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**Spina Bifida: lumbosacral myelomeningocele**

**Introduction**

Spina bifida (SB) is known as a neural tube defect, because the caudal neural tube fails to close during the fourth week of embryogenesis.1,2The three most common types of spina bifida are myelomeningocele, meningocele, and spina bifida occulta.3 Myelomeningocele (MMC), the most severe form of spina bifida, involves protrusion of the spinal cord and meninges through a defect in the vertebral arch,2 and will be the focus of this review.

**Epidemiology**

 Many epidemiology studies look at spina bifida together with other neural tube defects. Neural tube defect (NTD) is a general term for a congenital malformation of the CNS due to lack of closure of the neural tube.4 The two most common neural tube defects are anencephaly, or lack of closure in the head region, and spina bifida, or lack of closure below the head.4 The prevalence of neural tube defects in the U.S. and many European countries is estimated to be 0.5-0.8/1000 births, whereas it is reported to be over 20 times higher in some areas of China.5 In the United States, there are around 1,500 babies born with spina bifida each year,6 but estimates of NTDs worldwide are as high as 140,000 cases per year.5 Within the U.S., differences have been observed between racial groups as well, as Hispanics have a higher spina bifida prevalence than non-Hispanic whites, whose prevalence is also higher than African Americans.5 Out of the three types of spina bifida, myelomeningocele is the most common, accounting for more than 90% of spina bifida cases.4

**Pathology of MMC**

Because the neural tube fails to close in the embryonic spinal region, the open neural tube is exposed to the amniotic fluid environment.5 At the beginning, the bifid neuroepithelium experiences relatively normal neural differentiation, with development of spinal sensory and motor function distal to the level of the lesion.5 However, neurons die due to toxicity of the amniotic fluid and the exposed spinal cord becomes hemorrhagic as gestation continues.5 Axonal connections end up being interrupted and the result is a loss of function.5 Because of this, MMC is considered to be a “two-hit” process, with an initial failed neural tube closure and subsequent neurodegeneration in utero.5

 Both genetic and non-genetic factors contribute to neural tube defects. Heritability is estimated at 60-70%, with the highest risk factor for spina bifida being a history of previous affected pregnancy with the same partner.1,5 Few genes have been identified, despite extensive research in mouse models.4,5 Other established risk factors for spina bifida include inadequate maternal intake of folic acid, pregestational maternal diabetes, and in-utero exposure to anticonvulsant drugs such as valproic acid or carbamazepine.1

**APTA Guide Patterns**

The *APTA Guide to Physical Therapist Practice* identifies two practice patterns related to individuals with spina bifida:

5B: Impaired Neuromotor Development7

5C: Impaired Motor Function and Sensory Integrity Associated with Nonprogressive Disorders of the Central Nervous System – Congenital Origin or Acquired in Infancy or Childhood7

**Body Functions/Structures**

The impairments and resulting effects on body structure and function in lumbosacral myelomeningocele vary according to spinal lesion level, as well as secondary complications presenting in the following systems:

1. *Musculoskeletal:* Asymmetrical motor loss below the level of the lesion is common.8 Assessing motor function is necessary in order to predict mobility and determine the need for bracing.8 Lower limb weakness or paralysis can prevent walking in some with MMC.5 Possible orthopedic issues include clubfoot, hip dislocation, contractures, kyphosis, and scoliosis.5 Muscle weakness can result in abnormal positioning in utero, leading to clubfoot (calcaneovalgus, equinovarus, or vertical talus) in 50% of babies with MMC.8 Individuals with L3-L5 lesion levels typically present with a pronounced crouch gait with hip and knee flexion contractures, increased lumbar lordosis, genu and calcaneal valgus alignment, and a pronated foot during weight bearing.9 Those with sacral lesions may walk with a mild crouch gait and have mild hip and knee flexion contractures with the foot and ankle either in varus or valgus, in addition to a pronated or supinated forefoot.9 The crouch postural deviation occurs across lesion levels due to soleus muscle weakness, as well as orthopedic deformities, such as calcaneal valgus, which leads to tibial internal rotation and knee flexion.9 The hip and knee flexion contractures are secondary due to the adaptive shortening of muscles over a prolonged period.9 Crouch standing and gait increase demands on the musculoskeletal system and can negatively impact function, and should therefore be addressed during intervention.9 Subluxed or dislocated hips occur in 25 to 50% of infants with high or mid-lumbar lesions, with another 25% becoming unstable in early childhood.8 Asymmetric hips can lead to secondary issues resulting from pelvic obliquity, such as seating problems, pressure sores, and scoliosis.8 Finally, congenital scoliosis occurs in 15 to 25% of infants with SB, but scoliosis can also be acquired in early school age and progress quickly during puberty.8 Kyphosis is most common in lumbar MMC, and like scoliosis can interfere with sitting, walking, and respiratory function.8 The combination of flaccid musculature and decreased loading of the long bones due to altered mobility results in decreased bone mineral density and often leads to osteoporotic fractures.9 Fractures often go unnoticed initially due to lack of sensation, but then present subacutely with swelling and warmth at the fracture site and a low-grade fever.9

1. *Integumentary:* Asymmetrical sensory loss below the level of the lesion is also common and sensory levels often don’t correlate with motor levels.8 Lack of sensation in these individuals increases the risk of pressure sores, so patients should be educated on skin inspection and pressure relief techniques.5 Decubitus ulcers and other types of skin breakdown occur in approximately 85 to 95 percent of all children with MMC by the time they are young adults.9 The risk for perineal decubiti and breakdown is greater for those with higher-level lesions, but lower limb skin breakdown is the same for all lesion levels.10 Causes of skin breakdown can include tissue ischemia from excessive pressure, friction and shear, burns, skin maceration from urine and stool soiling, and excessive weight bearing over bony prominences of the pelvis due to obesity or spinal deformity.10 It’s important to make individuals with MMC aware that their sensory deficits can affect their balance and then teach them how to compensate by using other senses, such as vision.9 Finally, up to 73% of children have been reported to have latex allergies that can lead to life-threatening anaphylaxis,11 so it’s important to avoid latex products and educate the patient and family on which everyday products can contain latex.
2. *Cardiopulmonary:* MMC can lead to kyphoscoliosis, which can decrease pulmonary function and compromise respiratory function.12 A study by Ronchi et al.12 found that maximum respiratory pressure values were significantly lower in the MMC group than the control group, indicating children with MMC have reduced respiratory muscle force. As to be expected, a higher the lesion level was associated with more compromise, as seen by a lower maximum expiratory and inspiratory pressure.12 Decreased caloric expenditure and cardiovascular fitness leads to obesity in greater than 20% of school-aged children with MMC.8 Obesity can significantly inhibit mobility and result in additional health complications. In a study by Buffart et al.13 42% of individuals with MMC showed a cluster of at least two risk factors for cardiovascular disease. Another study revealed that 32% of individuals with SB had metabolic syndrome, which is an established predictor of death from coronary heart disease and cardiovascular disease.14
3. *Neuromuscular:* MMC affects sacral parasympathetic nerves that innervate the muscular walls of the urethra, bladder and rectum, and are vital to sexual function.8 In addition, the sympathetic nerves controlling the bladder outlet are usually involved.8 Bowel and bladder dysfunctions present in almost all individuals with MMC, along with differing degrees of sexual dysfunction.8 Effective bladder intervention for most individuals is setting up a regularly timed schedule for voiding through clean intermittent catheterization.9 Young children should be taught to catheterize themselves, with mastery typically occurring around 6 to 8 years old.9 Most with MMC have Chiari II malformation, where the cerebellum herniates downward through the foramen magnum, with associated hydrocephalus.5,8 Out of those with Chiari II malformations, 80% with sacral lesions and over 90% with higher-level lesions require a shunt.8 Chiari II malformations can present with apnea, swallowing difficulties and stridor in a newborn baby.1 In older children, symptoms of Chiari II malformations can include balance and coordination difficulties, headache, quadriparesis and scoliosis.1 It’s important to be aware of the signs of shunt failure, which presents as rapidly enlarging head circumference and swelling or redness along the shunt track in infants and toddlers.8 In young children the signs are more subtle and insidious and include a headache, irritability, lethargy, and vomiting, mild drowsiness and impaired attention and coordination.8 Tethered cord can also cause neurologic deterioration in children with MMC. Normally during growth, the spinal cord ascends within the canal and the conus medullaris moves from L4 to L2 by puberty, however, in spina bifida, the abnormal cord can become tethered to scar tissue or bony deformities, resulting in ischemic damage.8 Signs and symptoms of tethered cord are most common around 6 to 12 years old and include back and leg pain, spasticity, increasing scoliosis, deterioration of walking, progressive foot deformity, and deterioration of bowel and bladder function.8 Infants and children with MMC can have muscle tone ranging from spastic to normal to flaccid.9 Most individuals with SB without hydrocephalus or with uncomplicated hydrocephalus have normal intelligence, with trends toward higher intelligence scores in lumbar and sacral lesion level groups than in thoracic groups.1,9 However, specific language difficulties and learning disabilities are common and can have a negative effect on their ability to do well in school, the workforce, and live independently.1 Children with MMC may have limitations with organization, executive functions, working memory, problem solving, and attention, with many maintaining a diagnosis of ADD or ADHD.8

**Activity, Participation and Quality of Life**

 The level of injury and resulting degree of motor preservation will determine if the child is able to ambulate or will rely on a wheelchair as his or her primary means of mobility. Those with high lumbar lesions may eventually stand upright and walk with significant support of the ankles, knees and hips.8 Those with mid-lumbar MMC may be able to ambulate with braces and crutches initially, but as they get older will gradually rely more on wheelchairs for mobility.8 Forearm crutches and bracing above the knees is usually required for those with L3 paralysis, and children with lesions at the sacral level are usually able to walk by 2 to 3 years old with the help of AFOs.8 Depending on the lesion, a child could have significant activity limitations, including stair climbing, indoor and outdoor ambulation, independent transfers, and self-care activities such as bathing or dressing.15

 Children with spina bifida are at risk for decreased participation in community activities, which can negatively affect their life satisfaction and preparation for critical adult roles.16 A study by Kelly et al.16 used the Children’s Assessment of Participation and Enjoyment (CAPE) to compare participation in children with spina bifida according to age differences, family characteristics, and SB-related factors, such as hydrocephalus, motor level, ambulation, medical issues, and bladder/bowel needs. When comparing young children (ages 2-5), school-aged youth (ages 6-12) and adolescents (ages 13-18), adolescents participated in less recreational, physical and skill-based activities.16 Participation did not differ by caregiver marital status, caregiver education or the child’s gender, but those whose caregivers were employed did participate more frequently in social actvities.16 As to be expected, children without a shunt participated more often in skill-based and physical activities, and those without recent major medical issues participated more in physical and social activities.16 Barriers to participation due to bowel and bladder needs were the most prevalent for youth ages 6 to 12 years old as compared to younger children and adolescents.16 Another study by Peny-Dahlstrand et al.17 used the School Function Assessment to assess participation of children with spina bifida in school-related activities. When compared to their peers, children and adolescents with SB have lower self-esteem and less friends, and adolescents and young adults are at risk for being socially isolated.17 The authors also found that the students had a high level of participation for structured activities, but their level of active participation was low, especially in the recess and playground settings.17 This is consistent with other studies that have discussed the cognitive functional profile of children with SB, noting that these children tend to be successful in everything that is guided but have more problems acting on their own initiative.17 This shows that one feasible way to improve participation in these children with SB is to educate teachers on the importance of structured activities during recess, as children with SB not only have some motor deficits, but issues with processing as well.

 As to be expected, children and adolescents with spina bifida have a reduced health-related quality of life (HRQOL) compared to those without spina bifida, and this is due to many factors.5 A study by Schoenmakers et al.18 found that mental ability, good muscle strength, and being independently mobile were significantly more important for quality of life and daily function than other medical indicators of myelomeningocele. Other predictors of HRQOL include presence of shunted hydrocephalus, pain levels, parenting stress, and other family factors.5 Compared to their healthy peers, children with SB tend to present with lower levels of self-concept and more depressive symptoms during late childhood.5 Children with spina bifida often experience social difficulties that extend into young adulthood and many tend to be more dependent on adults for guidance, which can negatively affect their quality of life.5 A range of 43 to 77% of individuals with SB live with their parents, and only 52 to 68% have had a romantic relationship.5,19 Romantic relationships, employment, and financial independence are areas of lowest life satisfaction.19 Most individuals with SB lack knowledge regarding sexuality because their parents are less likely to discuss this with them.5 This lack of knowledge, combined with the high obesity rate and continence issues in SB can be significant barriers to attempts to form romantic relationships.5

**Personal and Environmental Factors**

Studies have shown that neural tube defects occur more frequently in children whose mothers are of low socioeconomic status (SES).4,20 Lack of education, which is often closely related to low SES, can also play a role in increasing the risk of having a child with a neural tube defect. One study by Grewal et al.20 found that women who did not graduate from high school and lived in neighborhoods of low socioeconomic status presented with a significantly higher risk for a NTD pregnancy than those who had completed high school or higher education. It’s suggested that the reason for this is because mothers with higher education or of higher social groups are more likely to use folic acid in the period of neural tube closure during pregnancy.21

 A study by Bloemen et al.22 looked at personal and environmental factors associated with improved participation in physical activity in children with SB. Important personal factors included self-efficacy, competence in skills, bowel and bladder care, sufficient fitness and medical events.22 Environmental factors that influenced participation and success included contact with and support from other people, adequate information regarding possibilities for adapted sports, accessibility of playgrounds and sports facilities, and the use of assistive devices for mobility and care.22 An important environmental factor affecting daily activities is handicap accessibility in the community and available paratransit services, allowing those with SB to get to their medical appointments.23 Parental intervention in order to save time can be a barrier to autonomy, and is particularly important in the performance of personal care as the child gets older.23 Barriers to housing include architectural barriers, low income, and governmental policies that deny access to adequate housing when one of the roommates does not have a disability.23 Personal factors such as fear, anxiety, and lack of confidence often contribute to children limiting their learning and goals for their future.23 Parental encouragement, efforts to integrate their children into regular school settings, and open-minded academic personnel are all factors that help facilitate learning and participation.23 In terms of employment, negative personal and environmental factors include negative attitudes of employers, inability to drive or lack of paratransit services, the need to take regular breaks on the job due to lack of bowel or bladder control and learning disabilities.23

**Medical Intervention**

 In terms of initial medical management, the spinal lesion is typically surgically closed within 48 hours of birth.1 Hydrocephalus usually doesn’t manifest until a few days after surgical closure, in which case a shunt is placed; however, if imaging studies confirm the presence of ventriculomegaly early on, a shunt can be placed at the same time the lesion is closed.1 A fetal surgery team at Vanderbilt performed the first in-utero repair for MMC in 1997. Since then, a 7 year clinical trial funded by the NIH titled Management of Myelomeningocele Study (MOMS) has compared fetal surgery before birth and surgical closure after birth.24 In-utero surgery has shown significant success, with a decreased need for shunting, reversal of hindbrain herniation, and preservation of neurologic function.24 At 30 months of age, 42% of the fetal surgery group was walking independently compared to only 21% of the postnatal surgery group, even though the fetal surgery group was comprised of higher and more severe MMC lesions.5 Although the results from this study favor in-utero surgery, there are significant risks related to premature birth that accompany the fetal surgery, which should be factored into the mother’s decision.5

**Physical Therapy Intervention**

 Walking onset for children with MMC is usually delayed an average of 2 years when compared to their typically developing peers.25 The likelihood that an infant will walk is affected by the lesion level, with a 20% chance of walking given to those born with a high-lumbar lesion, an 80% change for those with a low-lumbar lesion, and a 90% chance if the lesion is at the sacral level.25 Even with the ability to walk early on, many children have to transition to using a wheelchair for community mobility by late childhood or early adolescence.25 While there is extensive research showing that early gait therapy provides a better prognosis for independent ambulation in adults with spinal cord injury, there is no general agreement on best management of infants with MMC.26 This may be because with MMC the injury comes very early in development, whereas in SCI patients, the trauma is introduced to a well-developed neuromuscular system.26 Healthy infants are spontaneously very active, while infants with MMC have decreased leg movements, which slows their rate of improving neuromotor control.25 This can contribute to delays in acquiring functional motor skills and even nonfunctional behavioral responses, such as supported stepping.25 The idea is that treadmill training would assist the development of leg control in infants with MMC and expose them to an environment that encourages increased cycles of leg activity and patterns of movement related to walking.25

 A study by Teulier et al.25 compared infants with lumbar and sacral MMC to typically developing (TD) infants by testing them on a treadmill at ages one, three, six, nine, and twelve months for twelve 20-second trials. The authors wanted to know whether infants with MMC are able to increase their step rate or motor activity level when supported on a motorized treadmill the first year after birth.25 They also assessed the quantity and quality of stepping through measuring step rate, interlimb stepping patterns and stepping parameters. The results indicated that the treadmill practice was successful in eliciting steps in infants with MMC (14.4 steps/minute), but less so than in typically developing infants (40.8 steps/minute).25 Infants with MMC had similar step parameters to the TD infants, but their interlimb stepping was less readily alternating.25 The study also showed that holding infants with MMC on a moving treadmill resulted in a 17% increase in motor activity during the year when compared to holding the infants on a nonmoving treadmill,25 which suggests that this may be a superior method to improving motor activity in these patients than overground gait training. This study shows that during the first year of life, supporting infants with MMC upright on the moving belt of a treadmill elicits stepping patterns and leads to improvements in overall motor activity, but will still not be able to put them at the level of their TD peers. The study did not state when these infants with MMC achieved the motor milestone of walking, so there is no way to know whether or not this treadmill training led to earlier ambulation.

 Another study by Pantall et al.26 also examined infants 2 to 10 months of age with lumbar and sacral MMC while supported on a motorized treadmill, but also added enhanced sensory inputs during the trials, including visual flow, unloading, weights, Velcro, and friction. There was no control group of typically developing infants. Increased friction by covering the treadmill belt with Dycem and enhancing visual flow by using a checkerboard pattern on the treadmill belt significantly increased step rate compared to baseline, especially for the older group.26 In addition, friction and Velcro increased stance phase duration, as it helped maintain greater foot contact after touchdown, but many babies lacked the strength needed to pull their feet off the Velcro on the belt.26 Adding weights may have increased proprioceptive input, but led to poor results because the babies lacked the physical strength to overcome the added mass.26 Those in the older group with the lowest lesion levels had a greater response to all enhanced sensory conditions than to baseline.26 Enhanced sensory input had very little effect on leg activity when the infants with MMC were not stepping.26 This study adds to the study by Teulier, indicating that if treadmill training is incorporated into an infant’s treatment program, sensory inputs of increased friction and enhanced visual flow should also be used to improve results.26

 More research needs to be completed with larger sample sizes and include follow-up to determine if the improvements in motor activity and stepping while on a moving treadmill can have lasting effects, such as earlier ambulation. The results from these studies seem promising, but other than these small studies there is not a significant amount of research on this topic in infants with lumbosacral myelomeningocele. There are many important impairments and functional limitations to address in infants with MMC because so many systems are involved. Because of this and the fact that the current level of evidence for treadmill training is relatively low, I would not make treadmill training a priority, but may consider it as an adjunct to therapy if there is additional time and the equipment is available in the PT clinic.

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