Spina Bifida and Neurogenic Bladder

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1. Introduction

The most common causes of neurogenic bladder in the pediatric population are spinal neural tube defects also known as spinal dysraphisms which account for 50% of all neural tube defects followed by anencephaly. Myelomeningocele, which is a type of spina bifida cystica, is also a form of spinal dysraphism where the spinal cord (central nervous system) and meningeal membranes protrude out the back through an unfused portion of the spinal column. Another type of spina bifida cystica is the meningocele which, as opposed to the myelomeningocele only has protrusion of the meningeal membranes. Patients with neural tube defects with exposed nerve roots and spinal cord are affected and can lead to neurogenic bladder, neurogenic bowel, and varying degrees of lower extremity dysfunction. Spina bifida occulta is seen in 10-20% of people and is an isolated dorsal vertebral bony defect with normal coverage of skin and generally does not lead to any clinical issues such as neurogenic bladder. Another form of spinal dysraphism is the lipomyelomeningocele where fatty tissue abnormally attaches and tethers the spinal cord while protruding through a defect in spinal column. These are congenital anomalies that may have clinical changes over time and require constant follow-up. Regardless of the type of spinal dysraphism, and the spinal level of the defect, there is poor correlation with the clinical presentation and bladder function compromise.

Isolated incidental lower lumbar (L5) and sacral vertebral arch defects with no signs or symptoms to suggest a neurological deficit are not categorized as spina bifida and should not prompt further workup.[1] Other causes of neurogenic bladder in children include caudal regression such as sacral agenesis, and tethered cord with or without presence of other anomalies, such as imperforate anus or persistent cloaca. The presentation and clinical severity of neurological deficits is unpredictable in the latter group. It is important to not confuse neurogenic bladder secondary to spinal dysraphisms with other forms of non-neurogenic bladders such as cerebral palsy, Hinman or Ochoa syndromes.[2,3]

For the purposes of this chapter, we will focus on patients with spina bifida cystica as the most common type of spinal dysraphism. The principals of neurogenic bladder management can apply to any cause of neurogenic bladder. In this chapter we will discuss the management of pediatric neurogenic bladder during different phases from infancy to transition to adulthood. In addition, we will discuss the common reconstructive surgeries available for neurogenic bladder management in this

patient population.

1.1 Keywords

Neurogenic Bladder, Spina Bifida, Myelomeningocele, Tethered Cord, Urodynamics, Intermittent Catheterization, Anticholinergics, Bladder Neck Reconstruction, Bladder Augmentation, Continent Catheterizable Channel

2. Epidemiology

In the United States, the birth prevalence of spina bifida is around 3.5 in 10,000 births which correlates to approximately 1500 children born each year.[4] Identified risk factors include extreme maternal age and family history. Having one child with a neural tube defect, increases the risk about 50 times on a subsequent pregnancy. Other risk factors are maternal diabetes, obesity, use of perinatal valproic acid or carbamazepine. Folic acid supplementation has been shown to decrease the risk of neural tube defects including spina bifida in randomized controlled studies.[5,6] Therefore, in 1992 the CDC recommended that women of childbearing age take 400 micrograms of folic acid supplementation daily to help prevent neural tube defects including spina bifida.[7] In the United States, folic acid also started to be fortified in cereal grain products in 1996 with mandatory compliance in 1998. Regulations requiring fortification of cereal grain products with folic acid has been associated with a 30-50% decrease in birth prevalence of spina bifida.[8,9]

The level of spina bifida defect varies from cervical to sacral. Lumbosacral level spina bifida is most common at 47%, followed by lumbar (26%), sacral (20%), low thoracic (5%), and cervical or high thoracic (2%).[10] The level of spina bifida lesion affects ambulatory function significantly with most ambulatory patients being sacral or lumbosacral and most patients with high lumbar or thoracic lesions being non-ambulatory.[11] The level of spina bifida does not correlate as well with bladder function. However, those with lower-level lesions and those who are ambulatory are somewhat more likely to achieve continence.[12] The majority of cases have no evidence of bladder dysfunction at birth yet over time clinical signs may progress. If these changes are not timely detected and treated, about 60 to 80% may develop complications.[13]

3. Goals of Management

Patients with neural tube defects require a multidisciplinary approach that involves neurosurgery, physical therapy, urology, nephrology, orthopedic surgery and gastroenterology. Of these specialties, urology typically follows these patients most closely due to the constant requirements to control the neurogenic bladder. For this reason, the urology team needs to have a holistic approach to offer a better care to these patients and families. Management will depend on the type of neurogenic bladder patterns. There are four main types: 1) Overactive sphincter with overactive bladder, 2) Overactive sphincter with underactive bladder, 3) Underactive sphincter with overactive bladder and 4) Underactive sphincter with underactive bladder. These types are defined by the urodynamic and clinical assessment.

Treatment expectations and objectives vary throughout life. Initial establishment of a treatment includes understanding of the type of neurogenic bladder and initiation of therapies that protect renal function. Subsequently, initiation of measures to improve continence becomes more important for the patient and the family. This is followed subsequently with preparation for transitioning into an adult more independent life where fertility is also a key component of the treatment. The goals of pediatric neurogenic bladder management include:

1. Protect the kidneys and prevent their deterioration resulting from high bladder pressures.
2. Achieve continence.
3. Achieve independence.
4. Avoid reconstructive surgery if possible.
5. Avoid or reduce frequency of symptomatic urinary tract infections.

4. Care of Antenatal, Newborn and Young Pediatric Patients – Protect Kidney function.

Advances in antenatal detection have increased early detection of neural tube defects with the possibility of prenatal interventions that also include termination of pregnancy with rates as high as 65% of the pregnancies with detection of these anomalies. [14] Prenatal therapeutic options include early closure of the neural tube defect. This has been studied by a multicenter randomized clinical trial (MOMS) that has revealed a benefit in reducing the need for ventriculo-peritoneal shunt diversion, and reduction on lower extremity motor deficit at birth if the defect is closed *in-utero.* No benefit has been identified in postnatal bladder function preservation.[15] Another benefit from prenatal detection is the possibility to organize events related to the deliver of the child and arrange for multidisciplinary management at birth. Patients that have had their defect closed in the first 24 hours have been shown to have better bladder dynamics. [16] Parental counseling in the perinatal period, will allow them to emotionally and socially prepare to receive their newborn. This includes preparation and training on intermittent catheterizations.

Almost all newborns have a normal upper urinary tract at birth. Newborns with spina bifida will undergo closure of the spina bifida defect within the first few days of life if this was not performed prenatally. These patients often cannot lie on their back. Due to the fact that most patients with spina bifida have an associated Chiari malformation and resulting hydrocephalus, a ventriculoperitoneal (VP) shunt is often placed in the first few weeks of life as well. It is important to always remember the presence of a VP shunt when abdominal surgery is planned, including bladder augmentations of diversions to manage bladder issues. The overall VP shunt infection risk for these surgeries is 9.6%. [17]

4.1 Urology Evaluation After Spina Bifida Closure

The first goal of pediatric neurogenic bladder management is to protect the kidneys from high bladder pressures and incomplete emptying; therefore it is important to identify newborn patients who are at

risk for renal damage. Newborns with spina bifida should have a renal and bladder ultrasound obtained within the first few days of life. This is to evaluate for any hydronephrosis, renal parenchymal anomalies, and to assess the bladder appearance. Most newborns will have normal anatomy. Clinicians should be mindful about radiation exposure and avoid unnecessary studies that will not change management. Patients with spina bifida have an average cumulative effective dose of 81.9 mSv in their first 18 years. [18] Most of this radiation comes from regular head CT scans, orthopedic and urological studies. Some centers include in their protocol an early voiding cystogram to evaluate the presence of trabeculation and vesicoureteral reflux. One option for reducing the amount of irradiating studies is the use of contrast enhanced ultrasonography for these early evaluations if this imaging technique is available. These kind of studies should be performed once patients can lie on their back which may be 1-2 weeks after defect closure. Bladder emptying should be assessed in some fashion after spina bifida closure by either bladder scans or CIC every 4-6 hours. Urodynamics are typically not done until 2-4 months of age. The reason for delaying this study is to allow medullary shock to improve after closure. [19] In theory, babies with prenatal closure could get the UDS prior to discharge after sooner birth. Therefore, the decision on whether to start and continue clean intermittent catheterization (CIC) immediately after birth is based on renal ultrasound findings, VCUG or contrast enhanced ultrasonography findings, and determination of bladder residuals. Assessment of kidney function is also performed routinely at some centers to use it as a baseline. Serum creatinine or cystatin C have been used in the first week of life for this purpose. [20]

The initial management of newborns with spina bifida is highly variable.[21] Some centers will start all infants with spina bifida on CIC, some centers will start CIC initially but then stop if residual urine obtained with CIC is low, and some centers will evaluate bladder emptying in newborns with bladder scans and only do CIC if bladder residuals are high. There are some concerns that CIC in patients who do not need it will increase their risk of UTI and a more selective approach may be prudent.[22,23] Nonetheless, more recent evidence has proven CIC to be safe.[24,25]

Continuing CIC should be considered in infants who have consistently high bladder pressures or high residuals, trabeculated bladders, high grade VUR, and/or high grade hydronephrosis. A multi-institutional protocol recommends continuing CIC in newborns with spina bifida if there is grade 5 VUR, residuals consistently > 30 mL while on Q6 hour CIC, or moderate to severe hydronephrosis (≥ SFU grade 3).[26] In addition to these findings, a trabeculated and thick bladder is associated with risk of upper tract damage in infants with spina bifida and, thus, indefinite CIC should be considered in these infants as well.[23]Some infants will initially have high residuals on CIC during hospitalization after birth and be discharged on CIC but parents will report lower and lower residuals on CIC. These patients can sometimes have CIC weaned safely.

4.2 First Urology Evaluation After Discharge

If the urologist has not had the opportunity to meet with the family in the perinatal period (ideally antenatal), this is a good time to discuss the expectations and objectives of treatment. There are two approaches: expectant/conservative or proactive. Long-term follow-up studies have reported higher

rates of bladder augmentation and renal function deterioration when managed conservatively.[27] Also, bladder dynamics will vary throughout infancy, and this will require adjustments in management. The benefit of conservative management is to reduce associated morbidity that comes along with proactive management. Clinicians that support conservative management have shown high resolution rates of new-onset of hydronephrosis and reflux once CIC and anticholinergics are started.[14] Some series have shown deterioration of renal function in 5% of patients followed conservatively.[14] A major limitation of conservative management will depend on the health system in areas of the world where health care access is limited.

Definition of proactive management varies but regular urodynamics guide follow-up and management. This protocol may apply better for high-risk patients. Urodynamics and a repeat renal bladder ultrasound are typically obtained around 2-4 months of age. It is important to highlight that there are no reference values for bladder dynamics this early in life. Several urodynamic findings have been associated with risk of UTI and kidney scarring including bladder trabeculations, VUR, high storage pressures evidenced by end fill pressure or detrusor leak point pressure > 40 cm H2O, and detrusor sphincter dyssynergia.[23,26] A patient who is very low risk for upper tract damage on urodynamics will have a smooth walled bladder without VUR, low bladder residuals, and low leak point pressures.[23] The decision on when to initiate Q 4-hour CIC in the above mentioned prospective protocol is based on urodynamics at 3 months of age if there is high end fill or detrusor leak point pressures (> 40 cm H2O), evidence of detrusor sphincter dyssynergia, or grade 5 VUR.[26] In addition to Q 4-hour CIC, this protocol starts patients on oxybutynin 0.2 mg/kg TID.[26]

4.3 Urology Management During 1st Year of Life and Childhood

Follow up of spina bifida patients during the first year of life typically involves a clinic visit with assessment for any interim UTIs and renal bladder ultrasound every 3-4 months, with urodynamics often repeated around 1 year of age or sooner if clinically needed.[26] After the 1st year of life, follow up visits are typically spaced out to every 6-12 months. The need for routine urodynamics after the 1st year of life is unclear. Some centers recommend a baseline DMSA scan to establish the presence of renal scars as these scars correlate well with development of hypertension.[26] However, in patients with normal ultrasounds who do not have a history of UTIs, VUR, or trabeculated bladder the utility of routine DMSA scan is of questionable utility as these patients are unlikely to have any DMSA abnormalities.[23] Thus, following ALARA principles, many pediatric urologists reserve these studies for patients who are at greater clinical risk of renal scarring. It is good practice to evaluate clinically bladder patterns and get a voiding diary to make objective assessments. Similar with bowel dynamics. About 19% of individuals with spina bifida develop pressure ulcers. Screening for those on every visit is of great importance.[28]

It is important to remember that patients on chronic CIC are typically colonized with bacteria that cause no clinical problems. Antibiotic treatment is recommended only in symptomatic patients and use of antibiotic prophylaxis has shown no benefit. Clinically, not all urinary tract infections present with a fever and attention to atypical symptoms is important such as more frequent episodes of

incontinence and lower abdominal discomfort.

4.4 Management of High-Risk Bladder in Infancy and Childhood

It is very important to identify a high-risk bladder in infancy and quickly escalate management to protect the kidneys. [29] Approximately 30% of children with spina bifida will have a high-risk bladder.[30] A patient with a trabeculated bladder with VUR and high storage pressures has a very high risk of developing UTIs and renal damage. [23] Starting CIC and anticholinergics in these patients may prevent UTIs and renal damage.[30] The anticholinergic most commonly used is oxybutynin, 5mg/5mL elixir 0.2 mg/kg BID-QID. Oxybutynin is FDA approved for use in children with neurogenic bladder over the age of 5 and solifenicin oral suspension is approved for use in children with neurogenic bladder over the age of 2. Most other anticholinergics are used off-label in neonates and children. Early initiation of medical treatment has shown lower rates of renal function deterioration and need for bladder augmentation. [31,32] Side effects may limit dose adjustments. This can be reduced with intravesical use of anticholinergics.[33] Intravesical oxybutynin can be dosed as 0.1 – 0.8 mg/kg TID. More recent literature supports the use of β3 agonists such as mirabegron and has shown improvement in urodynamic parameters.[34,35] Mirabegron is FDA approved for use in children with neurogenic bladder over the age of 3.

Overnight Foley catheter drainage can also be started to avoid high storage pressures by keeping the bladder empty all night as well as to help prevent UTIs.[36]

4.5 Vesicostomy

In infants or young children with neurogenic bladder who have persistent UTIs or concern for upper tract deterioration, despite regular CIC, anticholinergics, and overnight catheter drainage, early and strong consideration for vesicostomy should be given. A vesicostomy is highly successful in protecting the kidneys from the bladder and CIC and anticholinergics can usually be stopped. [37,38] Risks of vesicostomy include bladder prolapse and stomal stenosis. Eventually, the vesicostomy is typically taken down and a bladder augmentation with other reconstructive surgeries can be done at the same time as vesicostomy take down. We typically recommend waiting until at least age 5 before considering taking down the vesicostomy and obtaining a urodynamic study prior to this to evaluate for persistent of VUR, bladder size, and bladder compliance. Management of VUR with ureteral reimplantation has not shown any benefit and should rarely be considered. Because these patients typically have high outlet resistance, a bladder outlet procedure is generally not needed at time of vesicostomy take down and augmentation cystoplasty with resulting high continence rates.

5. Childhood – Continence

The goal of protecting kidneys remains the primary goal of pediatric urologists in childhood but the goal of achieving bowel and bladder continence becomes important as children age. Some children will already be on CIC and anticholinergics and already be continent of urine. A small percentage of children will be able to void on their own and achieve continence and these patients typically are

ambulatory with sacral level spina bifida. It is critical to proactively manage ambulatory patients as there is a poor correlation between bladder function and lower extremity mobility. Variability in the definition of continence makes interpretation of literature difficult. Nonetheless, reports describe overall continence between 5 to 37% of cases. [39] When the definition is “completely dry”, reports describe an overall rate of 25%.[40,41] However, many patients after infancy will still be incontinent either managed by diaper drainage or by CIC with or without anticholinergics. Prenatal closure of spina bifida may be associated with increased likelihood of voiding spontaneously for continence with one recent abstract reporting volitional voiding in 24% of those with prenatal closure compared to 4% of those with postnatal closure. [42]

5.1 CIC and Anticholinergics

In those who have not yet started CIC to protect kidneys and cannot achieve continence with voiding, starting CIC with anticholinergics for continence is considered. The typical age range to start CIC for continence alone is age 2-5. [29] Most families will prefer to be on a CIC program before starting kindergarten so children will be accustomed to CIC before a school nurse would be doing some of the catheterizations. Typically, CIC is started at a frequency of every 3-4 hours during the day. No catheterizations are done at night as long as there are no issues with recurrent UTIs or upper tract changes. If leakage persists in between catheterizations, anticholinergics can be started. Children at this age generally cannot swallow pills and are started on oxybutynin 5mg/5mL 0.2 mg/kg BID-QID. Other options for anticholinergics in children who cannot swallow pills include solifenacin oral suspension, mirabegron oral suspension, and topical anticholinergics such as oxybutynin chloride 10% gel. If leakage persists in between catheterizations, increasing CIC to every 2 or 2.5 hours is an option. As children get older and are able to swallow pills, they are typically switched to longer acting oral anticholinergics in pill form such as oxybutynin extended release (Ditropan XL®), tolterodine (Detrol®), fesoteradine (Toviaz®), solifenacin (Vesicare®), or darifenacin (Enablex®). Of note, only oxybutynin is FDA approved for use in children, but the others are commonly used in this population. There is some evidence that some of the newer oral anticholinergics may have lower side effect profile in children than oxybutynin. [43,44] Mirabegron is a β-3 adrenoceptor agonist that has a different mechanism than anticholinergics and therefore has a different side effect profile with lower risk of typical anticholinergic side effects such as dry mouth and constipation but some risk of hypertension. There is limited data in pediatric spina bifida patients on its efficacy and effect on urodynamic findings, but it is another option to consider and it is FDA approved for use in children over the age of 3. [45,46]

5.2 Botulinum Toxin

The use of intra-detrusor botulinum toxin is an option for children who are not able to achieve urinary continence with CIC and medications. Intra-detrusor botulinum toxin is FDA approved for the management of neurogenic bladder in pediatric patients over the age of 5. Typically, most studies performed in the pediatric population have a dosing protocol of 10 units/kg with a maximum of 300 units of botulinum toxin. These are distributed in 10 to 20 injections to cover the entire detrusor

muscle. Intra-detrusor botulinum toxin does improve urodynamic parameters for continence such as bladder capacity, bladder compliance, and end fill pressures. [47] Reported continence rates for pediatric patients vary widely from 30%-100% and typically injections need to be repeated every 6-12 months and in most cases under general anesthesia. [47]

5.3 Bowel Continence

Patients with spina bifida typically have neurogenic bladder and neurogenic bowel. Therefore, bowel continence is an important aspect of management during childhood as well. The bowel regimens used for continence vary widely between different centers.[48,49] Many centers use a combination of a stool softener/laxative and something to promote bowel emptying. Commonly used stool softeners/laxatives include senna and polyethylene glycol. Common methods to promote bowel emptying include timed toileting, suppositories, enemas, and cone enemas. The Peristeen® system is a method of retrograde trans-anal enemas/irrigation with similar goal to trans-anal cone enema. [50] A typical bowel regimen in an older child at our center would include senna around noon and then something to promote emptying such as a suppository or cone enema 6-8 hours later.[51] Finding a successful bowel program may take a lot of trial and error and a motivated family. Surgical management in these patients includes the creation of an antegrade continence channel to start patients on regular enemas. This has shown significant improvement in QoL scores. [41]

6. Older Childhood to Adolescence – Independence

As a child gets closer to adolescence, privacy and independence become more important to them and their families. Depending on fine motor function, presence of any developmental delays, and ambulatory ability; achieving independence can be simple to not possible. Therefore, achieving independence is a highly individualized process. Obesity is a very common comorbidity in patients with spina bifida, especially in those who are not ambulatory.[52,53,54] This can negatively affect the ability of patients to achieve independence with self-catheterization and attention to this common comorbidity is warranted. [54]

With regards to bladder management for patients utilizing CIC, an ambulatory female with good manual dexterity may be able to use a small catheter contained in a discrete tube to catheterize per urethra and empty into a toilet. An example of this type of catheter would be a Coloplast Speedicath® Compact. Ambulatory males may be able to catheterize themselves and empty directly into the toilet standing or sitting. Patients who are non-ambulatory may have more difficulty with independence with CIC. Some non-ambulatory patients can transfer themselves to the toilet and catheterize but others rely on help from caregivers for all transfers. Males who are non-ambulatory can catheterize while in wheelchair and empty bladder into a urinal or use extension tubing attached to catheter to empty bladder into a toilet. Females who are non-ambulatory generally need to be transferred to a toilet or a bed for catheterization. A mitrofanoff channel in the form of an appendicovesicostomy or Monti channel may be considered in patients with difficultly or inability to catheterize per urethra specifically for more independence. With regards to bowel management, percutaneous cecostomy

tubes and antegrade enemas are often successful in achieving fecal continence and patient independence. [55]

7. Transition to Adulthood

As survival for patients with spina bifida has improved, there is increasing focus on the successful transition of care from pediatric providers to adult providers.[56,57] Babies with major congenital anomalies of the genitourinary tract have all-embracing holistic care during childhood and they require the same level of care in adult life. Persistent care in a pediatric hospital is not an ideal option, yet in a survey of academic pediatric units in the US, there were 60, 000 adult admissions from 1999 - 2008, with a 6.9% annual increase.[58]

Transition is defined as a process that ensures high-quality developmentally appropriate health care services are available in an uninterrupted manner as the patient moves from adolescence to adulthood (see Core Curriculum: **Transitional Care**). The goal of a planned health care transition is to maximize lifelong functioning and well-being for all youth, especially those who have special health care needs. Transition can mean moving from a pediatric to an adult provider or moving from a pediatric to adult model of care with the same provider. Transition also encompasses preparing the patient for self-care and independence with medical care and activities of daily living. Most pediatric patients can find a high level of multidisciplinary care at a pediatric hospital, but adults with the same conditions can fall through the medical “safety” net and struggle to find quality care. Reasons for this include lack of insurance, poor social support, knowledge deficits, and lack of specialists with interest in this population. Despite these barriers appropriate transition is extremely important for this patient population as it has been previously documented that patients who fail to transition to reliable adult care are at much higher risk of kidney damage, UTIs, sepsis, and stones all potentially preventable conditions that lead to increased morbidity and mortality and increases in healthcare costs. [59]

Several centers have created transitional urology clinics to help facilitate this period of transition with varying degrees of success.[60,61,62] Previous reports have found that lack of insurance coverage and type of insurance (public vs private) are some of the main barriers to successful transition and thus recommend the use of social work and financial counseling services routinely in the transition process. [62]

Caring for an adult patient with neurogenic bladder is within the scope of general urology in the United States. The transition from a pediatric urologist to an adult urologist is a highly individualized process. For some patients it may be quite simple with little to no effort required and for some patients successful transition may be extremely difficult. An ambulatory patient who is continent on CIC and anticholinergics, does not have history of reconstructive surgery or upper tract changes, and has private insurance will likely be able to transition to an adult urologist easily. This type of patient may just need to be encouraged to reach out to urologists in their area and make an appointment. On the other hand, a patient who has a history of bladder augmentation and some upper tract damage, has issues with recurrent UTIs and incontinence, and has private insurance may have a difficult time finding an adult urologist near them who is willing to take on their care but could likely

find a urologist at a tertiary care center. However, if this same complex patient had government insurance, it is even more difficult to find a urologist willing to take on their care. Some counties in the United States have well organized safety net hospital systems that have urology clinics associated with a urology residency that can take care of these patients while many do not.

Got Transition is an excellent resource with tools for patients and providers in the transition process. A potential timeline for transition is as follows:

- Age 12: Make youth and family aware of transition policy
- Age 14: Initiate health care transition planning
- Age 16: Pre you and parents for model of care and discuss transfer
- Age 18: Transition to adult model of care
- Age 18-22: Transfer care to an adult provider with transfer package

Age 23-26: Integrate young adults into adult care. The goals of management of adults with spina bifida include preservation of renal function, to maintain or improve bowel and bladder continence, monitor for sequelae of neurogenic bladder, including urinary tract infections, calculi and malignancy, and to prepare for sexuality and fertility. [63] Patients should be followed at least annually with a renal bladder ultrasound with consideration for urodynamics for any upper tract changes or new urinary incontinence.[64] In addition, though patients with congenital bladder anomalies do have an increased risk of bladder cancer, cystoscopy and cytology do not appear to be effective screening tests for bladder cancer in this population and thus should be reserved for patients with gross hematuria, recurrent UTIs, new urinary incontinence, and/or new pelvic or perineal pain.[65]

8. Symptomatic Tethered Cord

Essentially, all children with spina bifida have a tethered spinal cord due to scarring after initial closure of the spina bifida defect. Approximately 25% of children with spina bifida will develop signs and symptoms concerning for a symptomatic tethered cord and will undergo a subsequent tethered cord release. [66,67] It has been previously reported that the risk for subsequent tethered spinal cord release is not related to functional lesion level and is lower among non-ambulators and those with treated hydrocephalous and higher in those who have undergone prior Chiari decompression and who are community ambulators.[68]

Changes in bladder function can be a sign of a tethered cord as well as changes in lower extremity function or back pain.[66,69] Findings such as new incontinence, urodynamic parameter changes, such as worsening compliance or more neurogenic detrusor overactivity, as well as new bladder trabeculations or VUR, can be potential signs of symptomatic tethered cord.[67,69] The diagnosis of symptomatic tethered cord can be difficult to make and there are risks and potential benefits with the detethering surgery, so the decision process of whether to undergo a detethering surgery is difficult and individualized.[70,71]

9. Reconstructive Surgery

In general, there are two reasons to consider reconstructive surgery for the neurogenic bladder in children. The first is to protect the upper tracts from damage particularly in the setting of a high pressure non-compliant bladder despite maximal medical management with CIC and anti-cholinergic therapy. The second is to improve bladder and bowel continence and independence (aka “social continence”) when non operative interventions have failed. Reconstructive surgery to protect the upper tracts may sometimes be necessary but reconstructive surgery to improve continence and independence is always optional and the decision to proceed with this should be driven by the patient and family.

There are 4 main categories of reconstructive surgery:

1. Procedures to increase bladder size and compliance
2. Procedures to increase bladder outlet resistance
3. Catheterizable channels
4. Antegrade enemas

Which surgeries from each of the three categories that a patient needs is individualized and based on bladder dynamics and urodynamics findings, upper tract findings, ambulatory and functional status, and patient and family preferences. For example, some patients may only need one of the three types of reconstructive surgery while other patients may require all three.

9.1 Procedures to Increase Bladder Size and Compliance

Children with neurogenic bladder due to spina bifida may present with a classic picture of a small capacity poorly compliant bladder. Although such patients may achieve success with protecting their upper tracts and achieving continence with anti-cholinergic medications and CIC as described above, the bladder pressures may still be high enough that upper tracts are affected due to poor drainage or VUR leading to recurrent pyelonephritis and ultimately resultant renal dysfunction or failure. It is generally accepted that a detrusor leak point pressure of greater than 40 cm of H20 places the patient at risk of upper tract deterioration. [72] In cases such as these, when more conservative measures fail to achieve safety for upper tracts or continence, surgical intervention should be considered to address the hostile bladder.

9.1.1 Cystoscopy with Injection of Botulinum Toxin

Botulinum toxin has been used as a muscle paralytic with varying success for many neurologic conditions that result in increased muscle tone or spasticity.[47] As noted above, cystoscopy with direct injection into the detrusor muscle can effectively inhibit detrusor contraction. This in turn can decrease overall bladder pressure and improve compliance as well as the frequency and amplitude of bladder contractions. This can be effective in addressing pressures that put the upper tracts at risk while sometimes providing enough of an effect to achieve continence as well.[47] Typically, 200 to 300 units of botulinum toxin A is drawn up in 20cc of saline. This is injected in a grid like pattern of 10 to 20 injections over the detrusor muscle. In children this procedure is typically performed under general anesthesia but the minimally invasive nature of the procedure allows patients to return home the day

of surgery and risks are limited. However, if successful, the effect is usually limited to 6-12 months thereby making repeat injections necessary. As of February 2021, intra-detrusor botulinum A toxin injections are FDA approved for children over age 5 with detrusor over-activity associated with a neurologic condition.

9.1.2 Bladder Augmentation

Bladder augmentation is another option to increase bladder volume and compliance, with or without a procedure at the bladder neck to increase outlet resistance. Typically augmentation cystoplasty is performed by utilizing a detubularized and reconfigured bowel segment as a patch-graft over a widely opened bladder (**Figure 1**). Although stomach has been used historically, this has largely been abandoned due to the published reports of the development of adenocarcinoma in the augmented bladder, as well as hematuria-dysuria syndrome, in these patients. Other options include ileal, ileocecal, or colonic bowel segments as well as ureter. Today, bladder augmentation is usually performed with ileal or sigmoid bowel segment depending on the surgeon's preference and mesenteric length.[73] The bowel augment solves two problems with a hostile neurogenic bladder. First, the added volume gives more time for the bladder to fill between catheterizations before pressures rise and/or leakage occurs. Second, the bowel wall has more elasticity than a stiff neurogenic bladder which improves compliance. Therefore, both safety and continence are addressed.

With these benefits come the future potential complications of small bowel obstruction, bladder stones, increased risk of UTI, and even bladder rupture in the case of an overfilled bladder.[74] To reduce the risk of bladder stones after augmentation daily bladder irrigation is recommended. In addition, minimally invasive and robotic approaches for bladder reconstruction have been described which may reduce complications and expedite recovery. [75]

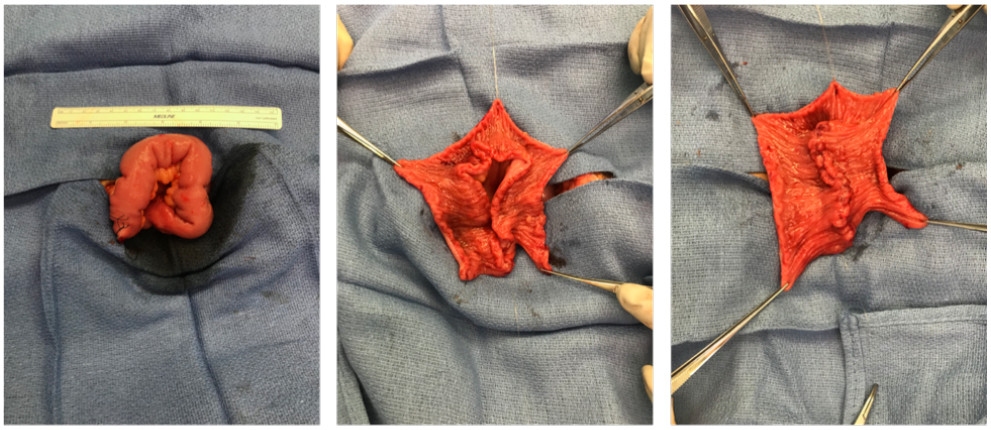

Figure 1. The ileal bowel segment for the augment is harvested (A), detubularized (B), and reconstructed into a U-shaped patch graft (C) to be sewn onto the bladder.

Figure 1

9.2 Procedures to Address Low Bladder Outlet Resistance

Although urinary incontinence can result from a high pressure and low compliance bladder in the patient with spinal dysraphism, low outlet resistance can contribute to the same outcome even if the bladder itself is of good capacity and compliance. In order to determine this, outlet resistance can be measured on urodynamic testing by assessing leak point pressures and presence of bladder trabeculations. If the Valsalva leak point pressures are low and the bladder has a smooth walled appearance, especially in the setting of clinical history of stress incontinence, the low outlet resistance should be addressed as part of any intervention to improve continence. This can be done at the time of bladder augmentation or, in the case of a large compliant bladder, independently. Care should be taken to ensure that there is adequate compliance and volume before raising the outlet pressure without doing a bladder augmentation in the neurogenic bladder. Often times it can be difficult to assess compliance in the setting of a low outlet pressure. In the case where a bladder outlet procedure without bladder augmentation is done in a small noncompliant bladder the outcomes are frequently poor in patients with spinal dysraphism, resulting in continued incontinence with multiple additional procedures, or worse yet, upper tract deterioration. [76] Surgical options to address low bladder outlet resistance include bladder neck reconstruction, bladder neck slings, bladder neck bulking agents, urethral slings, bladder neck closure, and artificial urinary sphincters.

9.2.1 Bladder Neck Reconstruction

Commonly, a formal urethral reconstruction and/or concomitant bladder neck sling is performed to address an open bladder neck with low outlet resistance in children. Multiple forms of bladder neck reconstruction have been described and typically involve excisional tapering and lengthening of the bladder neck (e.g. Young Dees Leadbetter type) or construction of a detrusor tube for urethral lengthening with or without ureteral reimplantation. [77,78,79] Results have varied with dryness achieved in 58-81% of patients. However a majority of patients also underwent bladder augmentation and catheterizable channel indicating the necessity of an adequate bladder reservoir and frequent difficultly in performing CIC per urethra after bladder neck reconstruction. [79]

9.2.2 Bladder Neck Slings/Wraps

In contrast, bladder neck slings require no incision of the bladder neck while raising outlet resistance by circumscribing the urethra just below the bladder and typically elevating it towards the superior ramus. Various materials can be used to construct slings including autologous rectus fascial grafts, xenografts, and synthetic materials. [79] Slings may allow for continued catheterization via the urethra though many reports emphasize the necessity of simultaneous bladder augmentation due to the risk of upper tract deterioration with increasing bladder outlet resistance. [79] A sling can also be performed at the same time of a formal reconstruction in order to suspend the bladder neck and enhance outlet resistance as well. As with bladder neck reconstructions a catheterizable channel may also be required. Outcomes vary with continence rates ranging from 35-88%. [79]

9.2.3 Bladder Neck Bulking Agents

A more minimally invasive method of addressing poor resistance at the bladder neck is injection of a

bulking agent trans or peri-urethrally which can, in theory create more effective anatomic resistance at the outlet. Various substances can be used including bovine collagen, autologous fat or chondrocytes, polydimethylsiloxane, stem cells and dextranomer/hyaluronic acid (Deflux).[79] Unfortunately the efficacy of this procedure is debatable with continence rates ranging from 20 to 60% of patients and success often decreasing over time.[79,80,81] While some authors have reported success with repeated injections to achieve dryness, others have found no improvement after a second injection.[79] Bladder neck injections can also be considered after prior failed bladder neck sling or bladder neck reconstruction.[79] Unfortunately, due to the poor success rates and lack of long term efficacy some authors suggest it not be considered as a primary treatment to achieve dryness in children with neurogenic sphincter incompetence. [79]

9.2.4 Urethral Slings

Mid-urethral transvaginally placed slings are another minimally invasive option to raise urethral resistance in patients with neurogenic bladder. There is far less literature in support of this approach due to the fact that historically most slings in this population have been placed at the bladder neck through an abdominal incision. Slings placed more distally from a perineal or vaginal approach are reasonable options in patients that are older and don't need a concurrent bladder surgery. These procedures were initially utilized in females with non-neurogenic stress incontinence who void spontaneously. However, the use of mid-urethral slings in patients with neurogenic bladder aims at creating an obstruction and therefore CIC is usually needed. [79] In these cases the outcomes can be favorable with prior literature reporting a 92% continence rate after pubovaginal sling placement in females with neurogenic incontinence.[82,83] Due to the risk of erosion with mesh slings, autologous fascia, xenograft, or synthetic materials should be considered for slings placed in children and young adults.

9.2.5 Bladder Neck Closure

In cases where prior bladder neck sling, injection, or reconstruction have failed or are unlikely to successful, surgeons can consider complete closure of the bladder neck. Of course this must be concomitantly performed with a catheterizable channel and strong consideration should be made for bladder augmentation as well due to the previously reported risk of renal deterioration in isolated bladder neck procedures.[76]

9.2.6 Artificial Urinary Sphincter

Artificial Urinary Sphincter Article urinary sphincter (AUS) placement is another option for treatment of low outlet resistance in children with neurogenic urinary incontinence. In neurogenic patients this has been reported to be performed with sphincterotomy to enhance emptying but AUS is also reported to be compatible with CIC. Continence has been reported anywhere from 54 to 100% of patients.[79,84] Consideration must also be made for the unique complications of AUS including infection, erosion, and mechanical failure.

9.3 Catheterizable Channels

9.3.1 Catheterizable Channel for CIC

Many patients with spina bifida or other causes of neurogenic bladder have impaired mobility, making catheterization of the urethra difficult. As mentioned above, this is particularly true for females who are non-ambulatory and full time wheelchair users. Continent catheterizable channels with direct access to the bladder through an abdominal stoma can make CIC a more practical option in someone who is unable to catheterize per urethra independently. In addition, procedures at the bladder neck can make urethral catheterization difficult to impossible necessitating the creation of abdominal access to the bladder. Two channels are commonly used—the appendicovesicostomy (APV) [85] and tubularized intestinal catheterizable channel (Yang-Monti).[86] **(Figure 2)**

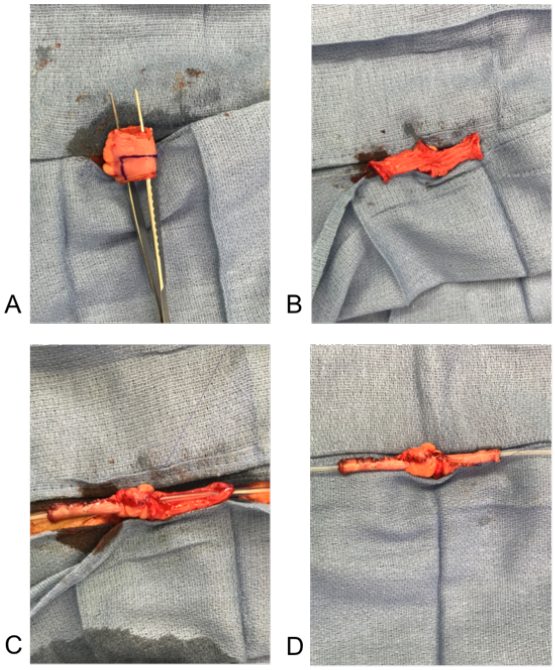

Figure 2. The Yang-Monti Channel (spiraled). A 2cm segment of small intestine is harvested (A) and detubularized in an offset fashion (B). Reconstruction over a 12F catheter (C and D).

Figure 2

An APV is performed by harvesting the appendix while maintaining its blood supply. A tunneled anastomosis is created within the bladder wall as a continence mechanism while the other end is brought to the umbilicus or right lower quadrant as a catheterizable stoma. While an APV has been reported to have less complications than a Monti channel, families must be prepared for either as the appendix may not always be suitable for use as a catheterizable channel. If there is no appendix available, or if the appendix is being used as an antegrade continence enema or is too short or not patent, a short segment of small bowel or colon can be used to fashion a tube as described above for catheterization. The APV has been demonstrated to have fewer complications and better long term outcomes however it is not always an option and a Yang-Monti channel creation will be necessary. [87]

9.3.2 Antegrade Continence Enema (ACE)

Bowel continence is often just as problematic in patients with neurogenic bladder as urinary

incontinence. If a patient needs to be in a diaper for bowel accidents, valiant and invasive measures to achieve urinary continence are difficult to justify. There are many bowel regimens that can be utilized to attain fecal control which have been described, including dietary regimens, medications, and retrograde enemas all of which can be very successful. In some cases an antegrade enema can be useful in order to provide mechanical evacuation of stool from the proximal colon which may not be effectively cleared by retrograde techniques. Antegrade enemas may also be beneficial for patient independence, especially in the case of full time wheelchair users who may find transferring and administering a retrograde enema difficult. Options include an appendicocecostomy which can be created by pulling the distal end of the appendix to the skin for daily catheterization and irrigation.[88] If the appendix isn't available, another option is to place a cecostomy tube, mini-ACE cecostomy button, or create a tubularized ileal segment which can be used in a similar fashion. Opinions and results vary in terms of continence and some families can be dissatisfied if there is leakage from the stoma or recurrent issues with stomal stenosis.

10. Conclusion

The management of pediatric neurogenic bladder is something with which all urologists should be familiar. From infancy to adulthood, the most important goal is to protect the kidneys. If a child develops concerning findings such as upper tract changes or recurrent UTIs, quick escalation of care to protect the kidneys should be done. As children age, achieving continence and independence become important goals in addition to protecting the kidneys. CIC, medication, and selective use of reconstructive surgery are used to achieve these goals. The transition of these patients from pediatric urologists to adult urologists is highly individualized but all urologists are trained to care for patients with neurogenic bladder.

Presentations

Spina Bifida and Neurogenic Bladder Presentation 1

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