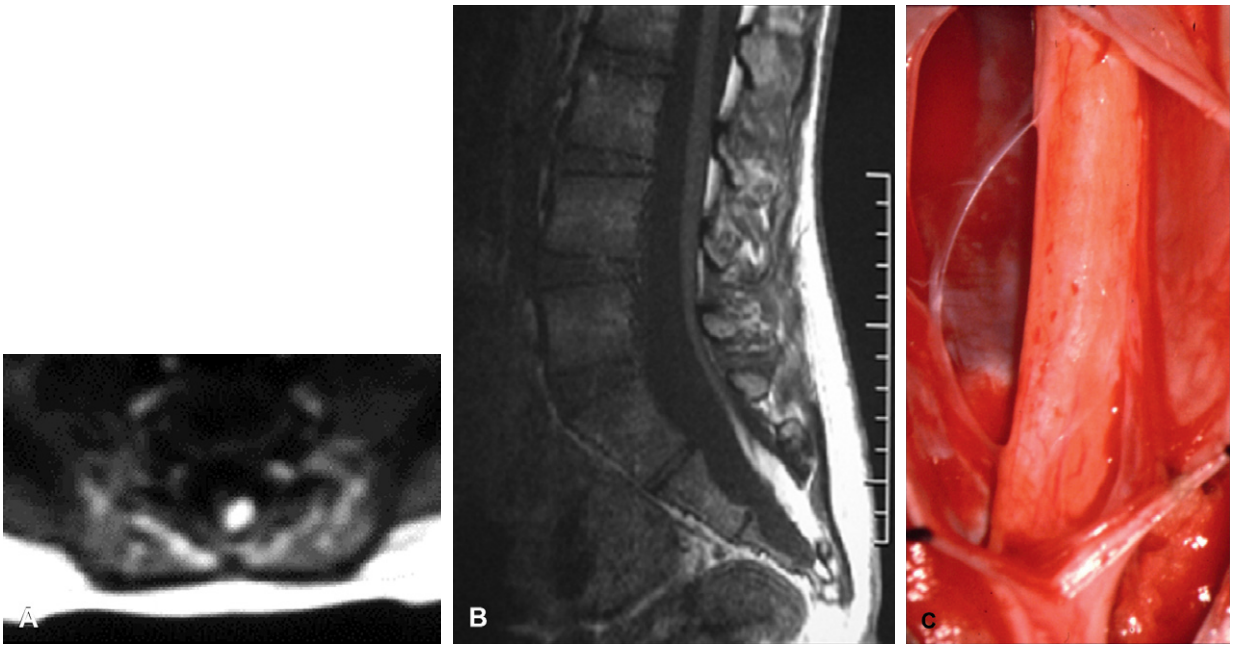

Fig. 102.4. Lipoma of the filum. **(A)** T1-weighted axial MR; **(B)** T1-weighted sagittal MR; **(C)** surgical view.

The roots of the cauda equina are generally free and not malformed. In the large majority of the cases, lipomas of the filum are asymptomatic at birth and diagnosed only by the cutaneous stigmata. Ultrasound, if done early enough (before the 6th week), is often sufficient to make the diagnosis. There is no need to do an MR before the third month. A small filum lipoma is best appreciated on axial T1-weighted images. Although systematic prophylactic surgery (division of the filum) is often proposed with excellent results, this is controversial. If the diagnosis is not made at birth then it is possible that neurological or urological deterioration may occur later in life. Surgery remains indicated in those cases, but the expectation is that of stabilization of symptoms.

Lipoma of the conus

Different anatomical forms of lipoma of the conus have been described (Pierre-Kahn et al., 1995, 1997; Lellouch-Tubiana et al., 1999; Kulkarni et al., 2004; Zerah et al., 2008). All have in common an insertion onto the lumbar spinal cord and some relationship with the roots (Fig. 102.5). It extends typically from L2 to S3, with a median rostro-caudal length of 4 vertebral levels. The zone of insertion on the cord is usually wide. Chapman classified lipomas into four types according to the localization of the interface (dorsal, dorsolateral or lateral, caudal, and dorsocaudal). In our series, very complex forms were found in the majority of patients (62.9%). In lipomyelomeningoceles, a subcutaneous meningocele is associated with an extraspinal extension of the spinal cord. In lipomyeloceles, the spinal cord extends extraspinally within the subcutaneous lipoma. In lipomyelocystoceles, which are rare, the spinal cord ends in a pseudocystic terminal hydromyelia closed superficially by the lipoma itself.

The neurological syndrome associated with lipomas of the conus involves neurological deficits in the lower limbs, sphincter disturbances, and orthopedic deformities. Sphincter disorders are the most common problem (60% of the symptomatic cases). Micturation difficulties are common, with incontinence resulting in most of the cases from dysuria, urgent micturation, and incomplete voiding. Bladder infection with pyelonephritis is also common and might be the first or only sign of the disease. The neuro-orthopedic syndrome is less common (32%), affecting the distal lower limbs. Paralysis or sensory deficits are usually associated with muscular atrophy or progressive deformity of the feet. The upper level of the deficits almost never exceeds L4. Pain is also frequent, especially in adults (33%). Progressive deterioration has been well documented. It could start at any age including in adults and the elderly. It usually occurs slowly and insidiously. The real incidence of deterioration is controversial. Fifteen years ago, we started a prospective study following a cohort of asymptomatic lipomas of the filum at birth. We have enrolled more than 150 children. Only a third of them deteriorated with a return to a completely normal status after surgery in

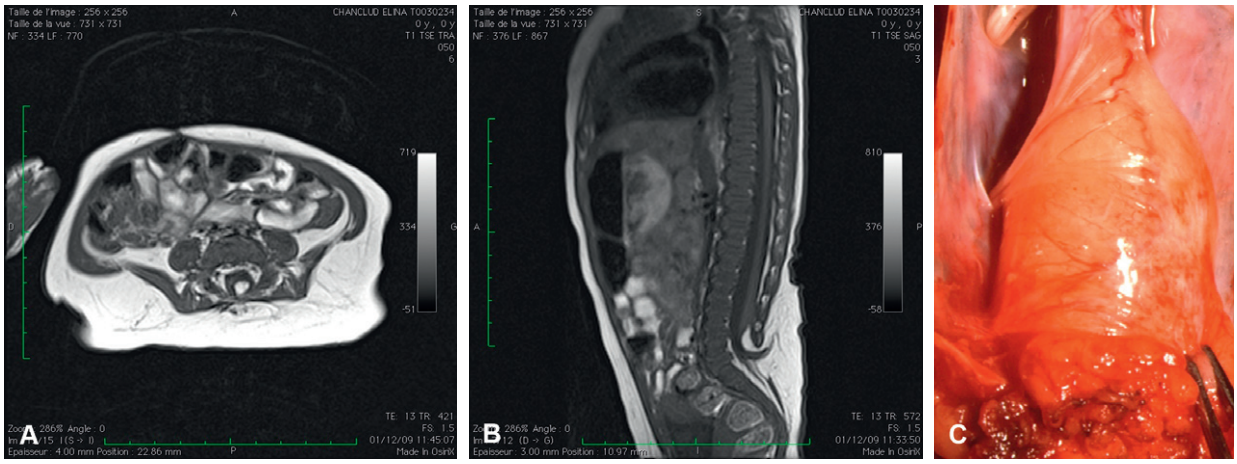

Fig. 102.5. Lipoma of the conus. **(A)** T1-weighted axial MR; **(B)** T1-weighted sagittal MR; **(C)** Surgical view.

half. With this protocol of conservative management 94% of the children have a normal life at 15 years of follow-up.

Prenatal diagnosis is possible in some cases from week 15 of gestation on the basis of lumbosacral meningocele overlying hyperechogenic skin. Unlike MMC, no hydrocephalus or Chiari malformation is found. There is a low-lying terminal cord and, over time, the meningocele component diminishes and the lipoma becomes more prominent. In no case, in our experience, did prenatal MRI provide more information than ultrasound.

Ultrasound is the examination of choice in neonates and up to 6 weeks. Our preference is to recommend US as the first investigation, although MR remains the main investigation prior to surgery. Sagittal and axial view in T1- and T2-weighted images are necessary to analyze the lipoma and its relationship with the spinal cord, the roots, and the spine. There is a consensus opinion for surgical detethering and subtotal removal of the lipoma in symptomatic patients. For asymptomatic patients, based on our 15-year prospective study we advocate for conservative management.

Diastematomyelia

The word diastematomyelia was introduced by Ollivier in 1837. It came from the Greek διαστεμα (diastema meaning slit or cleft) and μψελσ (myelos meaning cord). Ollivier clearly states that this definition applies to a division of the spinal cord into two halves. It must not be confused with the diplomyelia, which is a supplementary, completely formed spinal cord situated anterior or posterior to the original one. It is an exceptional malformation, described in mutated animals but only described in autopsy in humans.

Classification

Since 1991, most authors have followed the classification proposed by Pang. He proposed the term of split cord malformation (SCM) and clearly differentiated two main types of diastematomyelia (Fig. 102.6).

- Type I, characterized by two hemicords, having their own dural envelope, separated by an osteocartilaginous septum or spur. In this type, spinal anomalies (hemi, butterfly, or fused vertebra) are present in the large majority of the cases.
- Type II, in which the two hemicords are contained in a single dural sac with or without a fibrous septum.

The embryology of the diastematomyelia remains debated. The classical explanation of the neurenteric canal persistence cannot be accepted in the absence of any clue of the existence of this canal in primates. Disorders of neurulation or adherence between endoderm and mesoderm have also been proposed, but the most popular theory is based on abnormal gastrulation with an abnormally wide primitive stalk.

Diastematomyelia affects in most of cases the lower spine. Fifty-five perent of cases are found at the lumbosacral region, 32% at the thoracolumbar level, and only 13% above. In 5–10% of cases several clefts coexist (Sheptak and Susen, 1967; Mcmaster, 1984; Han et al., 1985; Szalay et al., 1987; Maiuri et al., 1989; Kogler et al., 1991; Pang et al., 1992; Kim et al., 1994; Dias and Pang, 1995; Unsinn et al., 2000; Gan et al., 2007).

Hydromyelia can involve one or both hemicords. A tight filum or a low cord is often present in lower diastematomyelia. Lipoma, dermal sinus, myelomeningocele, or hemimyelomeningocele have also been described in association with diastematomyelia. On the other hand, Chiari malformation has only rarely been described.

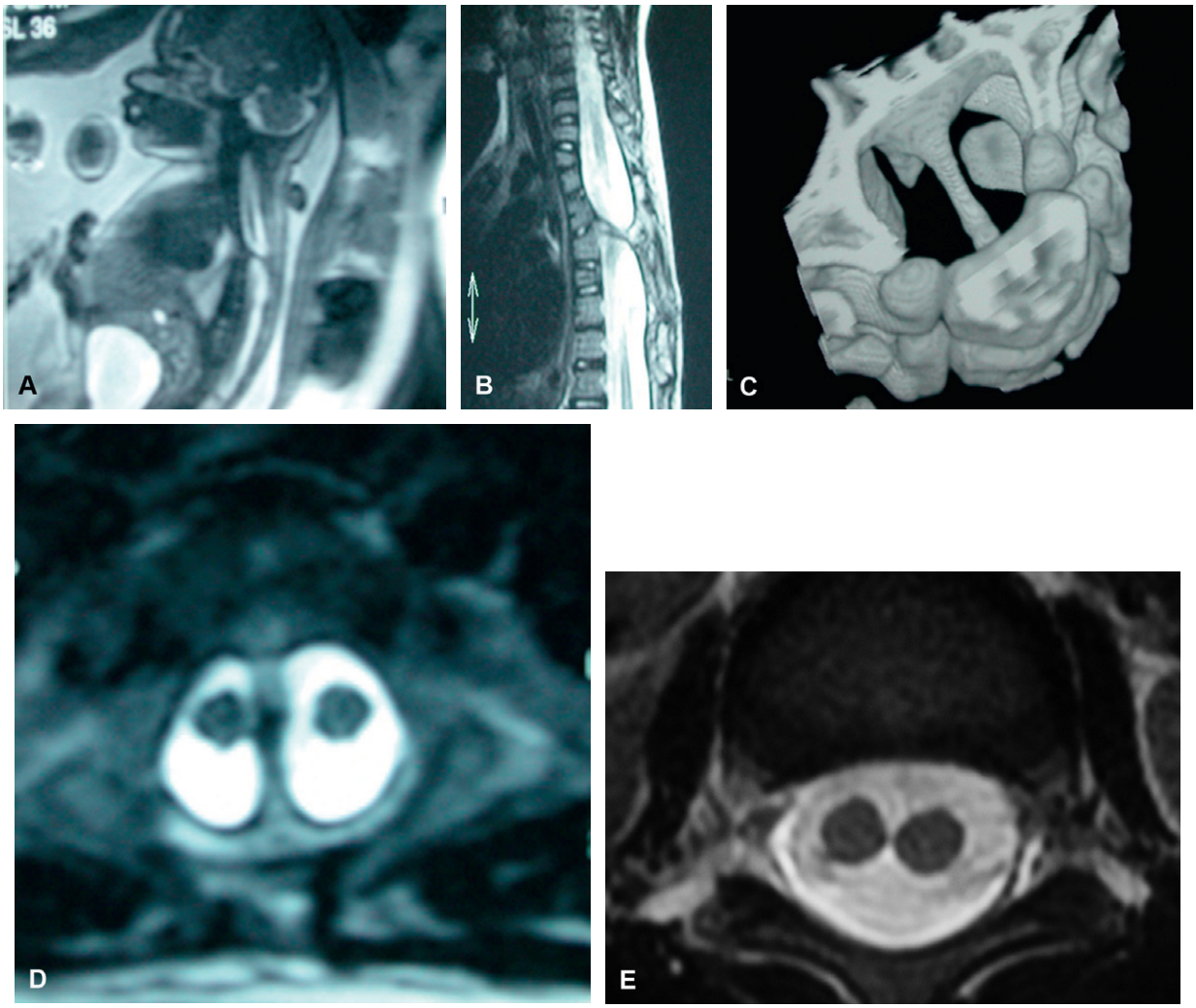

Fig. 102.6. Diastematomyelia. **(A)** Antenatal sagittal MR. Type I with bony spur (arrow). **(B)** Postnatal sagittal MR. Same child. **(C)** Type I diastematomyelia. CT-scan 3D view. **(D)** Type I diastematomyelia. Axial T2-weighted MR. 2 hemi-spinal cord separated by a complete bony spur. **(E)** Type II diastematomyelia. Axial T2-weighted MR. 2 hemi-spinal cord in a unique dural sac without bony spur.

Clinical symptoms and signs

Most cases are sporadic with a female predominance reported in all series (1.2:1 to 1.5:1). It has been described in every part of the word but seems to be rarer in Asia and more frequent around the Mediterranean Sea (especially in Turkey) and in India.

Diastematomyelia can be easily diagnosed before birth. In our own antenatal clinics, diastematomyelia is the commonest cause of antenatally diagnosed dysraphism. Over the last 5 years, two-thirds of our cases have been diagnosed before birth. Type II diastematomyelia is asymptomatic in the vast majority of cases. Type I diastematomyelia can be diagnosed based on skin stigmata and orthopedic or neurological syndromes.

Any of the skin markers described in Fig. 102.3 can be associated with diastematomyelia, but the presence of a hairy patch ("queue de faune") is present in more than 90% of cases and is quasi-pathognomonic of a type I diastematomyelia.

The orthopedic syndrome is characterized by a severe and progressive scoliosis (more rarely kyphosis) relating to spine column anomalies and the spinal cord malformation. In our experience, the scoliosis is twice as common in cases of hydromyelia.

The neurological syndrome is related to the level of the malformation. Gait difficulties, asymmetrical weakness, and limb atrophy (on the side of the smaller cord), sensory deficit, pain, and sphincter dysfunction are the most frequent signs.

Radiological findings

Antenatal diagnosis is based on ultrasonography and confirmed by MR scan. This must separate isolated diastematomyelia, which is of good prognosis, from more complex forms with associated malformations of less favorable prognosis.

Postnatal diagnosis can also be achieved by ultrasonography during the first weeks of life. CT, MRI scan, and x-ray will help to secure the diagnosis and decide on the treatment of the malformation.

Management

The treatment of diastematomyelia remains controversial. Some authors are in favor of systematic surgery even in type II or asymptomatic type. We do not propose systematic surgery in type II diastematomyelia. In type I, surgery must be performed in all symptomatic children, before or in combination with any spine surgery. We are also in favor of prophylactic surgery in asymptomatic type I diastematomyelia because of the high risk of clinical deterioration with age, the difficulty of surgery in older children, and because postoperative improvement is rare in symptomatic patients. In case of antenatal diagnosis, we prefer to perform the surgery between 6 months and 1 year of age because of the hemorrhage risk in very young infants.

Dermal sinus

Dermal sinuses must be differentiated from benign coccygeal pits (Kuharik et al., 1985; Gok et al., 1995; Bajpai et al., 1997; Jindal et al., 1999; Hattori et al., 1999; Santiago Medina et al., 1999; Ackerman and Menezes, 2003; Emmez et al., 2004; Sen et al., 2005; Lode et al., 2008). Dermal sinuses represent a true tract going from a small hole in the skin to the spine (Fig. 102.7). In 60–70% of the cases they reach the subarachnoid space, half attaching to the filum or the conus. The tract includes both dermal and epidermal elements. It can end in an intradural dermoid or epidermoid cyst or, rarely, a teratoma.

It must be diagnosed as soon as possible after birth. The diagnosis is usually made on the basis of the skin stigmata. It presents as a midline dimple, higher than the coccygeal pit. It can be associated with hairy tufts, hemangiomas or telangectasia, hypo- or hyperpigmentation, or any other skin marker.

The main complication of dermal sinuses is infection with severe meningitis or intramedullary abscesses. These infections may lead to permanent neurological or sphincter deficits. Consequently they must be diagnosed and operated on during the first weeks of life. The diagnosis can be done by ultrasound, but the most detailed exam remains MR. T1-weighted sagittal and axial images with gadolinium injection and fat saturation is the gold standard to make the diagnosis. Although this usually demonstrates the sinus, it often fails to determine whether the tract ends in the intra- or extradural space.

Neurenteric cyst

Neurenteric cysts are one of the rarer occult dysraphisms (0.3% of spinal tumors) (Mann et al., 1984; McMaster, 1984; Pang et al., 1992; Catala and Poirier, 1996;

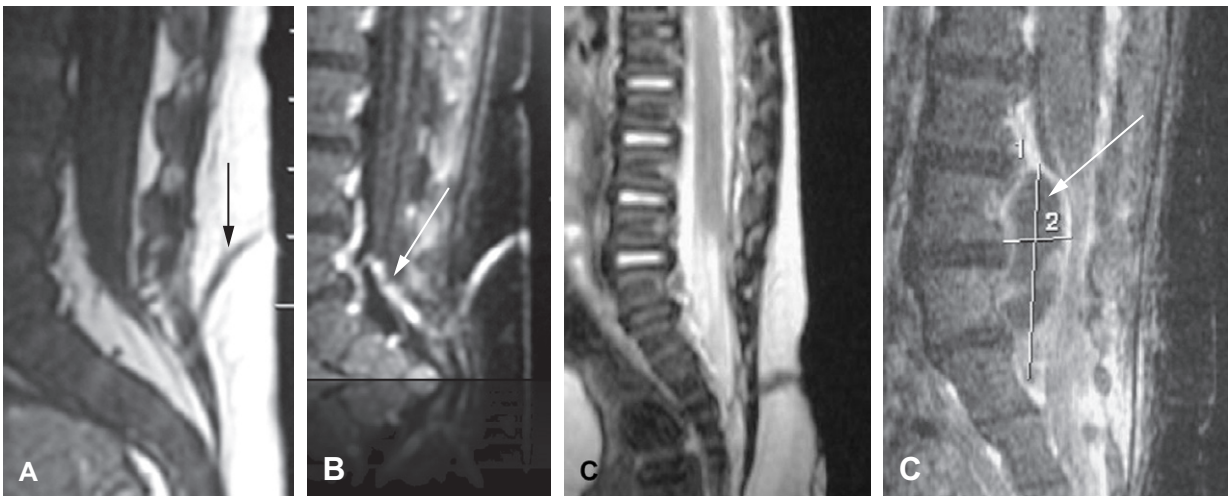

Fig. 102.7. Dermal sinus. **(A)** Sagittal T1-weighted MR. Visualization of the extradural sinus (arrow). **(B)** Sagittal T1-weighted MR after contrast injection and fat saturation (FATSAT GADO). Same patient. This sequence enhances the extradural sinus and allows the intradural tract (arrow) to be seen. **(C)** Sagittal T2-weighted MR. Neglected dermal sinus. **(D)** Sagittal T1-weighted MR with gadolinium. Same patient. Intradural abscess (arrow).

Muraszko and Youkilis, 2000; Rauzzino et al., 2001; Rossi et al., 2004b; de Oliveira et al., 2005; Aouad et al., 2008; Cai et al., 2008; d'Andrea et al., 2008; Garg et al., 2008; Menezes, 2008; Muzumdar et al., 2008; Rendle et al., 2008; Yasuda et al., 2008; Aydin et al., 2009; Mittal et al., 2009; Gadodia et al., 2010; Savage et al., 2010; Theret et al., 2010; Tucker et al., 2010; Zenmyo et al., 2010). We reported in a previous paper the largest pediatric series with 16 children operated on in a 14-year period. These cysts can occur at any level of the neuraxis from the posterior clinoid to the coccyx. They are most often found in the cervical and upper thoracic regions. They are generally located ventral to the spinal cord (Fig. 102.8). It is generally accepted that they result from the embryological remnants of the neurenteric canal. However, although it has been well described in avians, there is no evidence in the literature of the existence of a neurenteric canal during embryological life in mammals. Neurenteric cysts are lesions consisting of an intradural cyst line by mucin-producing nonciliated epithelium that is simple or pseudostratified. The cyst can be ciliated or have a mixture of gastrointestinal, pancreatic, respiratory, or squamous epithelium.

Clinical presentation

In the pediatric age group, there is a male predominance (60.4%) with a mean age of 6.4 years. In 40% of cases, the condition is diagnosed in the context of an onset of acute neurological symptoms (para- or teraparesis) or meningitis. In some cases neurological signs can be insidious or even absent, despite severe compression of the spinal cord. Pain, myelopathy, and spinal deformity are the most frequent signs in slow-growing forms.

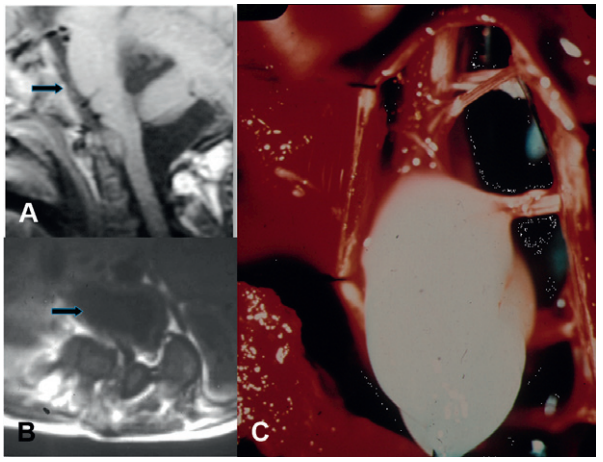

Fig. 102.8. Neurenteric cyst. **(A)** Sagittal T1-weighted MR. Retroclival neurenteric cyst (arrow). **(B)** Axial T1-weighted MR. Thoracic neurenteric cyst with a communication between the digestive tube and the dural sac (arrow). **(C)** Surgical view.

In case of recurrent meningitis, neurenteric cysts must be considered and thoroughly searched for.

Radiology

Few antenatal cases have been reported.

Because of the association of the cyst with complex spine malformations, plain spine radiography and CT and MR scans must be performed. In some small cysts presenting with recurrent meningitis, the cyst can be missed, especially if located at the anterior craniovertebral junction, and repeat examinations are mandatory.

Treatment

Complete excision is the aim of surgical treatment. If total removal is achieved, the prognosis is excellent. In case of incomplete treatment, the risk of recurrence is high and often leads to more complex surgery.

Complex forms

Currarino syndrome (Fig. 102.9) is an autosomal dominant congenital malformation characterized by three main clinical features: anterior sacral bone defect (sickle-shaped sacrum or sacral agenesis below S2), hindgut anomaly, and a presacral mass (anterior meningocele, teratoma, rectal duplication, or a combination of these). Additional associated malformations have been described namely: renal or ureteral duplications, hydronephrosis, horseshoe kidney, bicornuate uterus, and also neural tube defect. Among these, however, the most common are tethered cord and lipoma of the filum, but lipoma of the conus, dermal sinuses, and diastematomyelia have also been described. (See Currarino et al., 1981; Gudinchet et al., 1997; Ross et al., 1998; Riebel et al., 1999; Belloni et al., 2000; Hagan et al., 2000; Lynch et al., 2000; Kochling et al., 2001; Le Caignec et al., 2003; Horn et al., 2004; Martucciello et al., 2004; Urioste et al., 2004; Emans et al., 2005; Cretolle et al., 2006, 2007; Garcia-Barcelo et al., 2006; Kilickesmez et al., 2006; Merello et al., 2006; Verlinsky et al., 2005.)

More complex malformations may be associated with any of the lesions described above, with or without visceral, spinal, or limb anomalies.

CAUDAL REGRESSION

This group is a heterogeneous collection of caudal malformations (i.e., agenesis of the spinal column, anal imperforation, genital abnormalities, etc.). The lower extremities are usually dysplastic or atrophic. Fusion and atrophy result in the most severe case (sirenomelia). They can be part of syndromic complexes such as OIES (omphalocele, imperforate anus, exstrophy, and spinal defect) (Kallen et al., 2000; Keppler-Noreuil, 2001;

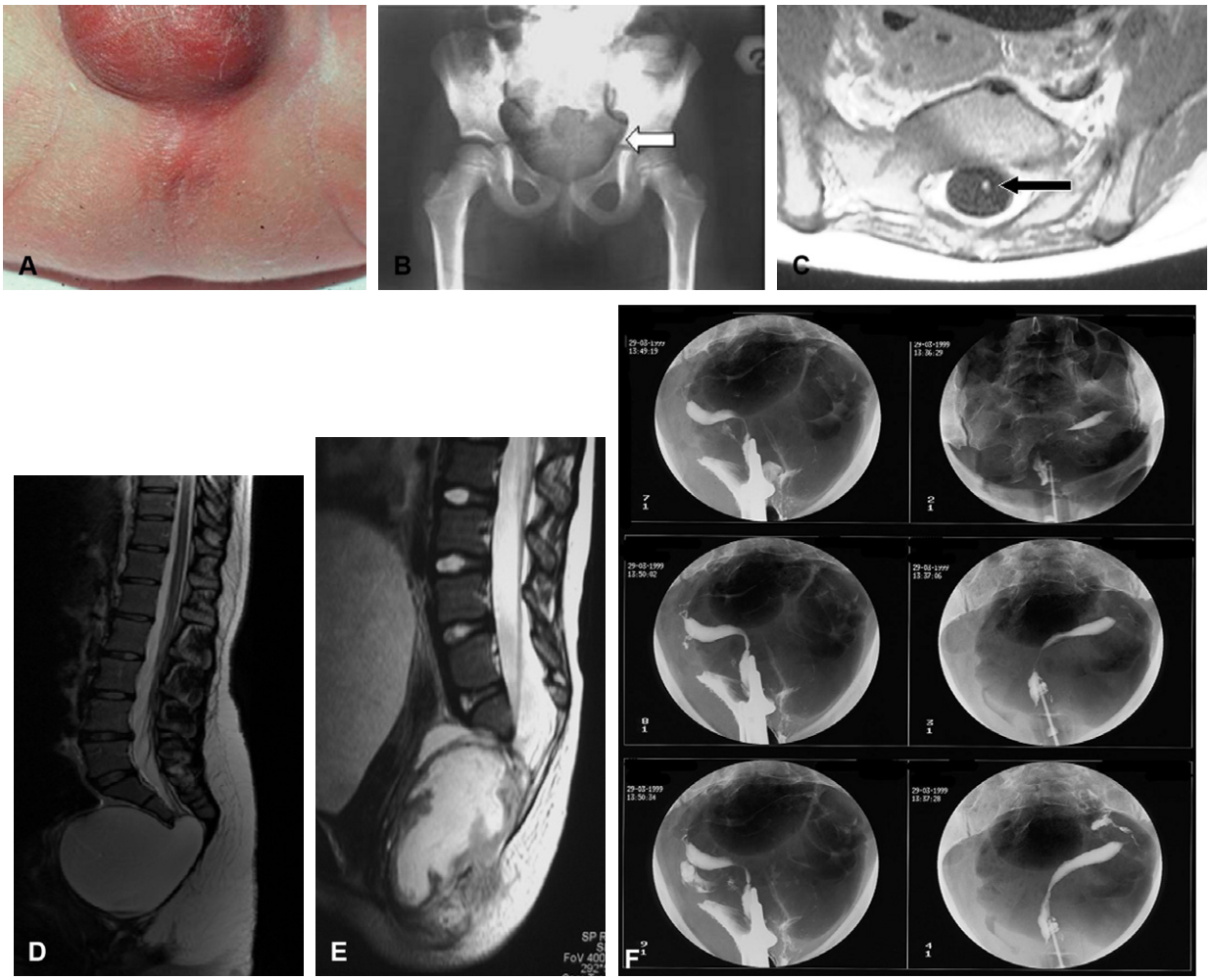

Fig. 102.9. Currarino syndrome. **(A)** Anal imperforation; **(B)** hemisacral agenesia; **(C)** lipoma of the filum; **(D)** anterior meningocele; **(E)** anterior teratoma; **(F)** double horn uterus with a vaginal wall.

Mittal et al., 2004; Kosaki et al., 2005; Ben-Neriah et al., 2007; Chen, 2008; Morioka et al., 2008; Tokunaga et al., 2009) or VACTERL (vertebral anomalies, anal imperforation, tracheoesophageal fistula, renal abnormalities, and limb deformities) (Kuo et al., 2007).

In less severe forms, there is only a partial sacral agenesia, a short intergluteal fold and a short spinal cord ending above D12. Clinically, sphincter problems are frequent (bowel rather than bladder) and there is often a history of pregnancy-related diabetes.

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