Congenital Brain and Spinal Cord Malformations and Their Associated Cutaneous Markers

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abstract

The brain, spinal cord, and skin are all derived from the embryonic ectoderm; this common derivation leads to a high association between central nervous system dysraphic malformations and abnormalities of the overlying skin. A myelomeningocele is an obvious open malformation, the identification of which is not usually difficult. However, the relationship between congenital spinal cord malformations and other cutaneous malformations, such as dimples, vascular anomalies (including infantile hemangiomas and other vascular malformations), congenital pigmented nevi or other hamartomas, or midline hairy patches may be less obvious but no less important. Pediatricians should be aware of these associations, recognize the cutaneous markers associated with congenital central nervous system malformations, and refer children with such markers to the appropriate specialist in a timely fashion for further evaluation and treatment.

INTRODUCTION

All pediatric care providers, regardless of specialty, encounter children with manifestations of an underlying congenital, or dysraphic, brain or spinal cord malformation. Identifying and treating these dysraphic central nervous system (CNS) malformations is important to prevent subsequent neurologic deterioration from spinal cord tethering, bacterial or chemical meningitis, or compression from growing mass lesions. The common embryonic derivation of CNS and skin from ectoderm creates an association between CNS malformations and certain cutaneous markers that, when recognized, affords an opportunity to identify and prophylactically treat the underlying CNS malformation. The purpose of this clinical report was to provide pediatric care providers with an overview of these CNS malformations and their cutaneous manifestations, discussing (1) the early embryology of the CNS as it relates to the embryogenesis of these malformations; (2) the pathophysiology of neurologic deterioration from spinal cord tethering; (3) a description of common dysraphic malformations; (4) the relationship between...
cutaneous markers and dysraphic malformations; and (5) the relationship between other related malformation sequences and dysraphism.

NORMAL EMBRYOLOGY AND THE PATHOPHYSIOLOGY OF SPINAL CORD TETHERING

Dysraphic CNS malformations arise during the second, third, and fourth weeks of human embryogenesis, generally referred to as the period of neurulation. The neuroectoderm is first visible during the second week as a pseudostratified columnar epithelium attached to the cutaneous ectoderm around its periphery (Fig 1). During primary neurulation, the neuroepithelium elevates about a midline central furrow; the 2 sides (the neural folds) then converge and fuse, forming a closed neural tube. The adjacent cutaneous ectoderm separates from the neuroectoderm (called dysjunction) to form the overlying skin. The last sites to close are the anterior neuropore at the level of the future lamina terminalis (located just above the optic chiasm) and the posterior neuropore located at the second sacral spinal cord segment (S2). Dysraphic malformations involving the brain and spinal cord down to the S2 segment arise from disordered primary neurulation. Primary neurulation is complete by the end of the fourth week.

The spinal cord below S2 and the filum terminale are formed from secondary neurulation, which begins late in the fourth week and involves the formation and subsequent fusion of multiple tubules of neuroepithelial cells from the caudal cell mass. Secondary neurulation underlies a fully formed cutaneous ectoderm (skin) so that disorders of secondary neurulation give rise to “closed” malformations. Because the caudal cell mass also gives rise to the sacroccocygeal spine, hindgut, and urogenital systems, dysraphic malformations often coexist with malformations of these structures. As they are generated, the spinal cord and surrounding spine are the same length; however, beginning at the sixth embryonic week, the spinal cord grows more slowly than the surrounding vertebral column, making the conus medullaris (CM) appear to “ascend” relative to the surrounding spinal column. This ascent of the conus medullaris places the conus opposite progressively higher vertebral levels so that, by 2 months after birth, the CM ends most commonly opposite the disc space between the first and second lumbar vertebrae (L1-L2 disc space), with the lowest normal level (95% confidence limits) being opposite the

**FIGURE 1**

include pain, sensorimotor dysfunctions in older children may be recognized solely by their age dependent. Infants are commonly evaluated for spinal cord tethering in the context of a myelomeningocele (MMC), an open neural tube defect that results from a failure of secondary neurulation. In MMC, the neural tube fails to close completely. The resultant malformation contains a placode of neuroectoderm and cutaneous ectoderm, with the inherent potential to prevent proper ascent of the CM and cause “spinal cord tethering.” The tethered cord syndrome refers to clinical deterioration resulting from spinal cord tethering and has been shown to involve physical stretching of the spinal cord leading to impaired blood flow, diminished oxidative metabolism and glucose utilization, and metabolic failure at the level of the mitochondrial respiratory chain. The severity and reversibility of these metabolic disturbances correlates with the severity and chronicity of the tethering.

**CLINICAL MANIFESTATIONS OF SPINAL CORD TETHERING**

The clinical signs and symptoms of spinal cord tethering are somewhat age dependent. Infants are commonly asymptomatic and the malformations may be recognized solely by their associated cutaneous abnormalities discussed later in this article. Symptoms in older children may include pain, sensorimotor disturbances of the lower limbs, and difficulties with bladder and/or bowel control. Long-standing untreated tethering can ultimately result in progressive musculoskeletal deformities and/or scoliosis.

As the child ages, muscle weakness and gait disturbances may develop. A previously ambulatory child may regress, may experience running becoming more difficult, and might not keep up with other children during athletic activities. Muscle atrophy may become apparent, with thinning of calf muscles and/or “saber shins” that may be misdiagnosed as Charcot-Marie-Tooth syndrome. Orthopedic deformities of the feet and spine deformities, such as progressive scoliosis and exaggerated lumbar lordosis, may develop. As the child becomes more verbal, back and/or leg pain become a more common complaint. The pain varies and may be dull and aching; sharp, lancinating, or electrical; or dysesthetic in character. The pain may be aggravated by flexion and extension of the spine or by walking or running. Pain in older teenagers and adults may radiate into the groin, genitalia, and/or perianal region. Objective sensory deficits may become more apparent as formal testing becomes more reliable. Sensory abnormalities generally start distally in the leg and become more proximal over time; on occasion, a “suspended” sensory loss may be present with preserved sensation both above and below the area of abnormality. Difficulties with bowel and bladder function may become evident with urinary and fecal urgency and/or incontinence, urinary tract infections, dribbling urinary stream, incomplete emptying, or inability to void.

People who become symptomatic as teenagers or adults often have a history of subtle abnormalities dating back to early childhood. They may always have been “slow” athletically, had difficulties with chronic constipation or were late in toilet training, had previously repaired orthopedic deformities or leg length discrepancies, or had scoliosis. With long-standing tethering, the skin of the leg and foot becomes thin, shiny, and hairless because of autonomic changes and lack of trophic influences; areas of skin breakdown and chronic discoloration may appear as a result of poor innervation, sensory loss, and repeated unrecognized microtrauma. A characteristic feature of tethered cord syndrome in adults is the sudden appearance of new pain and/or neurologic deficits after a sudden back stretching, such as during childbirth, falls onto the buttocks, vigorous sporting activities, and automobile crashes.

**OVERVIEW OF SPINAL DYSRAPHIC MALFORMATIONS**

**MMC**

An MMC is the most common of the dysraphic malformations and is also the most serious CNS malformation compatible with life. MMCs are the archetype of the neural tube defect and represent a localized failure of primary neurulation. The resultant malformation contains a placode of neural tissue attached peripherally to the surrounding skin (cutaneous ectoderm) as it was in its embryonic state (Fig 2). The underlying cerebrospinal fluid (CSF) elevates the placode on a dome or sac; if the skin tissue on the dome tears, the CSF is allowed to escape and the malformation is flat. Whether domed or flat, there will always be a placode on the skin surface and, by definition, MMCs are, therefore, open malformations.

The incidence of MMC has been declining over the past several decades, in large measure because of periconceptional folate supplementation, with a current birth prevalence in the United States of approximately 0.2 per 1000 live births.
The prevalence of neural tube defects in the United States varies by ethnicity, being highest among Hispanic infants at 1.12 per 1000 live births, lowest among African American and Asian infants at 0.75 per 1000 live births, and intermediate among non-Hispanic white infants at 0.96 per 1000 live births. The incidence of MMC also varies worldwide; for example, the incidence among continental European countries varies between 1 in 260 to 400. Ireland has the highest rate in Europe, at 1 in 200 live births. MMCs vary in appearance, size, and location; neurologic impairment generally is related to a larger size and more cranial location. Other associated malformations include hydrocephalus in 70%, Chiari type II malformation in 98%, syringomyelia in 40% to 80%, and spinal cord tethering in virtually all. It is not the intent of this report to provide details about all of the neurosurgical aspects of MMCs, as there are many excellent reviews of this topic, including an article in Pediatrics in Review.

The rare cervical or high thoracic MMC (also referred to by some as a cervical myelocystocele because of its ballooned-out dorsal fluid collection) is a pedunculated, full-thickness, skin-covered, fluid-filled sac (usually having thinned, violaceous skin at its apex) located on the neck or upper back of an infant (Fig 3A) and containing a small band of tissue (Fig 3B) composed of mesenchyme as well as both central and peripheral neural tissue that extends through a small defect in the posterior fascia and dura and attaches to the dorsum of the spinal cord. In contrast to the child with the typical thoracolumbar or lumbosacral MMC who has sensorimotor paralysis corresponding to the level of the malformation, children with cervical meningoceles have few if any neurologic deficits. It is vital to understand this point so that parents can be properly counseled if this condition is diagnosed prenatally.

**Meningocele**

A meningocele (Fig 4) is an isolated full skin thickness sac, filled with CSF and lacking central nervous issue. On magnetic resonance imaging (MRI), the meningocele sac contains only fluid without any visible tissue. The frequency of meningoceles is one-tenth that of MMCs. Affected children generally have no neurologic deficits. Meningoceles have been thought not to contain tethering elements, but careful dissection may disclose a fibrous tract that connects the inner lining of the sac with the spinal cord; a meningocele can, therefore, cause tethering.

**Atretic Meningocele**

An atretic spinal meningocele is rare malformation consisting of a small, flat area of dysplastic skin that looks like and has been referred to as “scarified,” “cigarette paper,” or a “cigarette burn” (Fig 5). The lesion is flat or slightly indented, sometimes painful to touch, and sometimes surrounded by a cuff of hyperpigmented skin (Fig 5A) or a cutaneous salmon-colored capillary malformation (Fig 5B). There is usually an underlying fibrous tissue tract (also called a meningocele manqué) that, like the fibrous tract of the meningocele described in the previous section (and the DST described subsequently), passes through the fascia, posterior vertebral elements, and dura, and attaches to the dorsum of the spinal cord.

**Lipomyelomeningocele/Myelocystocele/Enlarged or Fatty Filum Terminale**

Lipomyelomeningocele, myelocystocele, and enlarged and/or fat-infiltrated filum terminale all have in common some element of fat within the spinal cord and/or filum terminale; they may represent different manifestations of the same embryogenetic process and are, therefore, discussed together. A lipomyelomeningocele (also called a spinal lipoma) is a malformation in which a fatty subcutaneous mass extends into the vertebral canal and ends as an intramedullary spinal cord mass. Most spinal lipomas have a visible fatty mass, sometimes with an associated capillary malformation, infantile hemangioma, and/or dimple (Fig 6). However, a minority have no associated skin manifestations. Lipomyelomeningoceles may be dorsal (arising from the dorsum of the spinal cord), terminal (arising from the filum terminale or the tip of

**FIGURE 2**

MMC. The placode can be seen with its midline neural groove and is attached to the skin around its edges.

**FIGURE 3**

Cervical MMC. A, Lateral view showing full-thickness skin with violaceous apex and no cerebrospinal fluid leakage. B, Operative view demonstrating the thin stalk of tissue arising from a small fascial defect.
the CM), or transitional (arising from the junction of the 2 and having both dorsal and terminal components).\textsuperscript{15} In a fourth subtype, the spinal cord actually exits the spinal canal distally within the fatty mass.\textsuperscript{16} The fat within the lipomyelomeningocele is readily identified as a hyperintense mass on T1-weighted MRI sequences; caudal lesions may contain additional tissue types and appear heterogeneous on MRI.

Myelocystoceles most commonly present as full-thickness, skin-covered lumbosacral masses (Fig 7) that sometimes are referred to erroneously as “closed MMCs.” A myelocystocele has 3 components that are visible on MRI scans: (1) a dilated terminal spinal cord contained within (2) an even more largely dilated distal dural sac (commonly described on MRI as a “sac within a sac”), and (3) an adjacent spinal cord lipoma.\textsuperscript{17,18} Children with myelocystoceles may be normal or have variable neurologic deficits depending on the size and severity of the malformation.

Fatty filum terminale (also called an enlarged or thickened filum) is an enlarged filum (defined as >2 mm in cross-sectional diameter on MRI scans) that is often (although not invariably) infiltrated with fat; as such, some consider the thickened fatty filum terminale to be a forme fruste of terminal lipoma.

All 3 of these conditions may arise alone or in association with caudal malformations involving other organ systems, such as anorectal malformations, cloacal extrophy, VACTERL (vertebral defects, anal atresia, cardiac defects, tracheoesophageal fistula, renal anomalies, and limb abnormalities), OEIS complex (omphalocele, exstrophy, imperforate anus, spinal cord tethering), and other disorders of the caudal cell mass.

**Split Cord Malformation**

A split cord malformation (SCM) is a malformation in which the spinal cord splits over a portion of its length into 2 separate “hemicords” with an intervening, tissue-containing cleft. Two types have been described.\textsuperscript{19} Type I contains 2 hemicords, each contained with its own separate dural sac (analogous to 2 legs within 2 pant legs) and having an intervening extradural bony or cartilaginous tethering spike. Type II (previously referred to as diplomyelia) contains 2 hemicords within a single dural sac (analogous to 2 legs within a single pant leg) and usually having a fibrous band of tissue connected to the surrounding dura. A thickened and/or foreshortened filum terminale serves as an additional tethering element. The most common cutaneous manifestation of an SCM is a fawn’s tail or hairy patch on the back (Fig 8); other less common cutaneous manifestations include capillary malformations, DSTs, or subcutaneous masses.

SCMs can occur in isolation or may be associated with a variety of other congenital malformations, including MMC, lipomyelomeningocele, DSTs, neurenteric cysts, cervicothoracic myelocystoceles, sacral agenesis, and some cases of Klippel-Feil syndrome. Vertebral malformations are common, especially in SCM type I, and most commonly include hemivertebrae, sagittally clefted (butterfly) vertebrae, or fused (block) vertebrae. Visceral malformations may include enteric duplications, fistulae, or malrotations; neurenteric cysts; missing or ectopic kidneys; and other malformations.\textsuperscript{20}

**Lumbosacral DSTs and Innocent Coccygeal Dimples**

A spinal DST is a midline congenital epithelial-lined tract that can arise anywhere along the spine but most commonly occurs at S2 (representing the posterior neuropore as the most complex region of caudal neural tube closure).\textsuperscript{21} DSTs are thought to arise embryologically through incomplete dysjunction, leaving a tongue of cutaneous ectoderm attached to the neuroectoderm during primary neural tube closure. Spinal DSTs occur with a frequency of ~1 in 2500 live births.\textsuperscript{21} A skin dimple is present on the flat portion of the sacrum well above the upper end of the gluteal cleft.\textsuperscript{21} The dimple has an underlying tract of epithelial and fibrous tissue that pierces the

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**FIGURE 4**

Meningocele, covered with full-thickness skin.

**FIGURE 5**

underlying fascia and posterior vertebral elements, pierces the dura, and tracks cranially within the subarachnoid space to end on the dorsal aspect of the CM.

It is important to distinguish the lumbosacral DST from the innocent coccygeal dimple or pit, an innocent finding in ~4% of the population. Generations of physicians have been taught that a dimple is innocent if its base can be visualized and abnormal if its bottom cannot be seen; this teaching is incorrect. The presence or absence of a “bottom” to the dimple has little to do with its pathologic nature. Rather, it is the location of the dimple along the craniocaudal axis that is the most important feature. As the name implies, the innocent coccygeal dimple is more caudally located than the pathologic lumbosacral DST. It most commonly lies within a centimeter of the coccyx within the gluteal cleft and usually is invisible unless the buttocks cheeks are parted (Fig 9); a finger placed over the dimple can usually be rolled over the tip of the underlying coccyx. A good rule of thumb is that if one draws an imaginary line between the tops of the 2 forks of the gluteal cleft, a dimple at or below this line is normal, whereas a dimple located above this line is abnormal. Coccygeal dimples have no associated skin abnormalities and are not associated with any signs or symptoms of tethering. They are not, nor do they give rise to, pilonidal sinuses, dimples, or cysts. Imaging of coccygeal dimples is not necessary; the tract extends from the pit to the coccygeal tip, well below the end of the thecal sac, and is not connected to the spinal cord (Fig 9). Isolated coccygeal dimples do not require further workup or treatment.

In contrast, the DST is lumbosacral, located cranial to the gluteal cleft on the flat part of the sacrum (Fig 10A). DSTs are sometimes associated with surrounding cutaneous manifestations, such as vascular anomalies (Fig 10B), tufts of hair (Fig 10C), skin tags, or subcutaneous dermoid masses (Fig 10D). These tracts are always abnormal and require surgical correction. Spinal DSTs present clinically in 1 of 5 ways: (1) the presence of a cutaneous tract; (2) a CNS infection, such as meningitis or intraspinal abscess; (3) aseptic meningitis resulting from desquamation of epithelial cells from an associated dermoid or epidermoid cyst; (4) spinal cord compression from the growth of an intra- or extradural dermoid or epidermoid cyst; and (5) neurologic deterioration from tethering. Infection is the most feared complication, both because it can be highly morbid and because it generates an intradural scar that makes excision of the tract much more difficult without creating additional neurologic deficits.
Spinal DSTs may be investigated using spinal ultrasonography and/or MRI, although it is important to point out that the decision to treat is made solely on the presence of the pathologic dimple, regardless of imaging findings. The DST may not be visualized, and the spinal cord is not always radiographically tethered (ie, below the mid-body of L2); even high-resolution MRI may miss as many as 50% of DSTs. The value of neuroimaging is, therefore, largely to look for associated anomalies or the presence of dermoid or epidermoid cyst(s) as part of surgical planning. All spinal DSTs should be repaired regardless of imaging studies, because prophylactic treatment minimizes the risks of subsequent complications. The tract is completely excised down to its attachment to the spinal cord, because removing only the superficial subcutaneous portion of the tract does not eliminate tethering, aseptic meningitis, or growth of dermoid/epidermoid cysts.

**Currarino Triad**

Currarino triad is a very rare caudal malformation that combines an anorectal malformation (anorectal stenosis or agenesis, anorectal stenosis with rectovaginal fistula, or anal ectopia), a sacral bony defect (usually hemisacral agenesis with “scimitar sacrum”), and a presacral mass (most commonly a presacral teratoma or anterior sacral meningocele, less commonly a neurenteric or dermoid cyst). A genetic linkage can be established in 50% of cases with autosomal dominant and recessive as well as X-linked forms having been described; multiple genetic mutations involving the HLXB9 homeobox gene have been described. The embryonic mechanism appears to involve an abnormality of dorsoventral patterning within the caudal cell mass. Associated dysraphic malformations are uncommon. The presacral malformation may present as an enlarging pelvic mass during childhood or escape detection during childhood and present in adults, sometimes during pregnancy when the meningocele ruptures during delivery and causes meningitis.

**Caudal Agenesis (Including Sacral and Lumbosacral Agenesis)**

Caudal agenesis is a disorder in which the caudalmost portions of the spine and spinal cord do not develop properly (dysgenesis) or at all (agenesis). Most commonly, the sacrum (the second sacral segment and below) and coccyx are absent (sacral agenesis), although rarely the condition extends to the lumbar spine as well (lumbosacral agenesis). Additionally, the corresponding segments of the spinal cord are absent, producing a characteristic blunted CM on MRI scans. The filum terminale is also invariably absent in complete sacral agenesis, although it may be present (and tether the spinal cord) in sacral dysgenesis. Maternal gestational diabetes is a well-described risk factor for sacral agenesis. Sacral agenesis may occur in isolation or in association with other caudal malformations, such as anorectal malformations, cloacal or bladder extrophy, VACTERL, OEIS, and other disorders of the caudal cell mass. Bony sacral dysgenesis also can occur in isolation or as a component of the Currarino triad, discussed previously, as a “scimitar sacrum.” Children with sacral agenesis have characteristically flattened buttocks with a shallow gluteal cleft, a palpably absent coccyx, and distal leg wasting described as an “inverted champagne bottle” appearance (Fig 11). Distal leg and foot weakness are common, although sensation is curiously spared. Bowel and bladder dysfunction are universal. Although most children with sacral agenesis have fixed and static neurologic deficits, a minority can manifest progressive neurologic deterioration as a result of either to dural or bony spinal stenosis or, more rarely, spinal cord tethering from an associated thickened filum terminale or another congenital spinal cord malformation.

**OVERVIEW OF CRANIAL DYSRAPHIC MALFORMATIONS**

**Anencephaly**

Anencephaly is the cranial analog of MMC resulting from failure of anterior neural tube closure. The malformation is obvious at birth; open, exposed, and undifferentiated neural tissue is present above the orbital rims and nuchal line. Anencephaly is virtually always fatal.
during infancy; neurologic outcome in the few identified survivors is poor. No treatment is available.

**Cranial DSTs**

Cranial DSTs are less common than spinal DSTs. Like spinal DSTs, cranial DSTs can produce symptoms by (1) serving as a portal of entry for bacteria and producing meningitis, subdural empyema, or brain abscess; (2) causing aseptic meningitis through the desquamation of epithelial debris from the tract and/or associated dermoid or epidermoid cysts; and (3) causing intracranial hypertension and/or focal brain compression through the progressive enlargement of an intracranial dermoid or epidermoid cyst. Cranial DSTs are recognized as midline pits or dimples located between the glabella and nasal tip (Fig 12A) or in the parieto-occipital region (Fig 13A) but are not found between these areas. Although subcutaneous dermoid and epidermoid cysts may arise at the anterior fontanelle, they do not extend intracranially.

Frontonasal DSTs are innocuous appearing and could easily be overlooked or misdiagnosed as pimples or comedones. Sebaceous or creamy fluid can sometimes be expressed from the ostium; clear CSF may drain on rare occasions. A subcutaneous tract extends to the skull base between the nasal bone and nasal cartilage. An associated dermoid or epidermoid cyst or a small heterotopic mass of astrocytes and even neurons (called a nasal glioma) may be present within the tract. Although 70% to 90% of these tracts end extracranially, 10% to 30% extend to a variable extent intracranially through the skull base at the foramen cecum (Fig 12B). Computed tomography (CT) and MRI provide complementary information in the detection of frontonasal DSTs. CT may reveal bony defects within the foramen cecum or intracranial calcifications, whereas MRI may detect the soft tissue components of the tract and/or intracranial dermoid or epidermoid cysts. Unfortunately, intracranial tracts may not always be visible. Treating frontonasal DSTs regardless of the imaging findings eliminates the tract and prevents future complications, even though most will involve only a local nasal excision.

Parieto-occipital DSTs more frequently have intracranial extension through a midline occipital skull defect, penetrate the dura, and end intracranially in relation to either the occipital lobes or posterior fossa; associated dermoid cysts may be present (Fig 13B). Although MRI is most useful to identify intracranial extension, CT again may play a supplementary role in identifying...
small bony ostia through which the tract might extend.

**Encephaloceles**

Encephaloceles represent focal herniation of meninges, with or without brain tissue, through a focal defect in the skull and are thought by many to arise after neurulation from a defect in the calvarial mesenchyme rather than as a neural tube defect. They may be isolated malformations or associated with a wide variety of other genetic syndromes and malformation sequences. Encephaloceles may involve the calvarium or skull base. Calvarial encephaloceles can arise anywhere along the midline skull from the orbits to the craniocervical junction. Occipital encephaloceles are most common in European and North American populations, whereas frontal encephaloceles are most common among Asian populations. Calvarial encephaloceles are readily apparent externally as fully skin-covered sacs containing variable amounts of CSF and/or brain. Frontal encephaloceles may have associated hypertelorism. Tissue may extend into the orbits or the frontal, ethmoid, and sphenoid sinuses, where they may cause proptosis or present as intranasal or pharyngeal masses (neuroimaging should, therefore, be considered before surgical biopsy of an intranasal mass). Encephaloceles may rarely extend through defects in the sphenoid or petrous bones into the pterygopalatine or infratemporal fossae and may be completely invisible externally.

Neuroimaging defines both the extent and type of neural tissue within the sac. MRI provides superior visualization and is the preferred imaging modality. The outcome for encephaloceles is variable and depends, in large measure, on the amount and type of neural tissue within the sac. For example, large occipital encephaloceles containing solely or largely CSF may have an excellent prognosis, whereas those having large amounts of occipital lobe or brainstem generally have a poor prognosis.

The atretic parieto-occipital encephalocele deserves special mention, because it can be confused with cutis aplasia congenita (CAC) (described later). Midline atretic encephaloceles overly the parietal or occipital bones as a small area of dysplastic skin surrounded by whorls of distinctly colored hair sometimes referred to as a “horse collar” (Fig 14A). Neuroimaging may demonstrate an underlying small bony defect and/or a bifid superior sagittal sinus. In addition, MRI, and particularly magnetic resonance venography, may show a classic venous drainage pattern in which the straight sinus is atretic or absent and the deep cerebral veins instead drain through an embryonic primitive prosencephalic (or falcine) vein between the pineal region and

**FIGURE 12**

Frontonasal DST. A, DST arising from the glabella. B, Sagittal T2-weighted MRI showing dermoid cyst (arrow) with tract extending through the anterior skull base at the level of the foramen cecum (arrowhead).

**FIGURE 13**

Occipital DST. A, Midline tract. B, Sagittal T1-weighted MRI showing DST (arrow) with large posterior fossa dermoid tumor (asterisk).
superior sagittal sinus (Fig 14B). At surgery, the atretic parieto-occipital encephalocele contains an underlying tissue tract having a surrounding dural cuff. Despite its innocuous appearance, the parietal encephalocele may be associated with other congenital brain malformations and significant cognitive deficits in some cases.40

Parietal encephaloceles must be distinguished from CAC, a disorder of full-thickness skin of uncertain etiology that most commonly involves the scalp (Fig 15); 20% to 30% have skull aplasia as well. In the midline, CAC may extend to involve the dura.41 Both genetic transmission (autosomal dominant and, less commonly, autosomal recessive) and association with chromosomal abnormalities (trisomy 13, deletion of the short arm of chromosome 4) have been described.40 Unlike the skin-covered atretic encephalocele, CAC lacks skin and does not characteristically have a dysplastic skin collar or a whorl of surrounding hair; it has no intracranial tract of tissue and is associated with neither any underlying brain malformation nor intracranial venous anomalies. A CAC can, nonetheless, be dangerous for 2 reasons: first, it can serve as a portal of entry for bacterial meningitis or intracranial infection. Second, if allowed to desiccate from exposure to air, the dura lining the superior sagittal sinus can crack and bleed significantly. A midline CAC that exposes the superior sagittal sinus should be immediately covered with a sterile, saline-soaked gauze or petroleum gel until repaired by a neurosurgeon and/or plastic surgeon.

### RELEVANCE OF CUTANEOUS MARKERS

Cutaneous markers may be the only indication of an underlying spinal cord malformation, particularly in infants before progressive symptoms or neurologic deficits develop. Faced with a child having a cutaneous marker, the pediatrician is faced with a decision to (1) observe; (2) obtain some sort of imaging study and, if so, what type; and/or (3) obtain a neurosurgical consultation. Unfortunately, there are few prospective studies that meaningfully assess the frequency of underlying spinal cord malformations for these cutaneous markers, and the predictive value of these markers is implied largely from older studies on the natural history or surgical outcomes of occult dysraphism. However, cutaneous anomalies may generally be stratified into 3 risk categories based on the literature and collective experience (Table 1).

### High-Risk Cutaneous Anomalies

Children with 1 or more of the cutaneous markers described in the following paragraphs often have an underlying congenital spinal cord malformation. Almost 70% of children with congenital spinal cord malformations display at least 1 of these high-risk cutaneous markers, and it is common for 2 or more cutaneous markers to coexist. On the other hand, these high-risk cutaneous markers are present in only 3% of normal neonates.44

Hypertrichosis refers to a focal tuft of hair of variable thickness located in the posterior spinal midline (Fig 8C); because it resembles a horse’s tail, it has earned the mythological name “fawn’s tail.”43 This can be distinguished by its focality from the more diffuse and/or “light hair” often seen in infants (discussed in the section Low-Risk Cutaneous Anomalies, later in this article). Hypertrichosis is often accompanied by a capillary hemangioma and also may be associated with dimples or subcutaneous masses, such as lipoma, bone malformations, or even teratoma. Hypertrichosis may accompany spinal malformations of any type but is most commonly associated with split cord malformations, where it is associated with two-thirds of type I and one-third of type II SCMs.19,43

An infantile hemangioma (Fig 6C) is a highly vascular, usually raised lesion having well-defined borders. It is readily distinguished from the flat port wine, pink, or salmon-colored capillary malformations discussed in the next section, Intermediate-Risk Cutaneous Anomalies. Infantile hemangiomas develop in up to 5% of infants and may be located anywhere on the body. Infantile hemangiomas that are midline and overlie the spine, particularly in the lumbar region, are
differentiation is moot from a vestigial embryonic structure. This an abnormal outgrowth rather than embryonic kidney. It is thought to be anomalies, and renal anomalies.47 Anorectal malformations, arterial ulcerations, myelopathy, bony defects, urogenital abnormalities, hemangioma and other cutaneous LUMBAR syndrome (lower body to 55% of cases as part of the genital urinary malformations in up defects, anorectal malformations, arterial anomalies, and renal anomalies.47

Segmental hemangiomas in association with LUMBAR syndrome

LUMBAR, lower body hemangioma and other cutaneous defects, urogenital abnormalities, ulcerations, myelopathy, bony defects, anorectal malformations, arterial anomalies, and renal anomalies.

Sometimes associated with underlying dysraphic malformations.55 Although the sensitivity and specificity of the lumbosacral midline infantile hemangioma as a marker for spinal dysraphism are not entirely known, the presence of this marker raises suspicion for an underlying dysraphic malformation.43,45,46 A subset of infantile hemangiomas overlying the lumbosacral spine that are segmental, are large, and may have a reticular pattern are associated with spinal and genital urinary malformations in up to 55% of cases as part of the LUMBAR syndrome (lower body hemangioma and other cutaneous defects, urogenital abnormalities, ulcerations, myelopathy, bony defects, anorectal malformations, arterial anomalies, and renal anomalies).47

Caudal appendages represent focal skin-covered appendages described as true tails and pseudotails48 (Fig 16). A true tail is a vestige of the embryonic tail that ordinarily regresses in humans; it contains vertebrae and variably muscle, fat, and mesenchymal tissues. The tail may be covered with hair and is often capable of spontaneous or reflex movements.48 In contrast, a pseudotail is a skin-covered outgrowth containing fat, cartilage, or other organ-specific tissues, such as embryonic kidney. It is thought to be an abnormal outgrowth rather than a vestigial embryonic structure. This differentiation is moot from a practical standpoint, because both true tails and pseudotails may be associated with dysraphic malformations (although some studies suggest a more frequent association with pseudotails).

Atretic meningocoele (Fig 5) is another high-risk cutaneous marker that was discussed previously.

Intermediate-Risk Cutaneous Anomalies

Capillary vascular malformations may be classified as intermediate-risk anomalies and are of several types; all are flat malformations in contrast to most infantile hemangiomas, and microscopically they look similar despite the differences in their clinical appearance. Port wine stains (PWSs) are flat, darker, red-purple lesions, having well-defined borders, which tend to get darker with time (Fig 6D). Nevus flammeus simplex (NFS),49 also referred to as “salmon patch,” is a flat, pink or red capillary malformation having relatively ill-defined borders. These lesions are present in up to 43% of the general population49,50 and occur in a variety of locations. Nonmidline lesions as well as midline lesions that occur on the glabella, the lip (“angel kiss”) or the nape of the neck (“stork bite”) are not associated with underlying dysraphic malformations. On the other hand, midline or juxta-midline lumbosacral lesions are sometimes seen in association with dysraphic malformations including DSTS, split cord malformations, lipomyelomeningoceles (Fig 6A, 6B), and other malformations.

Whether isolated midline lumbosacral capillary malformations, particularly NFS, which are present in as many as 0.77% of the healthy population,49 are more frequently associated with underlying dysraphic malformations is controversial. In one study of 120 children with spinal dysraphic malformations, a capillary malformation was the only cutaneous manifestation of the underlying spinal cord abnormality in 17%.51 On the other hand, 2 studies involving a combined 40 infants with capillary vascular malformations but no other cutaneous markers of dysraphism identified only 1 (2.5%) with an underlying dysraphic malformation on spinal ultrasonography.49 Isolated NFS is much less frequently associated with dysraphic malformations than are PWSs. However, NFS may not always be easy to distinguish from PWSs clinically, leading to confusion and imprecise terminology.

Low-Risk Cutaneous Anomalies

A number of low-risk cutaneous markers do not require routine further neuroimaging or follow-up.

<table>
<thead>
<tr>
<th>TABLE 1 Risk Stratification for Various Cutaneous Markers</th>
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<tbody>
<tr>
<td>High Risk</td>
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<tr>
<td>Hypertrichosis</td>
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<tr>
<td>Infantile hemangioma</td>
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<tr>
<td>Atretic meningocoele</td>
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<td>Caudal appendage</td>
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LUMBAR, lower body hemangioma and other cutaneous defects, urogenital abnormalities, ulcerations, myelopathy, bony defects, anorectal malformations, arterial anomalies, and renal anomalies.

Whether isolated midline lumbosacral capillary malformations, particularly NFS, which are present in as many as 0.77% of the healthy population,49 are more frequently associated with underlying dysraphic malformations is controversial. In one study of 120 children with spinal dysraphic malformations, a capillary malformation was the only cutaneous manifestation of the underlying spinal cord abnormality in 17%.51 On the other hand, 2 studies involving a combined 40 infants with capillary vascular malformations but no other cutaneous markers of dysraphism identified only 1 (2.5%) with an underlying dysraphic malformation on spinal ultrasonography.49 Isolated NFS is much less frequently associated with dysraphic malformations than are PWSs. However, NFS may not always be easy to distinguish from PWSs clinically, leading to confusion and imprecise terminology.

Low-Risk Cutaneous Anomalies

A number of low-risk cutaneous markers do not require routine further neuroimaging or follow-up.
These include *non-midline cutaneous lesions, benign coccygeal dimples* (discussed previously); *diffuse and evenly distributed lumbosacral hair, isolated café au lait and Mongolian spots, hypo- and hypermelanotic macules or papules, and isolated gluteal cleft deviation or forking.* There have been no large prospective studies of *isolated* gluteal cleft abnormalities. One study demonstrated that *isolated* gluteal cleft deviation or forking carries a low association with dysraphic malformations, although a higher incidence is found when gluteal cleft abnormalities are combined with other cutaneous markers of dysraphism. Absent other cutaneous markers of dysraphism, isolated gluteal cleft abnormalities need not be further evaluated, but those that occur with other cutaneous markers of dysraphism and those having neurologic, urologic, or orthopedic manifestations of tethering suggest an underlying dysraphic malformation.

**ASSOCIATED CONDITIONS**

**Scoliosis, Orthopedic Deformities, and Dysraphism**

As many as 75% or more of patients with spinal dysraphism will present with lower extremity neurologic and orthopedic abnormalities from tethering. The exact presentation depends on both the age of the patient and the degree and type of lower extremity dysfunction. *Progression* is an important feature that suggests an underlying dysraphic malformation with spinal cord tethering. Unfortunately, although tethered cord release is effective in arresting or improving neurologic symptoms, sensorimotor dysfunction, or urologic deterioration, longstanding or severe orthopedic deformities are unlikely to improve, and subsequent orthopedic intervention may be required.

Scoliosis is another common manifestation of tethering. Like other orthopedic manifestations, scoliosis associated with tethering is often progressive and may be a levo-scoliosis rather than the more common dextroscoliosis seen in idiopathic scoliosis in some but not all studies. Scoliosis in the setting of dysraphism is multifactorial and may involve muscular imbalance, vertebral abnormalities, and other factors; for example, 18% to 58% of dysraphic malformations are associated vertebral malformations, such as hemivertebrae, butterfly vertebrae, or segmentation abnormalities, and it may be difficult in this setting to determine what role, if any, tethering plays in the development of scoliosis. However, scoliosis that is atypical, rapidly progressive (in excess of the rate of annual progression predicted by the associated vertebral malformations), or associated with neurologic abnormalities should prompt further workup and referral. Fortunately, early untethering can often halt progression and may even reverse deformities and restore function, particularly for those with mature spines and/or scoliosis curves of less than 40 degrees.

**Anorectal Malformations and Dysraphism**

The intimate temporospatial relationships between caudal spinal cord and anorectal and urogenital development during early embryogenesis may result in associated malformations involving all 3 organ systems. Between 10% and 52% of children with anorectal malformations have associated dysraphic malformations. Studies have not established a correlation with the level of the anorectal malformation (low, intermediate, or high); although there is a higher association with complex (43%) compared with simple anorectal malformations (11%). Both dysraphic and anorectal malformations may occur in conjunction with recognized malformation sequences such as the Currarino triad, VACTERL, and OES. MRI will identify children having underlying dysraphic malformations.

**Urologic Dysfunction and Dysraphism**

Urologic dysfunction is an important presenting feature of spinal cord tethering. Urologic function may be assessed by history (incontinence, frequency, repeated urinary tract infections), imaging (renal ultrasonography showing hydrourèter/hydronephrosis, sometimes with associated small, enlarged, or trabeculated bladder) or by formal urodynamic testing in which the bladder’s response to retrograde filling is assessed. Urologic manifestations of tethered cord vary according to the age at presentation and the severity of the response to the tethering process. More than 90% of children younger than 3 years at diagnosis have no urologic symptoms, and results of formal urodynamic testing at this age are rarely abnormal. Urinary tract infection is the predominant sign in an affected infant, but urinary retention is occasionally seen. Once a child is toilet trained, the onset of secondary urinary incontinence, especially in conjunction with fecal incontinence and/or constipation, is the most common presentation of a tethering lesion, although urinary tract infection is still common in this age group as well. As the child matures, urgency, urge incontinence, sudden or stress incontinence, new-onset enuresis, urinary frequency, and nocturia, often together with fecal soiling, are the most common modes of presentation. Renal ultrasonography may reveal hydronephrosis and/or increased bladder wall thickness. In addition, a plain abdominal radiograph may reveal bony abnormalities of the spine or disturbances in the bowel gas pattern. Urodynamic studies at this time demonstrate either an
enlarged bladder capacity with detrusor underactivity (no or poor bladder contractions) and denervation in the external urethral sphincter muscle (signs of lower motor neuron dysfunction) or a small, thick-walled bladder with detrusor overactivity and incoordination between the bladder and external sphincter muscle with voiding, called detrusor sphincter dyssynergia (signs of upper motor neuron dysfunction).79,82

Urologic and/or gastrointestinal symptoms in a child with a cutaneous midline skin lesion or with leg pain, sensorimotor loss, orthopedic deformity, or gait disturbance suggests an underlying spinal cord tethering malformation. A trained pediatric urologist will be able to identify and characterize voiding dysfunction in this population.84,85 A urodynamic evaluation before surgical correction provides information about the extent of sacral spinal cord involvement and serves as a basis for comparison postoperatively.79,86

SUMMARY AND CONCLUSIONS
A wide variety of congenital brain and spinal cord malformations may ultimately lead to neurologic deterioration. Cutaneous manifestations of dysraphic malformations are common, and their presence may alert the pediatric care provider to the presence of an underlying spinal cord abnormality, especially in association with a pattern of other signs and symptoms that suggest spinal cord tethering. Recognizing and prophylactically treating these malformations often provides the best opportunity to avoid subsequent deterioration.

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ABBREVIATIONS
CAC: cutis aplasia congenita
CM: conus medullaris
CNS: central nervous system
CSF: cerebrospinal fluid
CT: computed tomography
DST: dermal sinus tract
MMC: myelomeningocele
MRI: magnetic resonance imaging
NFS: nevus flammeus simplex
OEIS complex: omphalocele, exstrophy, imperforate anus, spinal cord tethering
PWS: port wine stain
SCM: split cord malformation
VACTERL: vertebral defects, anal atresia, cardiac defects, tracheo-esophageal fistula, renal anomalies, and limb abnormalities

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