INTRODUCTION

Nature of the Problem

There are several pediatric neuromuscular disorders (pNMDs), such as cerebral palsy (CP), myelomeningocele, spinal cord injury, chromosomal abnormality, acquired brain injury, acquired and hereditary neuropathy, myopathy, and motor neuron disorders that all share common complications. Immobility and weakness are the primary etiologies for most of these commonly seen conditions. Musculoskeletal complications in pNMDs include hip dysplasia with associated hip subluxation or dislocation, neuromuscular scoliosis, and osteoporosis and resulting fractures. Constipation and gastroesophageal reflux (GER), along with obesity and malnutrition, are commonly

KEYWORDS

- Pediatric neuromuscular disorder
- Nutrition
- Constipation
- Scoliosis
- Hip dysplasia
- Sleep

KEY POINTS

- Children with pediatric neuromuscular disorders suffer from common complications.
- The complications are related to immobility and weakness.
- Scoliosis, hip dysplasia, and osteoporosis are common musculoskeletal complications.
- Constipation, gastroesophageal reflux, obesity, and malnutrition are common gastrointestinal complications.
- Disordered sleep affects both the children and their caregivers.
- Screening for these common complications can lead to healthier children with pediatric neuromuscular disorders and a resulting higher quality of life.
experienced gastrointestinal (GI)-related complications. Disordered sleep also is frequently observed, and this affects not only the patients but also caregivers.

MUSCULOSKELETAL COMPLICATIONS

Musculoskeletal complications, such as limb contractures, hip dislocation or subluxation, and scoliosis are common in pNMDs (Table 1). They contribute to increased disability due to decreased motor performance, mobility limitations, reduced functional range of motion, loss of function for activities of daily living (ADLs), decreased quality of life (QOL), and increased pain.

Scoliosis in pNMDs leads to multiple problems, including poor sitting balance, difficulty with upright seating and positioning, pain, and preclusion of the ability to sit upright in a wheelchair. Screening for spinal deformities is important because it can have several clinical implications. Unfortunately, spinal deformity is neither preventable nor responsive to nonsurgical modalities such as bracing. Unlike idiopathic scoliosis, neuromuscular scoliosis almost always progresses. Early detection and screening are crucial for proper and ideal management of scoliosis.

The Adam forward-bend test is the primary screening test for neuromuscular scoliosis and should be performed on all patients with pNMDs. The screening examination is performed by having the patient bend forward as far as possible, flexing the cervical and thoracolumbar spine. If a patient is unable to stand, this can be performed in the seated position. Some patients will require postural support if they are unable to sit independently. The patient is viewed from behind focusing on the rib cage. The examiner is looking for one side of the rib cage to be higher than the other next to the vertebral column. The convex side of the scoliosis is the side with the rib hump. In obese patients, smaller curves can be missed, especially in the lower lumbosacral spine.

If a spine curve is detected or the patient’s body habitus precludes the test’s sensitivity, spinal radiographs should be performed. Anteroposterior (AP) and lateral spinal radiographs with the patient either sitting or standing, based on the individual’s function, are generally sufficient. On the AP film, the Cobb angle is measured. Serial measurements should be performed using the same anatomic landmarks to ensure comparable measurements (Fig. 1).

Hip subluxation and dislocation due to hip dysplasia are frequently encountered in children with pNMDs. Hip dysplasia is a condition of the hip that may be present at or shortly after birth with inadequate acetabular formation. At birth, neonates have a shallow acetabulum. As they grow, the acetabulum usually deepens and contours around the femoral head. When infants have decreased muscle tone, strength, and movement, the acetabulum remains shallow due to the reduced force applied to the acetabulum by the femoral head. Hip dysplasia is most commonly seen in pNMDs

<table>
<thead>
<tr>
<th>Musculoskeletal Complications</th>
<th>Cerebral Palsy</th>
<th>Myelomeningocele</th>
<th>Duchenne Muscular Dystrophy</th>
<th>Spinal Cord Injury</th>
<th>Charcot-Marie-Tooth</th>
<th>Spinal Muscular Atrophy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scoliosis, %</td>
<td>38–64</td>
<td>20–94</td>
<td>63–90</td>
<td>100 *</td>
<td>10</td>
<td>70–100</td>
</tr>
<tr>
<td>Hip dysplasia, %</td>
<td>2–60</td>
<td>1–28</td>
<td>35</td>
<td>29–82</td>
<td>6–8</td>
<td>11–38</td>
</tr>
</tbody>
</table>

a If injured before adolescent growth spurt.

with congenital or early-onset paresis, such as myelomeningocele, CP, congenital myopathies, congenital muscular dystrophies, and spinal muscular atrophy types 1 and 2. The presence of hip dysplasia predisposes children with pNMDs to progress toward hip subluxation and eventually dislocation. The primary physical examination maneuver screening for hip subluxation or dislocation is the Galeazzi sign or Allis sign. The maneuver is performed by laying the patient supine, flexing the hips and knees, and examining the knee heights. If the knees are not at the same level, the test is positive. The pathologic side is the lower knee height and subluxation is often associated with decreased hip abduction range of motion (Fig. 2). In the setting of complete dislocation, hip abduction can be reduced, normal, or excessive. If the Galeazzi sign is positive, an AP radiograph of the pelvis should be obtained.

In addition to joint complications, bone health also is significantly affected in pNMDs. There are several factors contributing to poor bone health in pNMDs, such as decreased mobility, muscle weakness, and medication side effects, such as glucocorticoid treatment for Duchenne muscular dystrophy (DMD). The consequences of osteoporosis in pNMDs can be long-bone fractures and vertebral compression...
fractures that can result in bone pain and a reduced QOL. Fractures can occur with minimal trauma, such as during transfers or with rotation, such as forearm supination to start a peripheral intravenous line. Osteoporosis is more severe in nonambulatory children with pNMDs. Sufficient vitamin D levels are required for normal skeletal development and mineralization. A recent study found that 97% of children with myelomeningocele had vitamin D levels in the insufficient range (<30 ng/mL) and 48.5% had levels less than 10 ng/mL. There was a significant correlation between serum 25-hydroxyvitamin D (25(OH)D) and osteoporosis, concluding that vitamin D supplementation may be helpful. There is insufficient evidence that weight-bearing activities are an effective intervention to improve bone density; however, there is also inadequate evidence to support the use of vitamin D supplementation to decrease fractures. A general rule is to supplement with double the recommended dietary allowance amount for age (Table 2). Serum levels of 25(OH)D should be screened in late winter, as levels reach their nadir in the northern hemisphere due to shortened daylight and the supplemental vitamin D3 (cholecalciferol) dose should be adjusted accordingly to achieve the desired level.

Pediatric neuromuscular disorders are associated with a number of associated musculoskeletal complications. Careful screening can lead to earlier detection. Detection often results in proactive responses, which may limit the progression of the complications and reduce the negative impact on QOL.

**GASTROINTESTINAL COMPLICATIONS**

Several factors contribute to GI complications in pNMDs. Constipation, GER, and dependence for feeding can lead to malnutrition. Conversely, obesity can result due to decreased caloric needs.

Constipation is almost invariably in children with mobility impairment. The reliance on a wheelchair for mobility increases the risk of constipation. More than 50% of children with severe generalized CP and almost half of boys with DMD experience constipation after transitioning to full-time wheelchair use. The decreased physical movement and reduced time upright results in a slower GI transit time. This results in increased time in the colon for water absorption, which results in hard, dry stool. The Bristol scale has been developed to communicate stool texture and assess constipation.

Prescription or over-the-counter medications are often necessary to prevent or minimize the symptoms of constipation. Polyethylene glycol 3350 (PEG 3350) is a colorless, odorless, and nearly tasteless compound that can be added to most fluids to help regulate constipation associated with immobility. The primary mode of action is thought to be through the osmotic effect of polyethylene glycol 3350, which causes water to be retained in the colon and limits the increased reabsorption of fluid due to the decreased transit time. Because PEG 3350 prevents the formation of hard stool,

<table>
<thead>
<tr>
<th>Age</th>
<th>RDA Dose, IU</th>
<th>Starting Dose, IU</th>
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</thead>
<tbody>
<tr>
<td>0–6 mo</td>
<td>200</td>
<td>400</td>
</tr>
<tr>
<td>7–12 mo</td>
<td>260</td>
<td>500</td>
</tr>
<tr>
<td>1–8 y</td>
<td>1000</td>
<td>2000</td>
</tr>
<tr>
<td>9–18 y</td>
<td>1300</td>
<td>2500</td>
</tr>
</tbody>
</table>

**Table 2**

**Vitamin D3 (cholecalciferol) dosing**

**Abbreviation:** RDA, recommended dietary allowance.
it is better used for prophylaxis, as opposed to treatment of already present severe constipation. Stimulants, such as bisacodyl or enemas, can be necessary if a patient has acute constipation or fecal impaction. Adequate fluid intake is necessary to minimize constipation. Dietary fiber supplementation may be a useful, but requires adequate hydration to ensure a softer stool texture. Inadequate hydration along with fiber supplementation can result in large amounts of hard stool.

The most ideal nutrition management and caloric needs of children with pNMDs is not known. Poor nutrition in pNMDs is of 2 spectrums: hypoalimentation and hyperalimentation. Causes of hypoalimentation are multifactorial, including severe dysphagia, gastroesophageal dysmotility, delayed gastric emptying, prolonged meal time due to neuromuscular weakness, and dependent feeding. Hyperalimentation is caused by decreased caloric needs due to decreased mobility without associated modifications to diet, guilt on behalf of caregivers resulting in lack of caloric restraints, abundant access to high-caloric foods, and medications resulting in appetite stimulation, such as corticosteroids for the treatment of DMD.

Increased body fat percentage as well as decreased lean tissue mass in individuals with pNMDs in comparison with anthropometrically similar controls has been confirmed by multiple investigators.\(^8\)–\(^{13}\) Age, height, weight, and body mass index (BMI) are often used to estimate caloric needs in the general population. BMI is not an appropriate index in neuromuscular disorders because it greatly underestimates the amount of fat mass in comparison with the general population.\(^{11}\),\(^{12}\) Most equations using anthropometrics to estimate caloric need are based on able-bodied subjects. Using the same information to estimate caloric needs in pNMDs results in an overestimation of calories. Similarly, clinicians strictly relying on the appearance of an individual with pNMDs to estimate caloric needs is problematic. Given the increased body fat in pNMDs, a low BMI may still represent a body composition with increased body fat percentage. For example, based on the dual-energy X-ray absorptiometry data from the author’s previous publications, to achieve a similar body fat percentage as a 10-year-old able-bodied boy at the 50th percentile weight-for-age, a boy with DMD would be below the 10th percentile weight-for-age.

The authors of the consensus statement for standard of care in spinal muscular atrophy (SMA) also concluded that BMI is not an adequate measure of obesity or underweight, and a normal BMI for age likely does not represent the ideal weight for children with SMA. There is altered body composition in children with SMA, and despite being significantly underweight based on standard age, weight, and height growth charts and percentiles, the children may have adequate fat mass.\(^{14}\)

The resting energy expenditure (REE) in pNMDs has been measured in several studies.\(^{15}\)–\(^{21}\) The development of obesity in children with DMD is not primarily because of a low REE but because of other causes, such as a reduction in physical activity and/or overfeeding. Similar trends have been observed in CP. Nonambulant children with CP have significantly lower total energy expenditures, which is largely due to decreased activity levels.\(^{19}\)–\(^{21}\)

Interventions are required for unintentional weight gain or loss. Metformin has been used for weight management in obese patients with pNMDs, and has shown positive effects on weight management and reduced metabolic syndrome. Metformin is dosed as low as 425 mg daily in younger children and can be increased up to 1000 mg two times daily.\(^{22}\) Undesirable weight loss is often due to dysphagia; therefore, medications are not as effective. The primary intervention for malnutrition is a feeding tube, but daily supplemental shakes are often implemented before placing a feeding tube.

Individuals with pNMDs have different nutritional needs in comparison with the general population. Clinicians must guide patients and families to promote good
nutritional management to prevent malnutrition and obesity. The physical and psychological impact of nutrition and feeding on children and their families should not be overlooked. Excessive weight gain can lead to decreased functional mobility as well as increased caregiver burden. As mealtimes increase due to orofacial weakness, less time is available for other recreational activities. The inability to self-feed can make children with pNMDs seem more dependent than their peers. It also can lead to a feeling of loss of control for patients.

DISORDERED SLEEP

Severe sleep disorders are present in more than 75% of children with pNMDs. There are many components contributing to disordered sleep, including poor initiation and poor maintenance of sleep. Neuromuscular restrictive lung disease and hypoventilation, poor bed mobility, body positioning discomfort due to scoliosis and/or contractures, adjustment to a breathing apparatus such as a bilevel positive airway pressure mask, and abnormalities of the central nervous system with resulting abnormal circadian rhythms can all disrupt sleep.

The normal sleep cycle consists of 5 stages of sleep divided into 2 categories: rapid eye movement (REM) and non-REM sleep. Non-REM includes stages 1 to 4. Stage 1 non-REM is the initiation of sleep and generally lasts 15 to 30 minutes. Stage 2 non-REM is intermediate sleep or alpha rapid-wave sleep and accounts for approximately 50% of total sleep time. Stages 3 and 4 are restorative sleep or delta sleep and are usually 15% to 20% of total sleep time. Stage 5 REM sleep is when dreaming occurs. The stages typically cycle every 90 minutes throughout the night.

Physical treatments, such as alternating pressure mattress overlays and adjustable beds to decrease pressure, may help alleviate some of the sleep disturbances; however, medications are often needed to promote adequate sleep.

Several studies in children report that melatonin may be beneficial for sleep, but the effectiveness of melatonin depends on dose, the individual sensitivity of the patient, and the time of administration. Very few adverse effects have been reported. Conversely, one randomized controlled trial of melatonin found children gained little additional sleep on melatonin. Although they fell asleep significantly faster, their waking times became earlier.

It is generally accepted that efforts should be made to avoid antihistamines and benzodiazepines for long-term sleep management and should be limited to only intermittent use. Although they may increase total sleep time, the effects are generally due to increases in stage 2 sleep but decreases in stages 3 and 4. There is also a development of tolerance to the sedation side effects, which renders the medications less effective over time.

An alternative approach is to use the side effects of commonly prescribed medications, such as baclofen dosed nightly. The sedation side effect can be more pronounced when dosed only nightly. Neither baclofen nor tizanidine interrupt the normal stages of sleep while still providing some degree of sedation to aid in both sleep initiation as well as sleep maintenance. In addition, the antispasmodic effects can reduce tone and discomfort contributing to improved sleep maintenance.

Sleep disturbance is a common problem in children with pNMDs. Effective physical and pharmacologic treatments are needed to ameliorate the sleep problems. Melatonin is the most assessed and safest pharmaceutical choice for pNMDs, but trazodone and mirtazapine are also widely used and appear to be effective. Both trazodone and mirtazapine are labeled as antidepressants, they both contribute to
improved sleep initiation and maintenance without disrupting the restorative stages of sleep and are generally safe and well tolerated.\textsuperscript{30}

**SUMMARY**

There are several common complications associated with pNMDs, primarily influenced by decreased mobility. Scoliosis, hip dysplasia, osteoporosis, constipation, nutrition, and sleep are frequently problematic. Early detection and/or addressing these issues should lead to healthier children living with pediatric neuromuscular disorders and a resulting higher QOL not only for the patients but also their caregivers.

**REFERENCES**


