Management of urological dysfunction in pediatric patients with spinal dysraphism: review of the literature

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An intact, fully functional spine is the result of a complex sequence of embryological events involving both nervous and musculoskeletal system precursors. Deviations from this highly ordered system can result in congenital abnormalities ranging from clinically insignificant cosmetic changes to CNS malformations that are incompatible with life. Closure of the neural tube, which is believed to be the embryological event gone awry in these cases, is complete by just 28 days' gestation, often before pregnancy is detected. Although progress has been made to help prevent neural tube defects in the children of those attempting to conceive, these congenital deformities unfortunately continue to affect a startling number of infants worldwide each year. Furthermore, the precise mechanisms governing closure of the neural tube and how they might be interrupted remain elusive. What is known is that there are a large number of individuals who must deal with congenital spine dysraphism and the clinical sequelae on a daily basis. Bladder and urinary dysfunction are frequently encountered, and urological care is a critical, often neglected, component in the lifelong multidisciplinary approach to treatment. Although many treatment strategies have been devised, a need remains for evidence-based interventions, analysis of quality of life, and preemptive education of both caregivers and patients as they grow older. Pediatric neurosurgeons in particular have the unique opportunity to address these issues, often in the first few days of life and throughout pre- and postoperative evaluation. With proper management instituted at birth, many patients could potentially delay or avoid the potential urological complications resulting from congenital neurogenic bladder.

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NEURAL tube defects are among the most common congenital abnormalities that result in significant infant morbidity and mortality, accounting for over 130,000 deaths each year (43% of all neonatal deaths from congenital abnormalities) in regions with low income and high neonatal mortality.^{7,8} Anencephaly and spina bifida, the most prevalent NTDs, occur in approximately 1 in 1000 pregnancies in the US and 300,000 newborns each year worldwide.⁹ Myelomeningocele, a form of spina bifida, is one of the most severe CNS malformations compatible with survival.⁵¹ The overall prevalence of closed NTDs that are clinically significant is less clear, since many of these abnormalities are less obvious or hidden at birth. Recently, extensive medical and surgical care has allowed considerable numbers of infants

born with myelomeningocele to survive into adulthood, creating a significant neurosurgical population requiring continuous multidisciplinary care. Urological dysfunction is a significant deficit in these children, and neurosurgeons play a significant role in both monitoring and management of these urological concerns.

Review of Spinal Dysraphisms

The clinical spectrum of NTDs includes anencephaly, the group of anomalies considered under the term "spina bifida," encephalocele, craniorachischisis, and iniencephaly.³⁵ Of those surviving after birth, and thus those disorders subject to clinical sequelae, the family of defects represented under the term spina bifida is by far the most prevalent. Traditionally spina bifida has been synonymous with "spinal dysraphism." Although spinal dysraphism should in theory only refer to abnormalities of primary neurulation, the term has been used to encompass all congenital spine

Abbreviations used in this paper: CIC = clean intermittent catheterization; EMG = electromyography; NBSD = neurogenic bladder sphincter dysfunction; NTD = neural tube defect; UDS = urodynamic study.

disorders involving problems with differentiation and/or closure of dorsal midline structures.⁶⁰

Spinal dysraphisms can be broken down into open or closed forms (Table 1). If neural elements and/or membranes are exposed to the external environment, the defect is classified as an open spinal dysraphism. The most common forms of open spinal dysraphism are myelomeningocele and myelocele, which share a common embryological pathogenesis and are associated with similar clinical implications. Closed spinal dysraphism, on the other hand, consists of spinal abnormalities covered by skin and representing a wide range of NTDs. Although many closed spinal dysraphisms go undetected or remain asymptomatic throughout the life of the patient, there are variants that may be associated with a subcutaneous mass, cord tethering, or more severe spinal cord abnormalities.¹¹

Tethered cord is not strictly considered a malfor-

mation but rather a clinical syndrome that is usually a complication of myelomeningocele repair (acquired or secondary) or the symptomatic presentation of a form of closed spinal dysraphism (congenital). The position of the conus medullaris is abnormally low (below the L-3 vertebra) and the filum terminale is often thickened. The arterioles, venules, capillaries, and nerve fibers are all subjected to stretching, distortion, and kinking that result in a spectrum of motor and sensory nerve dysfunctions.⁶⁰ Many cases of tethered cord syndrome are the result of retethering that occurs after the repair of a myelomeningocele (that is, in 2.8%–32.0% of patients usually between 5 and 9 years of age) or a lipomyelomeningocele, which is frequently associated with progressive neurological and subsequently urological deterioration.

Spinal dysraphisms are associated with a variety of structural abnormalities in addition to the primary defect

TABLE 1: Classification of spinal dysraphisms*

Classification	Description
open spinal dysraphism	
myelomeningocele	protrusion of spinal cord segment & meninges through a bony defect in midline of the back
myelocele	myelomeningocele w/o expansion of underlying subarachnoid space
hemimyelomeningocele	myelomeningocele w/ associated SCM (defect of 1 hemicord)
hemimyelocele	myelocele w/ associated SCM (defect of 1 hemicord)
closed spinal dysraphism w/ subcutaneous mass	
lipomyelomeningocele	large subcutaneous lipoma extending intraspinally; cord is tethered & lipoma-cord interface lies outside the spinal canal
lipomyeloschisis	large subcutaneous lipoma extending intraspinally; cord is tethered and lipoma-cord interface lies w/in or at edge of spinal canal
terminal myelocystocele	ependyma-lined cyst (dilation of terminal ventricle) bulging through a posterior spina bifida, causing herniation of meninges
lumbosacral meningocele	herniation of CSF-filled sac lined by dura & arachnoid through a posterior spina bifida
cervical myelocystocele	epithelial-lined cavity; only dorsal wall protrudes into meningocele
cervical myelomeningocele	fibroneurovascular stalk containing neurons, glia, & peripheral nerves traveling through a narrow dorsal dural opening; fans out into lining of meningeal sac; spinal cord remains in canal
cervical meningocele	herniation of CSF-filled sac lined by dura & arachnoid through a posterior spina bifida
closed spinal dysraphism w/o subcutaneous mass	
posterior spina bifida	simple failure of fusion of the posterior vertebra
intradural & intramedullary lipoma	encapsulated mass w/ fibrous bundles residing in spinal canal
tight filum terminale	short, hypertrophic filum terminale resulting in tethering & impaired ascent of conus medullaris
abnormally long spinal cord	absence of normally tapered conus medullaris
persistent terminal ventricle	cystic dilation of terminal ventricle; an ependyma-lined cavity in conus medullaris
dorsal enteric fistula	fistula connecting bowel w/ dorsal skin surface, traversing the spinal canal, spinal cord, neural arch, & subcutaneous tissue; involved segment of vertebral column & spinal cord is split around the fistula
neurenteric cyst	intradural cyst lined by mucin-secreting cuboidal or columnar epithelium that resembles gastrointestinal tract
split cord malformation	variations of splitting of spinal cord into 2 hemicords
dermal sinus	epithelium-lined fistula extending into the CNS; point of termination varies
caudal regression syndrome	family of anomalies representing total or partial agenesis of the spinal column, imperforate anus, genital anomalies, bilat renal dysplasia/aplasia, & pulmonary hypoplasia
segmental spinal dysgenesis	segmental agenesis/dysgenesis of lumbar/thoracolumbar spine, segmental abnormality of spinal cord & nerve roots, congenital paraplegia or paraparesis, and congenital lower-limb deformities

* Based in part on data from Tortori-Donati et al: *Neuroradiology* 42:471–491, 2000. Abbreviation: SCM = split cord malformation.

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of neurulation. The mesoderm that forms the vertebrae is also the precursor for the mesonephros, an embryological structure that represents an important stage in the development of the mature genitourinary system. This association explains the frequency of coexisting anomalies of the urinary tract and congenital spine dysraphisms.³³ In a study of infants with urogenital anomalies, it was noted that they had a higher prevalence of closed spinal dysraphism (23 per 1000 vs 1 per 1000).³⁶ Infants in the abnormal group exhibited a consistently lower conus medullaris and thicker filum terminale when compared with healthy infants without anomalies.

Diagnosis

Urological dysfunction in children may be present from birth in individuals with open NTDs, or it may present later in life in individuals with closed NTDs, such as lipomyelomeningocele, or in those with a secondary tethered cord. Establishment of a diagnosis generally relies on the children and parents monitoring urinary function to assess for changes such as incontinence, changes in urinary frequency, urinary tract infections, or other alterations in the patient's baseline urological function. Of importance for all children with spinal dysraphisms is the monitoring of urological function throughout their clinical course, as early detection of worsening urological function combined with timely surgical intervention is important for the prevention of progressive deterioration. A long-term follow-up study of 25 newborns after myelomeningocele and meningocele repair demonstrated the importance of regular follow-up of urinary function, as those individuals younger than 6 years were at higher risk of secondary tethered cord and subsequent urological deterioration.⁵⁷ In an evaluation of 25 children with spina bifida, Kumar et al.³⁸ demonstrated abnormal baseline urodynamics in 90% of children with open defects and 66.6% of children with closed defects. Because these children may have a baseline degree of urological dysfunction or subclinical urological dysfunction, the neurosurgeon must rely on colleagues in urology, as well as urodynamic function studies, to assess for changes in urological function. Further preoperative evaluation of these children will be discussed.

Innervation of the Genitourinary System

Central control of bladder function begins in the locus coeruleus of the pons, which is responsible for a reflex pathway that synchronizes bladder contraction with internal urethral sphincter relaxation during voiding (Fig. 1).⁴⁰ With appropriate training, cortical signals can voluntarily suppress this reflex. Infants who have not yet acquired this control have an uninhibited pontine reflex. Thus, the detrusor muscle contracts and the internal sphincter relaxes when a critical urine capacity is reached.⁶⁵ Parasympathetic fibers are the primary innervation of the urinary bladder. Presynaptic fibers arise from neurons in the S2–4 cord segments and travel via pelvic splanchnic nerves and the inferior hypogastric and vesical plexuses to the bladder. They form synapses with postsynaptic neurons that

Fig. 1. Diagram of the neural input to lower urinary tract function. The brainstem response is inhibitory to detrusor muscle via the pudendal nerve. Thoracolumbar autonomic innervation is responsible for relaxation of the detrusor and contraction of urethral smooth muscle. Reproduced from McGuire: *J Neurosurg* 65:278–285, 1986.

are found on or near the bladder wall. Parasympathetic fibers provide motor innervation to the detrusor muscle and inhibit the internal urethral sphincter. Sympathetic fibers arise from the T11–L3 cord segments, travel via lumbar splanchnic nerves, and synapse on the hypogastric system of plexuses.⁴⁶ Sympathetic nerves have little role in bladder motor activity, but they do appear to heavily innervate the neck and trigone of the bladder. Sympathetic stimulation allows for bladder neck closure, which is crucial for bladder filling. Somatic fibers to the external urethral sphincter arise from motor neurons in the S2–4 cord segments and travel to the bladder via the pudendal nerve. Although the external sphincter can be contracted voluntarily, it relaxes reflexively when micturition is initiated via cortical signals and the internal sphincter opens.²⁵

Urological Sequelae

Most closed spinal dysraphisms or tethered cord syndromes are diagnosed following manifestation of neuro-

logical symptoms or are discovered incidentally during workup for unrelated problems. These neurological sequelae can include muscular deformity, bowel and bladder incontinence, sexual dysfunction, lower-extremity sensory loss, and paraplegia in severe cases.³³ Patients with closed spinal dysraphisms may present with signs and symptoms much more insidious in nature, with the exception of the cutaneous markers that may be associated with 43%–95% of cases, so urological symptoms in these patients may go unnoticed until later in life.^{2,5,21,26,31,44,52} New-onset urinary incontinence, changes in voiding patterns, or recurrent urinary tract infections are indications for additional workup. Clinically significant symptoms are usually the result of pathology or abnormalities that cause spinal cord tethering.⁵⁵

The urological sequelae of myelomeningocele, the most common open spinal dysraphism, have been well studied. Urinary symptoms were initially thought to be the result of paresis of the detrusor muscle and/or sphincter muscles. It was not until the development of pediatric urodynamics in the late 1970s and early 1980s that physicians realized that detrusor-sphincter dyssynergia, which creates a functional bladder outlet obstruction, may also be the primary issue. In fact, children with myelomeningocele may show any of 4 unique combinations of detrusor muscle and urethral sphincter activity (detrusor overactivity with sphincter overactivity; detrusor inactivity with sphincter overactivity; detrusor overactivity with sphincter inactivity; and detrusor inactivity with sphincter inactivity). The type of detrusor-sphincter dyssynergia tends to remain consistent during follow-up because it represents the manifestation of the primary neurological lesion. The clinical manifestations include incontinence that results from urethral sphincter inactivity and obstruction, which results from urethral sphincter overactivity.⁶¹ Regardless of the underlying mechanism, the consequences of untreated urological sequelae are severe. Renal failure within the 1st year of life is responsible for up to 20% of deaths. Renal damage begins as early as 6 months of age, and up to 100% of children with untreated dyssynergia have renal scarring.¹⁶ Complications of poor urological management occur in a progressive fashion. Urinary stasis, combined with vesicoureteral reflux, leads to an increased incidence of infection of the urinary tract, bladder, and kidney, as well as an increased risk of urinary tract calculi. Elevated bladder pressure can lead to hydronephrosis, renal deterioration, renal failure, and ultimately death. Furthermore, the incidence of bladder cancer is significantly elevated, sexual dysfunction is common, and there is often physical damage due to long-term catheterization.²⁴ With proper treatment and patient compliance, physicians can now ensure preservation of renal function provided that interventions begin immediately after birth. Quality of life improvements continue to be explored to address the social implications of management strategies.

Urodynamic Testing

Urodynamic studies provide a reliable way to evaluate the function of the lower urinary tract and can be

adapted specifically for use in children. Significant controversy exists about the use of invasive urodynamic testing in children with nonneurogenic voiding disorders because these children may often be evaluated with noninvasive UDSs and managed expectantly with behavioral and pharmacological therapy.¹⁸ However, identification or confirmation of neurogenic bladder is an excellent use of UDSs, providing more specific and accurate information than imaging, neurological examination, and symptomatology alone.¹⁸ Noninvasive UDSs consist of uroflowmetry and postvoid residual measurement. Uroflowmetry can be used in isolation, simply measuring the child's ability to empty the bladder, or as part of more comprehensive studies. In children, the flow pattern is more useful than the rate of flow, as it can provide information about detrusor function, amount of outlet resistance, and degree of external urethral sphincter activity. Postvoid residual measurements may be performed using ultrasonography or specialized bladder scanners, and abnormal values indicate a need for repeated measurements or further workup. Jansson et al.²⁹ found that the median postvoid residual in 6-month old infants was 5 ml ($r = 0$ –22), decreasing to a median of 0 ml at age 3 ($r = 0$ –18).

If noninvasive UDSs show abnormal bladder function, either through postvoid residual measurement or bladder enlargement, invasive studies are warranted, including cystometrography, in which rectal and urethral catheters measure intraabdominal and intravesical pressures. Perineal EMG patches may be added to assess external urethral sphincter activity. To perform the test, the bladder is filled using a multilumen catheter until the child feels a strong urge to urinate, becomes uncomfortable, urination occurs, detrusor pressure exceeds 40 mm H₂O, greater than 150% of expected capacity has been infused, or the leakage rate exceeds the infusion rate. Fluoroscopy can be used during filling-phase studies to visualize the shape and contours of the bladder while full or voiding, as well as intrinsic sphincter deficiency in patients with neurogenic bladder disease and dynamic dysfunction. Evaluation of the storage function of the bladder is typically described subjectively in terms of bladder sensation (as well as objective values such as compliance, activity, and capacity) and, therefore, is only of use in patients able to describe what they are feeling. In younger patients, however, signs such as toe curling or abdominal tensing may be indicative of a full bladder, signifying incipient micturition.⁴⁸ Bladder capacity and compliance are then determined, although there are no standardized reference values available for compliance in children or adults; this is further complicated in that compliance varies according to capacity at the time of measurement and in that capacity does not change linearly with age.¹⁸ Finally, in children capable of spontaneous voiding, voiding-phase studies measure voiding pressure and flow rate, with attention paid to whether voiding pressure has been maintained throughout the duration of bladder contraction until completely empty, as well as any external urethral sphincter activity, monitored through EMG. As in filling studies, concurrent imaging of the bladder improves diagnostic interpretation and characterization of any pathology.²²

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Current Strategies for Management of Urological Dysfunction

Prompt detection of children with high-risk urological dysfunction and early intervention is key in protecting against hydronephrosis, preserving renal function and preventing the development of a poorly compliant bladder.¹⁶ Neurogenic bladder sphincter dysfunction can cause these problems long before continence becomes an issue. There are several types of NBSD seen clinically, consisting of the previously mentioned combinations of detrusor over- and underactivity and sphincter over- and underactivity. Management is determined by the consequences of the particular combination. Of all four types, only the combination of sphincter underactivity and detrusor underactivity is inherently “safe” in that, untreated, it will not lead to urinary tract damage, although it does result in incontinence and increased rates of urinary tract infection.⁶²

All of the other forms of NBSD include CIC to empty the bladder. In the case of sphincter overactivity with detrusor underactivity, it is the only management needed to control urinary tract damage and leakage. With proper parental/caregiver education, and with the practice of proper basic technique, including clean and atraumatic catheter application, the specific techniques and materials used are unimportant with regard to efficacy.⁶² It should be noted, however, that Credé voiding is not recommended for noncatheterized patients because it can result in compression of the external urethral sphincter, causing high pressure voiding or reflux in some patients, which is detrimental to the upper urinary tract.¹⁴ Beginning CIC early in infancy conveys several advantages over expectant treatment, including easier caregiver and patient adaptation to the routine and less need for augmentation cystoplasty.^{20,30,66} As the children age and develop manual dexterity, they may be transitioned to clean intermittent self-catheterization.⁶²

In addition to CIC, pharmacological treatment in the form of the anticholinergic oxybutynin is used to treat both forms of NBSD involving detrusor overactivity, long-term studies having demonstrated safety in children and infants and efficacy in lowering filling pressure, increasing bladder capacity, and preventing renal damage.⁶² Pharmacological treatment can be administered orally or as an intravesical preparation in children with significant side effects or a poor response to the oral form.¹² The combined therapy of CIC and oxybutynin is successful in treating 90% of patients with NBSD, but for those patients in whom this therapy is unsuccessful, other drugs such as propiverine or tolterodine are available, but there is relatively little published information on efficacy in children.⁶² Recent work has indicated that injection of botulinum A toxin may be a viable treatment in children unresponsive to CIC and oxybutynin.³⁹

After a treatment regimen is chosen, follow-up to assess for efficacy is needed. Assessment can include ultrasound, UDS, cystography, urinalysis, or other tests. The frequency of visits can be tapered from 3 per year in children up to age 3, 2 per year in school-age children, and annually in adults.⁶²

Several urological procedures exist for the purpose of increasing bladder capacity and for urinary diversion. These procedures include ureterostomy, vesicostomy, ileal conduit, and ileovesicostomy. Although these procedures are outside the scope of the present review, they are well described in the urology literature.^{23,63,64}

Neurosurgical Intervention

The particular role of the neurosurgeon in the management of urological dysfunction revolves around the preoperative evaluation of children with urological complaints, intraoperative techniques to release a tethered cord and limit neural injury during surgery, and postoperative monitoring for further deterioration. Newer techniques are emerging to reinnervate the bladder. A strategy for management during each of these stages follows.

Preoperative evaluation of any child with a primary urological complaint of possible neurogenic origin should include formal urological assessment, which may include a bladder ultrasound or invasive urodynamic testing as previously described. Additionally, imaging tests such as an MRI may reveal evidence of a closed defect or tethered cord as the likely cause. As many children may be referred to a neurosurgeon after advanced imaging studies have already been completed, the referral to a urologist and correlation of symptoms with results of a urological assessment should follow. This becomes especially important in children with secondary tethered cord in whom there are radiographic concerns of tethering even in the absence of clear symptoms.^{4,43} Often in these patients the presence of symptoms rather than radiographic findings should take precedence. Suspicion of a symptomatic tethered cord should be raised when there changes in a child's baseline urinary pattern because these changes may represent secondary tethered cord or development of syringomyelia.

Additional testing such as neurophysiological evaluation may be of assistance in confirming neurological dysfunction. Torre et al.³⁹ undertook electrophysiological testing in 28 children with spinal dysraphisms and found that a combination of electrophysiological tests yielded good predictive results. Combined results from EMG and perineal evoked potentials monitoring predicted vesico-sphincter dyssynergia with 100% sensitivity and bladder dysmotility with 86% sensitivity. Perineal evoked potentials alone detected urodynamic dysfunction with 90% specificity, and EMG combined with perineal evoked potentials confirmed urological dysfunction with 79% sensitivity, yet a negative predictive value of 90%.

Surgical intervention can be divided into 2 categories—primary surgery and secondary release of tethered cord—with an overarching surgical goal of releasing the tethered cord to prevent further deterioration in urological function. For open NTDs, the surgical technique involves releasing the edges of the neural placode, reapproximating the pial edges of the placode to reform the neural tube, and creating a CSF-filled space within the dural closure. Additionally, any existing filum may be transected at the time of initial surgery. For closed NTDs such as lipomyelomeningoceles, the area of tether,

namely where the lipoma pierces the lumbosacral fascia, should be identified and released, and attempts to debulk the lipoma and reapproximate the placode should be made where it is possible. Additionally, one should create a large CSF space around the spinal cord during the dural repair to reduce the risk of retethering. Children who have undergone a primary surgery previously mentioned are at risk for a secondary tethered cord due to scarring in the postoperative site. For these patients, the goal is to release the tether by lysing the arachnoid adhesions and scar tissue that serves as the location of tether and causes urological deterioration.

Recently, prenatal intrauterine repair has been receiving increased attention. The Management of Myelomeningocele Study (MOMS) was conducted to specifically address whether this strategy had improved outcomes compared with traditional postnatal surgery, but urological function in these patients was not assessed.³ Other studies with long-term outcomes of intrauterine myelomeningocele repair have shown a range of urological outcomes. A long-term follow-up study of 28 patients who underwent fetal myelomeningocele closure demonstrated a range of urological dysfunctions in this subset (decreased bladder capacity, detrusor overactivity, and increased detrusor pressure) and no significant difference compared with individuals who underwent traditional postnatal repair.¹⁵ However, a limited number of studies have also shown an improvement in urodynamic outcome, but there are minimal data to substantiate this.¹³ Given the evolving expertise in fetal myelomeningocele closure, further investigation into the urological outcomes after intrauterine repair should be forthcoming.

Neurophysiological monitoring may be used to assist the surgeon with intraoperative planning by alerting the surgeon to changes in monitoring parameters during surgery to reduce the risk of neurological injury and iatrogenic worsening of urological function.⁵³ Total intravenous anesthesia and minimal use of muscle relaxants facilitate the use of somatosensory evoked potentials, motor evoked potentials, and EMG, both free run and stimulated.^{6,28} Monitoring frequently includes lower-extremity muscle groups and sensory distributions as well as the anal sphincter. The innervation of the anal sphincter by the lower sacral nerves (S2–5) is a good proxy for assessing bladder function integrity because of similar innervation (Fig. 2).²⁸ It is possible to monitor the external urethral sphincter by way of a special ring electrode on a Foley catheter.³⁴ However, in a pediatric population, urethral size may be prohibitive to this monitoring strategy. The combination of free-run and stimulated EMG allows for continuous EMG monitoring and assessment of structures during dissection, which may be beneficial when encountering dysmorphic neural elements.^{34,37}

The risk of a retethering in patients with spinal dysraphisms may be as low as 3% or as high as 40%, occurring most frequently in patients who underwent primary repair of myelomeningocele and resection of lipomyelomeningocele.^{10,17,27,32,47,54,56} Given this elevated risk for future neurological decline, postoperative monitoring of urological function is critical. This includes monitoring of urological function by patients and their family,

most importantly noting changes in urological function, especially in the population in which a baseline degree of function requires catheterization. Symptoms may include episodes of incontinence or changes in urinary habits. These patients should be followed up by a urologist for urodynamic evaluation, especially during periods of growth when a patient's cord is at greatest risk of injury secondary to a tether. Similar to preoperative assessment, any concern about a change in urinary function should prompt urgent evaluation, either urodynamic testing or neurophysiological testing.

Neurosurgical Outcomes

The initial goals for neurosurgical repair in open spinal dysraphism include elimination of CSF leakage, prevention of infection, preservation of neural function, and prevention of secondary tethering postoperatively. Once definitive repair is completed, the focus generally shifts to lifestyle improvements. Bowel and bladder dysfunction remains a primary morbidity concern as bladder dysfunction predisposes this group to the risks of recurrent urinary tract infections, pyelonephritis, hydronephrosis, and, in severe cases, renal failure. Given that the primary repair of myelomeningocele often occurs within the first few days of life, when no baseline urological function is known, the outcomes of interest generally arise after a patient presents with worsening urological function due to a tethered cord.

Initial surgical intervention for spina bifida has been shown to result in some improvement in urological function. In the previously mentioned study by Kumar et al.,³⁸ 42.8% of patients with open defects and 46.2% of those with closed defects experienced improvement in urological function after an initial surgical intervention. Wu and colleagues⁶⁷ reviewed data obtained in 43 patients who underwent early surgery for lipomyelomeningocele prior to manifestation of urological dysfunction; they found that 84% of the patients maintained stable function. Macejko et al.,⁴¹ however, reviewed the cases of 79 patients who underwent primary release of a tethered cord inclusive of closed defects and demonstrated that those with lipomyelomeningocele were at risk for the poorest urological outcomes after surgery. In contrast, evaluation of 36 patients with occult tethered spinal cord who underwent sectioning of the filum terminale demonstrated improvement in urinary symptoms in 72% and resolution of incontinence in 42%.⁴⁵

Surgical intervention for tethered cord manifesting with worsening urological function also demonstrates a wide range of improvement in urological function after surgery. Tarcan and associates⁵⁸ reported on 56 patients with secondary tethering after repair of myelomeningocele and evaluated outcomes after a detethering procedure. They tiered the outcomes according to the initial grade of urinary tract dilation. Individuals with Grade 1–2 dilation had an improvement in grade in 40% of the cases and complete resolution of the dilation in 33.3%. Those with Grade 3–4 dilation had an improvement in 50% of the cases and resolution in none. However, more profound improvement was noted in the degree of vesico-

Fig. 2. Intraoperative EMG tracing obtained during a tethered cord release demonstrating train activity of the anal sphincter that can be noted with manipulation of the lumbosacral nerve roots. From top to bottom: left iliopsoas/adductor, left quadriceps, left anterior tibialis, left gastrocnemius, right iliopsoas/adductor, right quadriceps, right anterior tibialis, right gastrocnemius, left anal sphincter, right anal sphincter.

ureteral reflux, which resolved in 62.5% of patients with Grade 1–3 reflux and improved in 37.5%. Patients with Grade 4–5 reflux demonstrated resolution in 33.3% and improvement in 40%. These results were most significant in children treated before the age of 7 years. In a review of 20 patients who underwent surgery for various manifestations of tethered cord, Abrahamsson et al.¹ demonstrated that in all patients with deterioration in urodynamic function prior to untethering function improved after surgery, and in 90% with stable urological function prior to surgery function, remained stable. Dushi and coworkers¹⁹ introduced a urodynamic score as a means of assessing outcome and demonstrated that the postoperative score improved in 55% of patients who presented with urological symptoms and in 86% of those who did not present with urological symptoms. As previously mentioned, these positive outcomes may be subclinical. Palmer et al.⁵⁰ reviewed the cases of 20 children who initially presented with worsening scoliosis or lower-extremity function and no discernible change in their urological function; they found that even within this group, 75% of the patients had improved urodynamic function after tethered cord release. These results are not limited to the first untethering procedure, as Maher et al.⁴² demonstrated improvement in urological function in 71% of patients who underwent multiple repeat untethering operations.

Conclusions

Spinal dysraphism and other forms of NTDs continue to be significant sources of morbidity and mortality worldwide. Until the 1950s, the probability that an infant

with a severe abnormality, such as myelomeningocele, would survive to adulthood was low. Therapeutic advancements and improvement in neurosurgical technique have drastically changed the nature of these congenital malformations. In fact, adults with myelomeningocele now account for greater health care expenditures and more hospital admissions than children with this condition.⁴⁹ Thus, the focus of treatment is rapidly shifting toward early recognition and surgical intervention, postoperative monitoring and management, and improvements in patient quality of life.

Perhaps the most critical consideration is the lifelong bladder and urinary dysfunction encountered by these patients. A wide range of clinical pathology can lead to damage of nerves of the genitourinary system, often as a result of spinal cord tethering. Without treatment, the urological sequelae are debilitating and often fatal. For the neurosurgeon involved in the care of such patients, early and frequent urodynamic testing, combined with a multidisciplinary approach involving urologists to guide management, is crucial to improve outcomes. Early detection and surgery for worsening urological dysfunction remains the mainstay for treatment of primary and secondary tethered cord to minimize the long-term effects of irreversible urological dysfunction. Although recent trials have shown promising results with prenatal neurosurgical intervention, it remains to be seen whether these techniques result in consistent favorable urological outcomes. Increasing awareness among neurosurgeons who encounter spinal dysraphisms is one of the first steps in lifelong management that can both drastically improve quality of life and lower future health expenditures.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Tomei. Acquisition of data: Amarante, Shrensel. Drafting the article: Amarante, Shrensel, Tomei. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Study supervision: Gandhi, Tomei, Carmel.

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References

1. Abrahamsson K, Olsson I, Sillén U: Urodynamic findings in children with myelomeningocele after untethering of the spinal cord. **J Urol** **177**:331–334, 2007
2. Ackerman LL, Menezes AH: Spinal congenital dermal sinuses: a 30-year experience. **Pediatrics** **112**:641–647, 2003
3. Adzick NS, Thom EA, Spong CY, Brock JW III, Burrows PK, Johnson MP, et al: A randomized trial of prenatal versus postnatal repair of myelomeningocele. **N Engl J Med** **364**:993–1004, 2011
4. Arai H, Sato K, Okuda O, Miyajima M, Hishii M, Nakanishi H, et al: Surgical experience of 120 patients with lumbosacral lipomas. **Acta Neurochir (Wien)** **143**:857–864, 2001
5. Assaad A, Mansy A, Kotb M, Hafez M: Spinal dysraphism: experience with 250 cases operated upon. **Childs Nerv Syst** **5**:324–329, 1989
6. Beyazova M, Zinnuroglu M, Emmez H, Kaya K, Ozkose HZ, Baykaner MK, et al: Intraoperative neurophysiological monitoring during surgery for tethered cord syndrome. **Turk Neurosurg** **20**:480–484, 2010
7. Birnbacher R, Messerschmidt AM, Pollak AP: Diagnosis and prevention of neural tube defects. **Curr Opin Urol** **12**:461–464, 2002
8. Blencowe H, Cousens S, Modell B, Lawn J: Folic acid to reduce neonatal mortality from neural tube disorders. **Int J Epidemiol** **39** (Suppl 1):i110–i121, 2010
9. Botto LD, Moore CA, Khoury MJ, Erickson JD: Neural-tube defects. **N Engl J Med** **341**:1509–1519, 1999
10. Bowman RM, McLone DG, Grant JA, Tomita T, Ito JA: Spina bifida outcome: a 25-year prospective. **Pediatr Neurosurg** **34**:114–120, 2001
11. Bulas D: Fetal evaluation of spine dysraphism. **Pediatr Radiol** **40**:1029–1037, 2010
12. Buyse G, Verpoorten C, Vereecken R, Casaer P: Intravesical application of a stable oxybutynin solution improves therapeutic compliance and acceptance in children with neurogenic bladder dysfunction. **J Urol** **160**:1084–1087, 1998
13. Carr MC: Fetal myelomeningocele repair: urologic aspects. **Curr Opin Urol** **17**:257–262, 2007
14. Churchill BM, Abramson RP, Wahl EF: Dysfunction of the lower urinary and distal gastrointestinal tracts in pediatric patients with known spinal cord problems. **Pediatr Clin North Am** **48**:1587–1630, 2001
15. Clayton DB, Tanaka ST, Trusler L, Thomas JC, Pope JC IV, Adams MC, et al: Long-term urological impact of fetal myelomeningocele closure. **J Urol** **186** (4 Suppl):1581–1585, 2011
16. de Jong TP, Chrzan R, Klijn AJ, Dik P: Treatment of the neurogenic bladder in spina bifida. **Pediatr Nephrol** **23**:889–896, 2008
17. Dias MS: Neurosurgical management of myelomeningocele (spina bifida). **Pediatr Rev** **26**:50–60, 2005
18. Drzewiecki BA, Bauer SB: Urodynamic testing in children: indications, technique, interpretation and significance. **J Urol** **186**:1190–1197, 2011
19. Dushi G, Frey P, Ramseyer P, Vernet O, Meyrat BJ: Urodynamic score in children with lipomyelomeningocele: a prospective study. **J Urol** **186**:655–659, 2011
20. Edelstein RA, Bauer SB, Kelly MD, Darbey MM, Peters CA, Atala A, et al: The long-term urological response of neonates with myelodysplasia treated proactively with intermittent catheterization and anticholinergic therapy. **J Urol** **154**:1500–1504, 1995
21. Gibson PJ, Britton J, Hall DM, Hill CR: Lumbosacral skin markers and identification of occult spinal dysraphism in neonates. **Acta Paediatr** **84**:208–209, 1995
22. Glazier DB, Murphy DP, Fleisher MH, Cummings KB, Barone JG: Evaluation of the utility of video-urodynamics in children with urinary tract infection and voiding dysfunction. **Br J Urol** **80**:806–808, 1997
23. González R, Schimke CM: Strategies in urological reconstruction in myelomeningocele. **Curr Opin Urol** **12**:485–490, 2002
24. Gormley EA: Urologic complications of the neurogenic bladder. **Urol Clin North Am** **37**:601–607, 2010
25. Greenberg MS: **Handbook of Neurosurgery**, ed 7. New York: Thieme Medical Publishers, 2010
26. Guggisberg D, Hadj-Rabia S, Viney C, Bodemer C, Brunelle F, Zerah M, et al: Skin markers of occult spinal dysraphism in children: a review of 54 cases. **Arch Dermatol** **140**:1109–1115, 2004
27. Herman JM, McLone DG, Storrs BB, Dauser RC: Analysis of 153 patients with myelomeningocele or spinal lipoma reoperated upon for a tethered cord. Presentation, management and outcome. **Pediatr Neurosurg** **19**:243–249, 1993
28. Hoving EW, Haitsma E, Oude Ophuis CM, Journée HL: The value of intraoperative neurophysiological monitoring in tethered cord surgery. **Childs Nerv Syst** **27**:1445–1452, 2011
29. Jansson UB, Hanson M, Sillén U, Hellström AL: Voiding pattern and acquisition of bladder control from birth to age 6 years—a longitudinal study. **J Urol** **174**:289–293, 2005
30. Kaefer M, Pabby A, Kelly M, Darbey M, Bauer SB: Improved bladder function after prophylactic treatment of the high risk neurogenic bladder in newborns with myelomeningocele. **J Urol** **162**:1068–1071, 1999
31. Kanev PM, Lemire RJ, Loeser JD, Berger MS: Management and long-term follow-up review of children with lipomyelomeningocele, 1952–1987. **J Neurosurg** **73**:48–52, 1990
32. Kang JK, Lee KS, Jeun SS, Lee IW, Kim MC: Role of surgery for maintaining urological function and prevention of retethering in the treatment of lipomeningomyelocele: experience recorded in 75 lipomeningomyelocele patients. **Childs Nerv Syst** **19**:23–29, 2003
33. Kaplan KM, Spivak JM, Bendo JA: Embryology of the spine and associated congenital abnormalities. **Spine J** **5**:564–576, 2005
34. Khealani B, Husain AM: Neurophysiologic intraoperative monitoring during surgery for tethered cord syndrome. **J Clin Neurophysiol** **26**:76–81, 2009
35. Kondo A, Kamihira O, Ozawa H: Neural tube defects: prevalence, etiology and prevention. **Int J Urol** **16**:49–57, 2009
36. Koo BN, Hong JY, Song HT, Kim JM, Kil HK: Ultrasonography reveals a high prevalence of lower spinal dysraphism in children with urogenital anomalies. **Acta Anaesthesiol Scand** **56**:624–628, 2012
37. Kothbauer KF, Novak K: Intraoperative monitoring for tethered cord surgery: an update. **Neurosurg Focus** **16**(2):E8, 2004
38. Kumar R, Singhal N, Gupta M, Kapoor R, Mahapatra AK: Evaluation of clinico-urodynamic outcome of bladder dysfunction after surgery in children with spinal dysraphism—a prospective study. **Acta Neurochir (Wien)** **150**:129–137, 2008

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39. Kuo YC, Kuo HC: Botulinum toxin injection for lower urinary tract dysfunction. *Int J Urol* [epub ahead of print], 2012
40. MacDiarmid S: The patient presenting with neurological disease affecting the urinary tract, in Norman RW, Currow D (eds): **Supportive Care for the Urology Patient**. New York: Oxford University Press, 2005, pp 163–179
41. Macejko AM, Cheng EY, Yerkes EB, Meyer T, Bowman RM, Kaplan WE: Clinical urological outcomes following primary tethered cord release in children younger than 3 years. *J Urol* **178**:1738–1743, 2007
42. Maher CO, Bauer SB, Goumnerova L, Proctor MR, Madsen JR, Scott RM: Urological outcome following multiple repeat spinal cord untethering operations. Clinical article. *J Neurosurg Pediatr* **4**:275–279, 2009
43. Maher CO, Goumnerova L, Madsen JR, Proctor M, Scott RM: Outcome following multiple repeated spinal cord untethering operations. *J Neurosurg* **106** (6 Suppl):434–438, 2007
44. McAtee-Smith J, Hebert AA, Rapini RP, Goldberg NS: Skin lesions of the spinal axis and spinal dysraphism. Fifteen cases and a review of the literature. *Arch Pediatr Adolesc Med* **148**:740–748, 1994
45. Metcalfe PD, Luerssen TG, King SJ, Kaefer M, Meldrum KK, Cain MP, et al: Treatment of the occult tethered spinal cord for neuropathic bladder: results of sectioning the filum terminale. *J Urol* **176**:1826–1830, 2006
46. Moore KL, Dalley AF, Agur AMR: **Clinically Oriented Anatomy**, ed 6. Philadelphia: Lippincott Williams & Wilkins, 2009
47. Morimoto K, Takemoto O, Wakayama A: Spinal lipomas in children—surgical management and long-term follow-up. *Pediatr Neurosurg* **41**:84–87, 2005
48. Nijman RJ: Diagnosis and management of urinary incontinence and functional fecal incontinence (encopresis) in children. *Gastroenterol Clin North Am* **37**:731–748, 2008
49. Ouyang L, Grosse SD, Armour BS, Waitzman NJ: Health care expenditures of children and adults with spina bifida in a privately insured U.S. population. *Birth Defects Res A Clin Mol Teratol* **79**:552–558, 2007
50. Palmer LS, Richards I, Kaplan WE: Subclinical changes in bladder function in children presenting with nonurological symptoms of the tethered cord syndrome. *J Urol* **159**:231–234, 1998
51. Piatt JH Jr: Treatment of myelomeningocele: a review of outcomes and continuing neurosurgical considerations among adults. A review. *J Neurosurg Pediatr* **6**:515–525, 2010
52. Pierre-Kahn A, Lacombe J, Pichon J, Giudicelli Y, Renier D, Sainte-Rose C, et al: Intraspinal lipomas with spina bifida. Prognosis and treatment in 73 cases. *J Neurosurg* **65**:756–761, 1986
53. Pouratian N, Elias WJ, Jane JA Jr, Phillips LH II, Jane JA Sr: Electrophysiologically guided untethering of secondary tethered spinal cord syndrome. *Neurosurg Focus* **29**(1):E3, 2010
54. Shurtleff DB, Duguay S, Duguay G, Moskowitz D, Weinberger E, Roberts T, et al: Epidemiology of tethered cord with meningocele. *Eur J Pediatr Surg* **7** (Suppl 1):7–11, 1997
55. Sutherland RS, Mevorach RA, Baskin LS, Kogan BA: Spinal dysraphism in children: an overview and an approach to prevent complications. *Urology* **46**:294–304, 1995
56. Tamaki N, Shirataki K, Kojima N, Shouse Y, Matsumoto S: Tethered cord syndrome of delayed onset following repair of myelomeningocele. *J Neurosurg* **69**:393–398, 1988
57. Tarcan T, Bauer S, Olmedo E, Khoshbin S, Kelly M, Darbey M: Long-term followup of newborns with myelodysplasia and normal urodynamic findings: is followup necessary? *J Urol* **165**:564–567, 2001
58. Tarcan T, Onol FF, Ilker Y, Simsek F, Ozek M: Does surgical release of secondary spinal cord tethering improve the prognosis of neurogenic bladder in children with myelomeningocele? *J Urol* **176**:1601–1606, 2006 (Erratum in *J Urol* **176** (6 Pt 1):2749, 2006)
59. Torre M, Planche D, Louis-Borrione C, Sabiani F, Lena G, Guys JM: Value of electrophysiological assessment after surgical treatment of spinal dysraphism. *J Urol* **168**:1759–1763, 2002
60. Tortori-Donati P, Rossi A, Cama A: Spinal dysraphism: a review of neuroradiological features with embryological correlations and proposal for a new classification. *Neuroradiology* **42**:471–491, 2000
61. van Gool JD, Dik P, de Jong TP: Bladder-sphincter dysfunction in myelomeningocele. *Eur J Pediatr* **160**:414–420, 2001
62. Verpoorten C, Buyse GM: The neurogenic bladder: medical treatment. *Pediatr Nephrol* **23**:717–725, 2008
63. Westney OL: The neurogenic bladder and incontinent urinary diversion. *Urol Clin North Am* **37**:581–592, 2010
64. Wiener JS, Antonelli J, Shea AM, Curtis LH, Schulman KA, Krupski TL, et al: Bladder augmentation versus urinary diversion in patients with spina bifida in the United States. *J Urol* **186**:161–165, 2011
65. Winn HR (ed): **Youmans Neurological Surgery**, ed 6. Philadelphia: Saunders, 2011
66. Wu HY, Baskin LS, Kogan BA: Neurogenic bladder dysfunction due to myelomeningocele: neonatal versus childhood treatment. *J Urol* **157**:2295–2297, 1997
67. Wu HY, Kogan BA, Baskin LS, Edwards MS: Long-term benefits of early neurosurgery for lipomyelomeningocele. *J Urol* **160**:511–514, 1998

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