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Key Points

- Progressive neurologic and muscle diseases can cause progressive and severe scoliosis.
- These diseases commonly affect the pulmonary and cardiac systems, which need to be considered when managing the scoliosis.
- Early intervention in Duchenne muscular dystrophy is recommended to optimize cardiac and pulmonary function.
- Pelvic obliquity is commonly associated with scoliosis, and in many cases, pelvic fixation is recommended.
- Segmental fixation is recommended in the osteopenic bone commonly found in patients with neuromuscular scoliosis
- New methods of treating early-onset neuromuscular scoliosis are being evaluated including growing rods, VEPTR, and Shilla technique, but further studies are needed to determine its efficacy.

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13.1 Duchenne Muscular Dystrophy

Duchenne muscular dystrophy (DMD) is an X-linked inherited disorder isolated to the dystrophin gene causing an absence in the protein dystrophin [1]. DMD is usually first diagnosed by the age of 5 years. Initial complaints by parents include delayed walking, clumsiness, or flat feet. It has been suggested to screen any boy not walking by 18 months for DMD [2]. A later concern by parents, usually at age 4 or 5 years, is their son's inability to keep up with his peers or increased difficulty climbing up stairs. Other clinical findings seen on examination include pseudohypertrophy of the calves, proximal muscle weakness, Achilles and iliotibial band contractures, and a positive Gowers' sign.

In suspecting the diagnosis of DMD, the initial laboratory test is evaluating serum levels of creatine phosphokinase (CK). The diagnosis is then confirmed by genetic testing. In the remaining one-third of patients, a muscle biopsy is needed to specifically assess the quantity and quality of dystrophin present.

13.1.1 Spinal Deformity

Spinal deformity is the most critical orthopedic issue for the patient with DMD. The incidence of scoliosis is about 95 %. The onset of spinal deformity usually occurs at the same time that patients lose the ability to walk between the ages of 10 and 14 years. The risk of progression of scoliosis is also very high. Smith et al. reviewed the natural history of 51 patients with DMD and scoliosis who had no surgical treatment and were followed until their death [3]. Seventeen of these patients had curves greater than 90°. The mean rate of progression was 2.1° per month. In many cases, the curves continued to progress until the rib cage contacted the ilium.

The spinal deformity associated with DMD differs from the deformity seen in adolescent idiopathic scoliosis (AIS). The rate of progression is greater in muscular dystrophy patients [4, 5]. Unlike the typical hypokyphotic or lordotic

patient with AIS, most progressive scoliosis in DMD patients is kyphotic in the sagittal plane. Wilkins and Gibson suggested two types of spinal deformity in DMD [6]. The more stable deformity is associated with an extended position, while the unstable pattern is characterized by a progressive kyphosis [6, 7]. Oda et al. also utilized sagittal alignment to help differentiate the deformity in DMD into three types, recommending surgery for the kyphotic deformities [8].

Considering that scoliosis develops once the patients becomes wheelchair bound, screening is not needed while the patient is ambulatory. However, once the patient is unable to walk, radiographic screening should occur every 6 months.

13.1.2 Medical Considerations

In addition to the orthopedic manifestations, there are considerable medical complications associated with DMD. The problem that is most concerning for the spine surgeon is the progressive worsening of pulmonary function. Muscle weakness, contractures, and spinal deformity result in a restrictive disease pattern. This progressive decline typically occurs in the second decade of life, worsens with increasing age, and ultimately leads to the patient's death [9–11].

Kurz et al. strongly suggested that age and curve severity negatively affect pulmonary function [4]. Forced vital capacity peaked when the patient became unable to stand. Each year of age following this then resulted in a forced vital capacity decline of 4 %. If the patient developed scoliosis, an additional decline of 4 % occurred for every 10° of thoracic scoliosis. A study by Yamashita et al. also supported the relationship of scoliosis and pulmonary function [12].

Since age and thoracic scoliosis were the best predictors of pulmonary decline in their study, Kurz et al. recommended early surgical intervention in the DMD patient [4]. Others have also made similar recommendations. Galasko et al. demonstrated slightly improved survival and maintenance of forced vital capacity for the first 36 months in those patients that underwent

surgery before progression occurred [13]. Rideau et al. found static vital capacity at 2 years in five surgically treated DMD patients [14]. Recently, Velasco et al. supported spinal stabilization, demonstrating a significant decrease in the rate of respiratory decline post-surgery compared with pre-surgery rates [15].

Some authors have contradicted the positive effects of surgery on pulmonary function. Their studies found no significant difference between the surgical and nonsurgical group in terms of declining respiratory function [16–18]. Kennedy et al. demonstrated a similar decline in forced vital capacity of 3–5 % per year in both operative and non-operative patients [19]. The criticism of this study was that the surgical patients had severe scoliosis with pulmonary function too poor to benefit from surgery [20]. A recent Cochrane Review by Cheuk et al. was unable to give an evidence-based recommendation regarding the effect of surgery on pulmonary function since no randomized controlled clinical trials have been performed [21].

Prior to any spinal surgery, preoperative pulmonary function tests should be performed. Typical problems encountered included prolonged intubation and the need for permanent tracheotomy. Recently, studies have suggested that with aggressive postoperative pulmonary management, patients with low forced vital capacity could successfully undergo spinal fusion [22, 23]. Of the 45 patients prospectively collected, Harper et al. found no difference in outcomes between patients with a forced vital capacity greater than 30 % compared with those less than 30 %. We recommend that if spinal fusion is contemplated, early intervention should be performed before further decline in pulmonary function. Short ventilatory assistance followed by early extubation and aggressive pulmonary management minimize the risk of atelectasis and pneumonia.

Patients with DMD should also undergo a cardiac evaluation including echocardiogram. Cardiac involvement includes cardiomyopathy and conduction abnormalities [16, 24, 25]. In those patients with severely reduced cardiac function that cannot be controlled pharmacologically, surgery may not be an option.

Similarly to other myopathies, there is an increased risk of malignant hyperthermia in DMD [26, 27]. In extreme cases, patients have died intraoperatively from sudden cardiac arrest. Typically, anesthesiologists refrain from using anesthetics that trigger malignant hyperthermia. Awareness of the risk will maximize the preparedness of the entire team for these medically complicated patients.

13.1.3 Nonsurgical Management of Scoliosis

Spinal deformity in the DMD patient rarely develops in the ambulatory patient. Therefore, close screening of these patients should begin when the patient begins using the wheelchair fulltime. In those rare cases when scoliosis develops in the ambulatory patients, bracing should not be utilized. It has been suggested that bracing is ineffective and may end the ability to walk [20]. For the non-ambulatory scoliosis patient, bracing has also been discouraged. Multiple published reports have shown that while there is a decrease in the rate of progression, orthotics do not prevent the development of severe scoliosis [2, 28].

Since Drachman demonstrated positive outcome in the use of steroids for the treatment of DMD, there has been increasing work in investigating the effects on scoliosis [29]. Corticosteroids have been found to stabilize muscle strength for a period of time [30]. A recent Cochrane Review found evidence to support the use of steroids to improve muscle strength and function in the short term (6–24 months) [31]. However, it is not completely clear whether this will have any change in the management of scoliosis. Some studies have suggested that similarly to bracing, steroids can delay the progression of scoliosis [32, 33]. A previous prospective study compared 30 DMD patients treated with deflazacort with 24 similar control patients. While they suggested that steroids slowed the progression of scoliosis, they were unable to demonstrate the prevention of spinal deformity [33]. More recently, Lebel et al. compared long-term follow-up of ambulatory

DMD patients receiving deflazacort versus those not receiving the glucocorticoid [34]. At this long-term follow-up, they found that 20 % in the deflazacort group had developed scoliosis compared to 92 % in the non-treatment group. Currently, there are no data to support corticosteroids as a long-term option for the management of scoliosis. However, based on recent literature, it may be beneficial in the prevention of scoliosis. In addition, the use of steroids has to be balanced with the potential complications including weight gain, behavioral problems, fracture, glucose intolerance, gastrointestinal symptoms, skin changes, and cataracts [30, 31].

13.1.4 Surgical Management of Scoliosis

Posterior spinal fusion (PSF) and segmental spinal instrumentation (SSI) are the standard surgical treatments of DMD. For a patient with documented progressive scoliosis that can tolerate surgery, there is little controversy for the need for surgical stabilization. The goal is to maintain sitting balance and patient mobility and minimize the effect of scoliosis on pulmonary function. Due to the high likelihood of developing scoliosis, some authors have suggested performing procedures when patients lose the ability to ambulate [3]. This time period is when patients have maximum lung function and are most fit to withstand surgery from a pulmonary standpoint. Most authors, however, recommend surgery with radiographic evidence of scoliosis at about 20–30° [20, 35–37].

With the development of SSI by Luque, there have been major improvements in the surgical stabilization of DMD patients [38, 39]. SSI has improved the fixation in otherwise osteopenic bone and has minimized the need for prolonged immobilization. Currently, surgeons continue to effectively use the more traditional sublaminar wires with unit rods, while others have equal success with more modern instrumentation such as hooks or pedicle screws [40].

There is little controversy where the fusion should begin. It is recommended that the instrumentation should extend into the upper thoracic

spine, typically at T2 [11, 20, 36]. Stopping short of this may allow for cephalic progression of the curve due to progressive trunk and neck muscle weakness, causing the patient to lose head control.

The caudal extent of the fusion, however, continues to have some controversy. Specifically, should the instrumentation end at L5 or the pelvis? Fixation to the pelvis is technically more demanding, increasing both operative time and the potential risk of complications [41, 42]. Sussman suggested that spinal fixation to L5 was sufficient in the early treated patients [37]. Mubarak et al. similarly concluded that instrumentation to L5 was sufficient if treatment was early when there was minimal pelvic obliquity (<15°) [36]. They prospectively followed 12 patients with fusion to the sacrum and 10 patients with fusion to L5 only. The mean follow-up was 7 years. Fusions to the pelvis took an additional 30 min longer. Review of the patients' sitting balance and postoperative pelvic obliquity demonstrated only minor differences between the groups.

Sengupta et al. evaluated fixation to L5 utilizing modern pedicle screws and compared them to standard Galveston fixation or L-rod configuration to the pelvis [41]. The minimum follow-up was 3 years. The pedicle screw group had a mean preoperative curve of 19.8° and pelvic obliquity of 9°. The pelvic group had a mean preoperative curve of 48° and pelvic obliquity of 19.8°. The pelvic group was about 2.5 years older at the time of surgery. The authors documented improved correction of the major curve and pelvic obliquity in both groups. They also acknowledged the difference in deformity between the two groups. Their conclusion was that pedicle screw fixation to L5 provide a solid foundation for those patients that undergo surgery when performed early with minimal pelvic obliquity.

Other studies have recommended fusing to the pelvis at the initial time of surgical intervention [43–47]. Patients are healthiest at the first surgery. Any attempts to later fuse to the pelvis in those that have progressive pelvic obliquity will pose a greater risk with their worsening medical condition. Alman and Kim reported on 48 DMD patients that underwent spinal fusion [43].

Thirty-eight patients with less than 10° of pelvic obliquity and 40° curvature underwent fusion and instrumentation to L5. Of these patients, 32 had progression of their pelvic obliquity. They found that curves with an apex below L1 were at the greatest risk of progression. Therefore, Alman and Kim recommended fusion to the pelvis for all curves with an apex below L1.

Gainé et al. evaluated 85 patients that underwent spinal fusions to either L4, L5, sacrum, or ilium [45]. They demonstrated that the more proximal the implant ended, the worse the correction of major curve and pelvic obliquity. Intrapelvic fixation maintained the best correction in pelvic obliquity. Interestingly, they found no difference in correction of the pelvic obliquity between instrumentation and fusion that terminated at L5 compared with those that ended at S1.

Brook et al. reported on the results of ten patients that underwent fusion above the pelvis with an L-rod and seven patients that had Galveston fixation to the pelvis [44]. Six of the L-rod patients experienced some curve progression and sitting imbalance. The criticism of this study is that eight of the ten patients had curves greater than 40° and that preoperative pelvic obliquity was not recorded [20]. In addition, four of the ten patients had their fixation end at either L3 or L4.

SSI in the thoracic and lumbar spine has traditionally been with the use of sublaminar wires. With advancements made in instrumentation, some have chosen to use hooks or pedicle screws for the stabilization of the deformity. Recent studies involving pedicle screw fixation have demonstrated improved major curve correction in patients with DMD [48–51]. Another study reported on improved patient function, sitting balance, and quality of life with pedicle screw constructs [52].

Selection of implants is related to surgeon preference, cost, deformity, and patient anatomy and is beyond the scope of this chapter. Currently, our preferred technique is to utilize pedicle screws in the lumbar spine as well as at the cephalad portion of the construct. Depending on the deformity as well as bone quality, we will utilize either sublaminar wires or pedicle screws in between in the thoracic spine (Fig. 13.1).

There are similar choices for instrumentation to the pelvis. Options include the Galveston techniques with either Luque or Unit Rods, Dunn-McCarthy technique with an S-rod, sacral screw, and iliac screw fixation [42, 44, 53–55]. Each has advantages and disadvantages. Galveston technique is subject to loosening and migration of the rod [11]. In addition, the Galveston technique sometimes requires complex three-dimensional contouring to fit the altered pelvic anatomy. Iliac screws, on the hand, are placed individually into each iliac wing and then connected to the rod through connectors. A recent study by Peelle et al. demonstrated equal effectiveness in controlling pelvic obliquity between the Galveston technique and iliac screw fixation [55]. Our preferred method is to utilize iliac screws when instrumenting to the pelvis in DMD patients.

Another important consideration in the preoperative planning for scoliosis is the risk of blood loss during surgery. Of all pediatric spine surgeries, Duchenne muscular dystrophy has demonstrated, on average, to have the highest mean level of blood loss [56, 57]. This is important considering their poor cardiac reserve. These patients require a large exposure from the upper thoracic spine to the lower lumbar spine or pelvis. The paraspinal muscles are difficult to elevate subperiosteally. Dysfunction of vascular smooth muscle as well as decreased platelet adhesion is thought to contribute to increased blood loss [57, 58]. Besides diligent hemostasis intraoperatively, the use of antifibrinolytics may help to minimize the blood loss. Shapiro et al. retrospectively evaluated the use of tranexamic acid in 20 DMD patients and compared them with 36 control patients [59]. Tranexamic acid was found to reduce intraoperative blood loss and the need for homologous transfusions. Other options which have been published for adolescent idiopathic scoliosis but not DMD include the use aminocaproic acid [60–62]. Vitale et al. investigated the efficacy of preoperative erythropoietin on hematocrit and transfusion rates in neuromuscular patients. They found no clinical benefit in their treatment group. We currently work with anesthesia preoperatively to ensure that each patient is administered an antifibrinolytic during surgery. Intraoperative blood loss is also collected in a cell

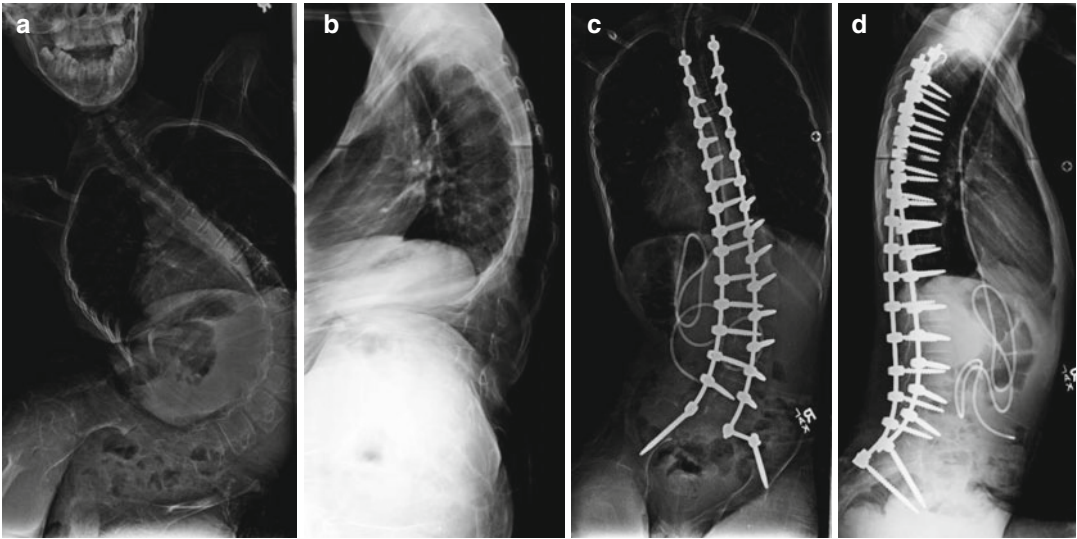


Fig. 13.1 (a, b) A 15-year-old male with DMD and delayed presentation of his progressive scoliosis. His lumbar curve is 128° and he has significant pelvic obliquity. (c, d) The patient underwent posterior spinal

instrumentation and fusion from T3 to the pelvis with iliac screws. To assist with correction, intraoperative traction as well as multilevel Ponte type osteotomies were performed

saver and given back to the patient. Postoperatively, hematocrits are monitored closely to ensure that cardiac function is not overly stressed.

improvement, and quality of life were all improved following spinal fusion [52, 64]. More than 90 % of their patients/parents would give their consent again for surgery.

13.1.5 Long-Term Outcomes

As previously discussed, there is controversy whether scoliosis surgery improves pulmonary function in the DMD patient. A recent Cochrane Review by Cheuk et al. was unable to provide an evidence-based recommendation for scoliosis surgery in DMD. Their reasoning was the lack of randomized clinical trials. Of the 36 relevant studies addressing the outcomes of scoliosis surgery, none met the inclusion criteria for review.

Studies have suggested that scoliosis surgery does benefit patients beyond pulmonary function [63–65]. Bridwell et al. sent questionnaires to 33 patients with DMD evaluating function, self-image, cosmesis, pain, quality of life, and satisfaction [63]. Patients reported benefits in all categories with the highest ratings in cosmesis, quality of life, and satisfaction. Granata et al. and Takaso et al. found that sitting position, aesthetic

13.1.6 Summary

Spinal deformity commonly affects the male patient with DMD. Treatment of this deformity is complicated by the progressive muscle weakness and deteriorating pulmonary function. Current literature suggests that surgical management of the deformity can maintain upright sitting posture, improve quality of life, and positively affect short-term pulmonary function. Unfortunately, a lack of randomized controlled trials has prevented any formal evidence-based recommendation from being made by a Cochrane Review. If surgery is contemplated, however, it should be performed early when the patient is at his or her maximal health. In addition, if there is more than mild pelvic obliquity, one should consider including the pelvis in the instrumentation and fusion.

13.2 Spinal Muscular Atrophy

Initially described by Guido Werdnig, spinal muscular atrophy (SMA) is a rare autosomal recessive disorder characterized by degeneration of the anterior horn cells of the spinal cord and the neurons of the lower bulbar nuclei [66, 67]. Two genes are associated with this disease: the survival motor neuron gene and the neuronal apoptosis inhibitory protein gene [68]. SMN protein appears to interact with RNA-binding proteins and is found in both the nucleus and cytoplasm of cells [69]. It is considered the most common fatal neuromuscular disease of infancy and the most common neuromuscular disease in children [66].

13.2.1 Classification

Common to all SMA patients is a symmetric muscular weakness predominantly affecting the lower limbs and proximal muscles compared with the upper limbs or distal muscles. Patients usually have normal intelligence with no effect on sensibility. The age of onset and clinical course can have a variable presentation. Due to this heterogeneity, spinal muscular atrophy is most commonly divided into three types [70–72].

13.2.1.1 Type I, Acute Werdnig-Hoffman Disease

Type I SMA is the most severe form of the disease, usually presenting at birth or within the first 2–6 months of life. These patients do not meet early motor milestones with the inability to gain head control, roll over, or sit up. It has been suggested that in utero osteoporosis from decreased movement is responsible for post-natal pathologic fractures [73]. Patients with Type I SMA usually do not survive beyond the age of 3 years. Respiratory failure from intercostal weakness and rib collapse is responsible for their mortality. Due to their early mortality, orthopedic intervention is rarely indicated in these children.

13.2.1.2 Type II, Chronic Werdnig-Hoffman Disease

The clinical onset of Type II SMA occurs between the ages of 6 and 24 months. Patients reach early motor milestones but are never able to walk independently. Weakness usually starts in the lower extremities, affecting the gluteal and quadriceps muscles initially. Life expectancy is variable from adolescence to adulthood with some patients living into their fourth decade [66, 74]. The cause of mortality is respiratory failure.

13.2.1.3 Type III, Kugelberg-Welander Disease

The clinical onset of Type III SMA occurs following the age of 18 to 24 months. In nearly all cases, the diagnosis is made before the age of 10 years. As expected, children attain greater motor milestones compared with Type II SMA. Patients are able to walk independently until early adolescence. Russman et al. reported that 50 % of those children with an age of onset before 2 years lost their ability to walk without assistance by age 12 [75]. Those children that presented after age 2 typically were ambulating into the fourth decade. Patients that never reached independent ambulation lost their ability to walk by age 7.

13.2.1.4 Functional Classification

Evans et al. described a functional classification based on the maximum physical function achieved [76]. The purpose was to give insight into the patient's prognosis. Group I patients never sit independently, have poor head control, and develop early progressive scoliosis. Group II children have head control and ability to sit but cannot walk or stand. Group III patients can stand by themselves and are able to walk with external support. Group IV children can walk and run independently.

13.2.2 Diagnosis

For those patients that do not present at birth, presenting concerns by families are a delay in

reaching motor milestones. Depending on the age of the patient, these include an inability to gain head control, roll over, sit, stand, or walk independently. Physical examination should then assess motor strength as well as deep tendon reflexes. For those patients that present early (Type I or II), gross fasciculations of the tongue or tremors of the finger are commonly present [66, 77].

Once SMA is suspected, further diagnostic workup includes laboratory studies, nerve conduction studies, electromyography (EMG), and DNA testing. Creatine phosphokinase and adolase are usually normal or slightly elevated in Type III patients [78]. Motor and sensory nerve conduction velocities are normal. EMG findings demonstrate fibrillation potentials associated with denervation as well as large polyphasic motor units associated with reinnervation [66, 78]. DNA testing is highly sensitive for SMA with PCR the diagnostic procedure of choice [79]. Muscle biopsy is also highly diagnostic. Histologic findings include muscle fiber degeneration and atrophy with no evidence of primary myopathy [78].

13.2.3 Spinal Deformity

Scoliosis is the most common orthopedic problem in patients with SMA [80]. Nearly 100 % of Type II SMA patients and half of Type III SMA patients develop a spinal deformity [76, 81–83]. The deformity is typically a right-sided C-shaped thoracolumbar curve. Ninety percent of the patients have a single curve. The curve is usual progressive and in approximately a third of the cases associated with a progressive kyphosis [81, 82]. Similarly to DMD patients, development of scoliosis in type III SMA occurs with their loss of ambulation [80]. Pulmonary function is similarly compromised in patients with SMA [84]. The worsening of lung function is secondary to muscle weakness as well as the progressive scoliosis.

As there is a difference in the clinical presentation between the three types of SMA, there is similar heterogeneity in the risk and progression

of scoliosis. Evans et al. demonstrated that the age of scoliosis onset correlated with the severity of muscle disease [76]. Type I SMA patients typically had scoliosis by the age of 2 years, while Type III SMA patients developed scoliosis between the ages of 4 and 14 years. The rate of progression was also highly associated with the disease severity ranging from 8.3° per year in severe cases to 2.9° in more mild cases.

As for the severity of the scoliosis, a study by Granata et al. reported curves ranging from 10 to 165° [81]. Schwentker and Gibson reported on 50 patients with SMA [80]. Seventy percent had scoliosis measuring greater than 20°, and 40 % had curves greater than 60°. The natural history of these large curves suggests that they can be quite disabling [76]. In addition to trouble sitting, patients can lose upper extremity function to maintain trunk balance as well as develop back pain or pain from rib impingement on the pelvis.

13.2.4 Nonsurgical Management of Scoliosis

Orthotics has generally been thought to be ineffective in preventing the development or progression of neuromuscular scoliosis [81, 85, 86]. It, however, has been shown to be effective in improving sitting balance. Letts et al. demonstrated an improvement in sitting stability in 80 % of patients with a collapsing neuromuscular scoliosis with the use of a soft Boston orthosis [87]. They also thought that a soft brace was more tolerable than a rigid orthosis and resulted in less skin breakdown.

Some studies have suggested that the use of orthotics may slow the rate of progression of scoliosis [82, 86, 88]. Slowing the rate of scoliosis progression has the advantage of allowing patients to get older when they are more suitable for a surgical intervention. This is especially critical in the early-onset patients (Type I and II SMA). Unfortunately, most of these studies report opinion and have not given reliable data to demonstrate that bracing truly slows the progression of spinal deformity. Bracing is also not without its morbidity. Aprin et al. reported on five

patients that had to discontinue their brace secondary to respiratory difficulty [86].

Our preferred nonsurgical treatment is to initiate bracing in patients with spinal deformities on sitting films between 30 and 40°. Typically, the curves in SMA are quite flexible and amenable to the orthosis. We find that the brace in addition to wheelchair supports help to maintain sitting balance. This is especially critical in pre-adolescent patients where attempts are made to delay surgery until the patient is more mature. In some cases, especially in the Type I patient where long-term survival or surgical tolerance is not expected, bracing may be the definitive management of the spinal deformity.

13.2.5 Surgical Management of Scoliosis

Similarly to other neuromuscular scoliosis, the decision to operate on an SMA patient is dependent on multiple factors. In general, the radiographic parameters for spinal fusion are not controversial and simple to follow. We recommend spinal fusion for curve magnitudes greater than 50° that are refractory to conservative measures and demonstrate progression. These indications for surgical fusion have been recommended by other authors as well [66, 76, 89].

Unfortunately, patient factors may not make the above rules simple to follow. In some patients with type I SMA, their early-onset scoliosis and grim long-term survival have made surgical intervention unreasonable. Type II patients may also present with a progressive scoliosis at an early age. Spinal arthrodesis would have a considerable negative effect on trunk growth as well as lung growth. These patients are also at significant risk of developing a crankshaft deformity necessitating an anterior fusion [90]. In these cases, spinal fusion is indicated, but an attempt at delaying surgery with the use of an orthosis is made. The goal is to maintain some control of the curve until a definitive procedure can be done at about the age of 10. Of course, this may mean watching a curve progress to greater than 80°.

13.2.5.1 Growing Spine Techniques

Previously, there has been some thought about using an expandable or “growing rod” construct in young SMA patients that developed significant scoliosis. Fujik et al. reported using an expandable or “telescoping” device in type II SMA patients [91]. The device was abandoned due to its technical demands and inability to prevent progression of the deformity and crankshafting. They concluded that a brace should be used until the age of 10 when a fusion can be performed.

However, more recent publications on early-onset scoliosis in SMA suggest increasing use of growing spine constructs. Growing rods may be the answer for these young patients. Chandran et al. found excellent deformity correction in 11 patients (mean age of 6 years) from 51° to 21.6° with a low complication rate at the initial surgery [92]. Sponseller et al. demonstrated in six patients that growing rods can be fixed to the pelvis and result in improved coronal balance, sagittal balance, and pelvic obliquity [93]. With similar constructs, McElroy et al. found improved major curve by nearly 50 %, improved trunk height, and improved space available for lung ratio at final follow-up. However, they did not find any halt in rib collapse, which is common in SMA. Additionally, they found that patients with SMA had longer hospital stays than did patients with early-onset idiopathic scoliosis undergoing the same procedure [94]. Recently, Tobert and Vitale published a case series of three SMA patients (aged 8, 7, and 3 years) undergoing rib to pelvis growing construct. They found stabilization of pulmonary function and overall improvement in quality of life and caregiver burden [95].

Additional literature is needed to know the long-term benefits and complications related to these surgeries. The tolerance for multiple anesthetics needed to expand the device on these already pulmonary compromised patients is also not known. To minimize this need for multiple anesthetics, we have utilized a modified Shilla technique to manage the early severe scoliosis (Fig. 13.2).

13.2.5.2 Posterior Spinal Fusion

In the older SMA patient that requires definitive spinal stabilization, the standard is PSF and

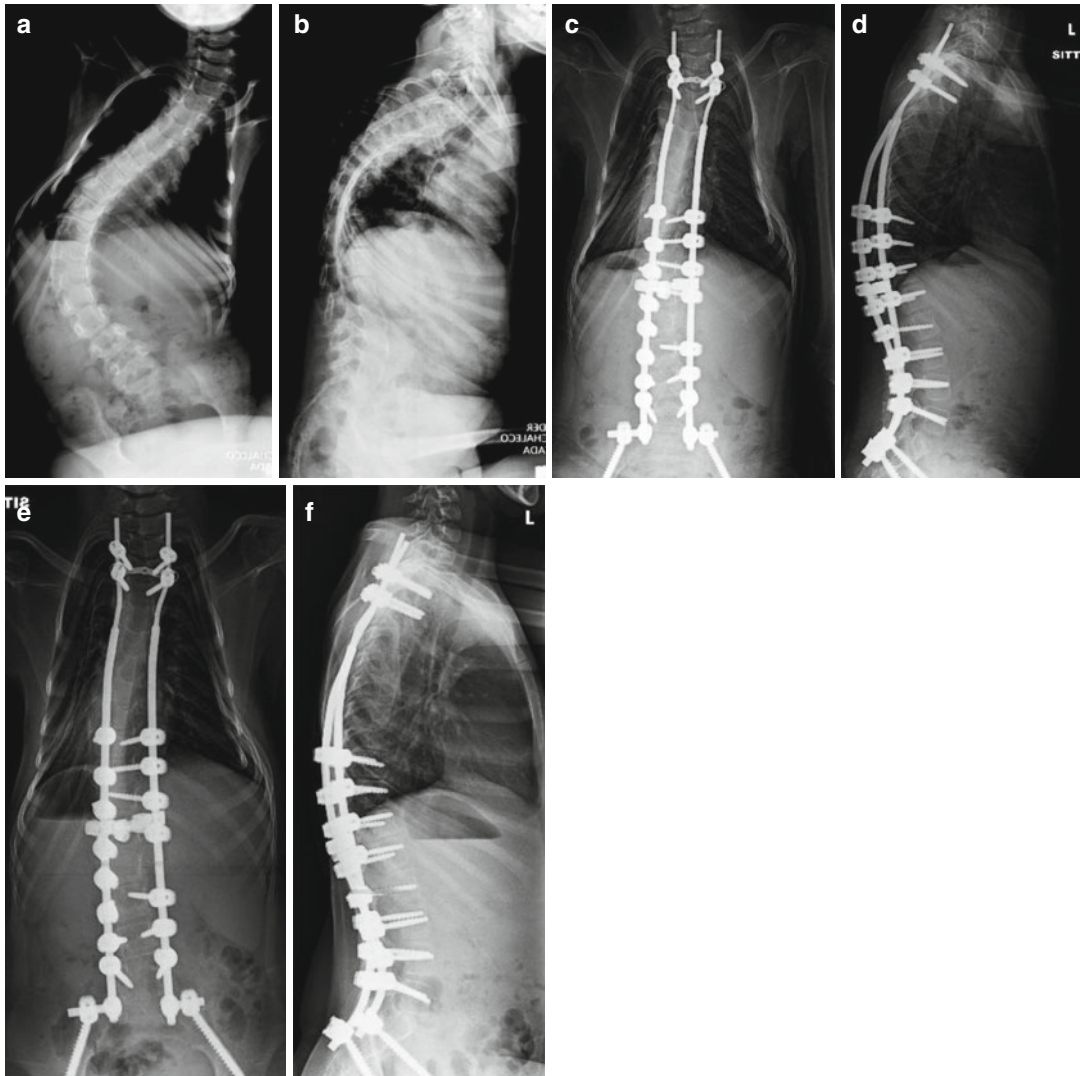


Fig. 13.2 (a, b) An 8-year-old female with SMA and progressive kyphoscoliosis. Her coronal major curve measures 90°. (c, d) The patient underwent a modified Shilla technique with instrumentation and fusion from T10 to the pelvis. The instrumentation was extended proximally to pedicle screws at T3 and T4 with fusion across

these two levels. The pedicle screws are allowed to slide along the rod as the spine grows. The goal of this procedure is to attain correction with the distal fusion but allow thoracic growth with the Shilla technique. (e, f) At 1 year postoperative, the patient had grown nearly 1 cm as measured by the movement of the top screws

SSI. The goal is to prevent progression and obtain an alignment that will improve or maintain balance and sitting ability. In the non-ambulatory patient, this typically involves segmental instrumentation from T2 to the pelvis. Many spinal deformity surgeons report good outcomes using sublaminar wires with Luque rods or a unit rod for the treatment of neuromuscular scoliosis [40, 83, 96]. Others are transitioning to the use of

pedicle screws to provide more rigid fixation [40]. The improved fixation to bone with pedicle screws has decreased the use of postoperative bracing for some neuromuscular patients [66]. We continue to brace all neuromuscular patients for 3 months postoperatively to prevent excessive stress on the osteopenic bone during transfers, including those with all pedicle screw instrumentation. Pelvic instrumentation is recommended to

prevent progressive pelvic obliquity and difficulty with sitting [80]. Similarly to patients with DMD, options include Galveston technique or iliac screws.

The use of an anterior approach has traditionally been reserved for severe curves or for patients at risk of developing crankshaft deformity. In the case of patients with SMA, other factors need to be considered. These patients typically have poor pulmonary reserve associated with weakness of their respiratory muscles. This places them at increased risk of developing pulmonary complications. The use of segmental fixation may decrease the risk of crankshaft deformity. Smucker and Miller reported on 43 patients with neuromuscular scoliosis and open triradiate cartilage treated with a unit rod [97]. They found no evidence of crankshaft deformity at 2-year follow-up. Some believe that pedicle screws may further decrease the risk by providing three-column fixation. However, this needs to be evaluated. There is also increasing evidence that severe spinal deformity can be completely managed from a posterior approach. Multilevel posterior osteotomies or single-level vertebral column resections stabilized with pedicle screws have been shown to adequately treat the severely deformed, rigid spine [98]. However, this, too, has not been adequately studied in patients with spinal muscular atrophy.

In preparation for spinal fusion, all patients with SMA should be evaluated by a pulmonologist, neurologist, and anesthesiologist. This will ensure that patients are optimized for surgery especially regarding their pulmonary function. In the immediate postoperative period, patients are most at risk of developing pulmonary complications. Aprin et al. reported a 45 % incidence of respiratory problems following surgery [86]. Four of their 22 patients required intubation. Brown et al. reported that tracheostomy was needed in 30 % of their patients [96]. The use of preoperative traction has been suggested to increase spinal flexibility and improve pulmonary function, possibly diminishing their risk of respiratory complications [86, 99]. Postoperatively, these patients should have aggressive pulmonary therapy and early mobilization. Ventilatory assistance with the

guidance of a pulmonologist may be needed several days following the surgery. Other long-term complications following spinal arthrodesis include crankshafting, pseudoarthrosis, prominent implants, narrowing of the chest, gastric volvulus, and diaphragmatic rupture [63, 82, 86, 100]. Except for crankshafting, these complications were more commonly seen in older patients with larger deformities.

13.2.6 Long-Term Outcomes

In general, the literature supports spinal fusion in SMA patients with progressive scoliosis. Multiple authors have reported improvements in sitting, balance, comfort, and cosmesis [81, 99]. Bridwell et al. evaluated 21 SMA patients with an average follow-up of 7.8 years after surgery [63]. Patients reported benefits in all categories with the highest ratings in cosmesis, quality of life, and satisfaction. In contrast, some authors have reported a decline in some functional activities, specifically upper extremity activities. Brown et al. demonstrated a decline in self-feeding, drinking, and self-hygiene at 2-year follow-up with some improvement at 5 years [96]. Furumasu et al. reported similar findings suggesting that the lack of spinal flexibility diminished gross upper extremity motor function due to a change in trunk position. What is unclear in these patients is the influence of a progressive muscle disease in the diminished functional activities.

Pulmonary function also appears to benefit from stabilization of the scoliosis. Robinson et al. demonstrated a significant improvement in lung function in the patients that underwent spinal fusion [84]. They also demonstrated a significant inverse linear relationship between curve magnitude and percentage of predicted vital capacity.

13.2.7 Gene Therapy

Spinal muscle atrophy is caused by a mutation in the survival motor neuron (SMN) 1 gene that results in a reduction of the SMN protein. Patients also can have variations in the copies of the

SMN2 gene, which produces reduced levels of SMN protein. This production, however, is insufficient for normal motor neuron function [101]. There are promising gene therapy pathways that are being tested to increase the number of SMN proteins produced [102, 103]. One approach is to antisense oligonucleotides to redirect SMN2 translation and increase production of fully functional SMN protein [104].

13.2.8 Summary

Spinal muscle atrophy is a heterogeneous disease commonly affected by progressive scoliosis. Depending on the severity of the disease, patients can have significant deformity at a very early age. While ineffective at preventing scoliosis, bracing is utilized to delay surgery. When severe scoliosis develops at a young age (<10 years), growing spine constructs can improve spinal deformity and sitting balance and may improve pulmonary function and quality of life, but this needs further study. The gold standard for spinal stabilization remains posterior spinal instrumentation and fusion. Current literature suggests that surgical management of the deformity can maintain upright sitting posture, improve quality of life, and positively affect pulmonary function. Whether this improvement in pulmonary status improves life expectancy is still unclear.

13.3 Arthrogryposis Multiplex Congenita

Arthrogryposis or “arthrogryposis multiplex congenita” (AMC) is a heterogeneous group of diseases with the similar phenotype of multiple congenital joint contractures [105, 106]. Currently, there are more than 150 subtypes that result from a failure of normal movement in utero. The etiology for this lack of movement may be myopathic, neurologic, or secondary to connective tissue abnormalities [107]. Amyoplasia is the term used to describe the more classic disease entity seen in orthopedics. These patients have a dysgenesis of

anterior horn cells resulting in replacement of muscle with adipose and fibrous tissue [108].

Patients with arthrogryposis multiplex congenita (AMC) have significant musculoskeletal deformities secondary to the contractures. The majority of patients have all four limbs involved (84 %) [105]. Severe equinovarus feet, hip dislocations (unilateral or bilateral), and scoliosis are commonly seen. Non-orthopedic abnormalities include hypoplasia of the labial folds, inguinal hernias, abdominal wall defects, cryptorchidism, gastroschisis, and bowel atresia [105].

13.3.1 Spinal Deformity

The incidence of scoliosis in AMC is reportedly between 30 and 67 % depending on the definition used [109, 110]. The deformities are similar to other neuromuscular conditions with lumbar and thoracolumbar curves predominating [111, 112]. The curves are frequently stiff. Progression of the deformity can be rapid, up to 6.5° per year [112]. The earlier the presentation of scoliosis, the more severe the curve may become and be associated with pelvic obliquity. Increased lordosis is frequently seen.

Scoliosis is typically refractory to orthotic management [111, 112]. Patients with arthrogryposis will frequently develop scoliosis early in life. Little literature has evaluated the treatment of early-onset scoliosis in these patients. Recently, Astur et al. and the Chest Wall Spinal Deformity Study Group evaluated ten children with arthrogryposis that underwent treatment with the use of the vertical expandable prosthetic titanium rib (VEPTR) device and found it to be an effective treatment method in these patients [113]. Using this rib-based distraction device, they obtained 37 % correction of scoliosis and 29 % correction of kyphosis. They also found improved thoracic volume. Six complications occurred in four patients in a total of 62 procedures performed. Proximal junctional kyphosis appeared to remain a problem, however, in this cohort. Other than this series, few studies have evaluated growing spine techniques in patients with AMC.

PSF and SSI remains the standard and appears to be effective in preventing progression of the scoliosis. However, correction of the curves appears to be modest, about 35 % [111]. Yingsakmongkol and Kumar reported slightly increased correction (44 %) with a combined anterior and posterior fusion [109]. These series are dated, however, and do not assess surgical outcomes with current segmental instrumentation. In some cases, instrumentation was not used. If pelvic obliquity is present, fusion to the pelvis should be attempted. Care should also be taken when positioning patients. Their stiff joints and osteopenia place them at increased risk of developing pathologic fracture.

13.4 Rett Syndrome

First described in 1966, Rett syndrome is a progressive neurologic disorder that affects one in 20,000 females [114, 115]. Patients initially appear normal at birth but then proceed through four stages of deterioration. The first stage typically has an onset between 6 and 18 months with developmental stagnation. The second stage (1–3 years of age) is characterized by lost language skills and autistic behaviors. In the third stage (2–10 years of age), patients may have seizures, exhibit some mental retardation, and have repetitive hand motions. In the fourth stage, patients develop spasticity and muscle wasting. Scoliosis is most likely to present in this final stage.

13.4.1 Spinal Deformity

The musculoskeletal manifestations of Rett syndrome include lower extremity contractures, coxavalga, and scoliosis [115, 116]. The spinal deformity is similar to other neuromuscular diseases with a long C-shaped curve being the most common [117, 118]. However, patients can also present with a single thoracic or double major curve. Large curves are frequently associated with pelvic obliquity. As a patient get older, so does the prevalence of scoliosis.

Curve progression has been suggested to be more rapid than in idiopathic scoliosis or other neuromuscular scoliosis. Lidstrom et al. demonstrated greater than 15° per year of progression in the final stage of Rett syndrome [119]. For this reason, it has been recommended that patients are evaluated every 6 months following the age of 5 [120].

Bracing has been found to be largely unsuccessful in preventing the progression of scoliosis [117, 118, 120]. It, however, can be used to delay the need for surgical intervention to allow for more truncal growth. Posterior spinal fusion and segmental spinal instrumentation are the treatment of choice for the progressive scoliosis. In those patients that are non-ambulatory, it is recommended to fuse from the upper thoracic spine to the pelvis to prevent delayed decompensation or pelvic obliquity. Ambulation is possible in patients with Rett syndrome and can be positively affected by surgery. Harrison et al. demonstrated no loss of ambulation in all five patients that walked preoperatively and improvements in some patients [118]. Overall, PSF and SSI are successful in halting curve progression and improving spinal balance in the sitting and walking patient. Improvement in activities of daily living has been seen following spinal fusion in Rett syndrome patients [121]. However, medical complications can be high especially pulmonary (63 %) and gastrointestinal (37 %) in some series [122].

13.5 Congenital Myopathies

Congenital myopathies are a heterogeneous group of disorders characterized by weakness and hypotonia from birth [123]. Typically, the diseases have similar clinical findings but are classified based on histologic and microscopic findings. Central core disease, nemaline myopathy, and myotubular myopathy are just a few of the multiple congenital myopathies wherein scoliosis has been described [124–128]. They are genetically transmitted and can have variable penetrance.

13.5.1 Spinal Deformity

The musculoskeletal abnormalities associated with these disorders include congenital hip instability, foot deformities, other joint contractures, as well as scoliosis [127]. The curves are similar to other neuromuscular curves with a long, thoracolumbar shape. Kyphosis can also be associated with the deformity. As scoliosis progresses, it often becomes rigid. Rigid spine syndrome, as described by Dubowitz, has often been associated with these diseases and other congenital muscular dystrophies [129, 130].

If the patients present early and have flexible curves, scoliosis may be amenable to management with an orthosis. Those patients that fail bracing or present with large, rigid curves should undergo spinal fusion. Similar consideration as with other neuromuscular scoliosis must be given to the health and age of the patient. Poor pulmonary function has been associated with congenital myopathies [128]. At a minimum, patients should undergo preoperative pulmonary function testing. These patients are also at increased risk of developing malignant hyperthermia [124]. The anesthesiologist should be made aware of this before the day of surgery so that adequate preparation can be done.

Depending on the severity of the disease, patients may present with early-onset scoliosis. Those that demonstrate progression with the use of an orthosis may require surgical treatment with an expandable device or “growing rod.” However, there have been no studies adequately evaluating the use of a “growing rod” in these patients. Those patients that present later in life do well with a posterior spinal instrumentation and fusion. Anterior release can be done for the large rigid curve if the patient can tolerate the exposure. In the non-ambulatory patient with pelvic obliquity, the fusion should be extended to the pelvis.

Similar principles to other neuromuscular diseases should be followed when treating patients with congenital myopathies. Posterior fusion is the treatment of choice. The need for traction or fusion to the pelvis should be determined on an individual basis. Depending on bone quality, a brace can be used postoperatively to support the instrumentation. Particular attention, however, has to be made towards the increased risk of hyperthermia.

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