Surgical advances in the treatment of neuromuscular scoliosis

Federico Canavese, Marie Rousset, Benoit Le Gledic, Antoine Samba, Alain Dimeglio


INTRODUCTION

Scoliosis is a three-dimensional deformity of the spine with lateral, antero-posterior and rotational components. In most cases, the disease is idiopathic. Non-idiopathic cases are often secondary to neuromuscular diseases affecting the neuro-musculo-skeletal system.

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Key words: Neuromuscular scoliosis; Surgery; Sub-laminar bands; Luque rod; Unit rod

Core tip: In patients with neuromuscular disease, the likelihood and severity of the scoliosis increase with the degree of neuromuscular involvement. There is little doubt that segmental instrumentation techniques have revolutionized the care of patients with neuromuscular scoliosis by providing lasting correction and significant relief of pain and by restoring quality of life and sitting position. The state of knowledge regarding neuromuscular scoliosis is a dynamic process, and a current literature review is mandatory. The somewhat large bibliography for this subject reflects the many opinions and findings currently available.

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with neuromuscular scoliosis and must be managed (pre- and post-operatively) by a multidisciplinary team of care providers. A multidisciplinary approach is the key to a successful outcome. Comorbidities often make corrective operations high-risk procedures. Orthopedic surgeons experienced in undertaking major spine reconstruction, anesthesiologists, pulmonologists, cardiologists, nutritionists and pediatricians must work together to evaluate and handle these complex surgical patients to obtain the best possible outcomes.

Furthermore, the post-operative complication rate is much higher (approximately 30%) in patients with neuromuscular deformities, compared to patients with idiopathic scoliosis. Therefore, the risk-to-benefit ratio is an important parameter that must be considered before surgery as the results can be gratifying if patients are properly selected.

Luque rods, or variations on the Luque technique, often remain the preferred instrumentation for neuromuscular curves. The success of treatment depends on the maintenance of a balanced spine on the coronal and sagittal planes over a level pelvis.

This article aims to provide a comprehensive review of how neuromuscular spinal deformities can affect normal spine balance and how such deformities can be treated with segmental instrumentation and sub-laminar devices.

Older concepts have been integrated with newer scientific data to provide the reader with a basis for better understanding of how treatment of neuromuscular scoliosis has evolved over the past few decades. Recent advances, as well as challenges that remain to be overcome, are outlined in the surgical treatment of neuromuscular curves with sub-laminar devices and in the management of post-operative infections.

### HISTORY AND PRINCIPLES OF SURGICAL TREATMENT

Surgical management of scoliotic curves in patients with neuromuscular conditions has evolved over the past five decades. Segmental fixation, sub-laminar wires, L-rods, unit-rods and sub-laminar bands have been progressively developed for the treatment of neuromuscular curves and they now form part of the armamentarium of the spinal surgeon in addressing such deformities. The surgical treatment must be adapted to the severity of the deformity and the neuromuscular disease. The treating surgeon should not be a prisoner of a single strategy; rather, the strategy should depend on the health of the patient.

#### Segmental fixation (early 1960s)

The concept of segmental fixation was pioneered in 1963 by Resina and Alves from Portugal, by fixation with segmental wiring for the treatment of scoliotic curves.

Stainless steel wires are passed through a hole at the base of the spinous processes (one wire per vertebra) and are twisted around to two straight rods placed on either
This technique allows for translation of the spine and correction of the deformity (mostly on the frontal plane) using an even distribution of corrective forces.

**Sub-laminar wires and L-rods (late 1970s)**

Eduardo Luque from Mexico popularized sub-laminar wires to attach to L-shaped rods during the late 1970s (Table 3).

In Luque’s system, two L-shaped rods are placed on either side of the spine, and they are wired to each of the vertebrae. The L-rods are contoured or bent to conform to the curve and to provide proper sagittal alignment. The wires are threaded through the spinal canal at each vertebral level and are then twisted around the rods on each side of the spine. The wires are usually doubled (to reduce the risk of fracturing the lamina), with one end joined by a bead and the other by a loop. The beaded end is contoured by creating a small bend at the tip that will emerge on the cephalad side of the lamina. A flatter contour minimizes intrusion into the canal. However, it is important to keep in mind that once metal wires are passed under the lamina, great care must be taken to ensure that none of the operating team inadvertently pushes one of the wires into the canal. To minimize this danger, each wire should be temporarily bent over the lamina.

Segmental instrumentation with sub-laminar wires results in even distribution of corrective forces with two lateral fixation points on each segment, which provide good rotatory control. The rods apply pressure on the spine to correct the deformity.

The L-rods and wire constructs aim at translation and coronal and sagittal balancing, rather than derotation, as their principle, so the extent of derotation is not the purpose that is intended to be achieved with this technique. Because there are multiple points of fixation with the Luque technique, the patient does not have to wear a brace after surgery. Therefore, segmental instrumentation with sub-laminar wires has been widely adopted in the treatment of neuromuscular curves because it provides rigid fixation and allows for early mobilization without external support.

Overall, the technique has proved to be safe and relatively easy to perform with a relatively low complications rate, providing rigid fixation and predictable correction with minimal post-operative external support required, and it is applicable for a wide variety of spinal deformities, offers a high rate of fusion with a low incidence of failure of the instrumentation and provides sagittal plane correction comparable to more recent implants.
Various

Various

CDI of the pelvis

Onimus

Various

sitting position was acquired in all the cases

Posterior spinal fusion with CDI of the pelvis

3 deaths;

Complications

Marchesi

associated medical pathologies were

Patients

In every patient, a good sitting balance

Duchenne muscular dystrophy

Pain disappeared in 2/3 of cases;

Hopf

Luque-Galveston

motor possibilities improved in 25% of cases;

Frischhut

CDI of the pelvis

Complications rate: 11%

3 deaths;

10 other

Onimus et al[27]

Cerebral palsy

Complications rate: 41%

Posterior spinal fusion with CDI of the pelvis is an effective treatment for patients with neuromuscular scoliosis.

Luque-Galveston instrumentation

14 hardware problems;

7 cases of pseudarthrosis;

3 neurologic deficits

Complications rate: 35%

Hopti et al[26]

Various

1 hardware failure;

1 deep wound infection

3 neurologic deficits

Complications rate: 11%

Neustadt et al[26]

Various

14 hardware problems;

7 cases of pseudarthrosis;

3 neurologic deficits

Complications rate: 35%

Luque’s wires

are made of steel or titanium alloy, the bands with this technique are made of acrylic or polyester material. The bands are supple and, once inserted, cannot be inadvertently pushed into the canal.

The sub-laminar system is composed of a connector, a band-locking set screw, a polyester or acrylic band and, depending on the manufacturer, a rod-locking set screw.

Compared to Luque’s metal wires, the technique described by Mazda et al[28] allows the surgeon to perform progressive tensioning and deformity correction because of the simplicity of the implant and the tensioning of the strips[28].

Sub-laminar bands have the same stress resistance as steel or titanium alloy sub-laminar wires. Moreover, the increased contact area between the bands and bone improves corrective forces and reduces laminar fracture risk[28].

Today, band-only and hybrid constructs, with lumbar transpedicular screws, thoracic sub-laminar bands and pedicle-transverse hooks at the upper end of the curve, have become widely used and have been shown to provide good correction of spinal deformities, as well as reduced operating time, radiation exposure, and blood loss, compared to all-screw constructs.

SURGICAL TECHNIQUE OF SUB-LAMINAR BANDS PLACEMENT

Basic principles

Patients can be treated either with band-only or hybrid

<table>
<thead>
<tr>
<th>Decade-Year of publication</th>
<th>Authors</th>
<th>Patients (n)</th>
<th>Neuromuscular condition</th>
<th>Instrumentation</th>
<th>Complications (number of patients)</th>
<th>Outcome/Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990-1999</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>1991</td>
<td>Gau et al[33]</td>
<td>68</td>
<td>Various</td>
<td>Luque-Galveston instrumentation</td>
<td>14 hardware problems; 7 cases of pseudarthrosis; 3 neurologic deficits Complications rate: 35%</td>
<td></td>
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<tr>
<td>1992</td>
<td>Hopti et al[29]</td>
<td>44</td>
<td>Various</td>
<td>CDI of the pelvis</td>
<td>1 hardware failure; 1 deep wound infection Complications rate: 11% 3 neurologic deficits 10 other</td>
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<tr>
<td>1992</td>
<td>Neustadt et al[29]</td>
<td>18</td>
<td>Various</td>
<td>CDI of the pelvis</td>
<td>14 hardware problems; 7 cases of pseudarthrosis; 3 neurologic deficits Complications rate: 35%</td>
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<tr>
<td>1992</td>
<td>Onimus et al[27]</td>
<td>32</td>
<td>Cerebral palsy</td>
<td>CDI of the pelvis</td>
<td>14 hardware problems; 7 cases of pseudarthrosis; 3 neurologic deficits Complications rate: 35%</td>
<td></td>
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<tr>
<td>1996</td>
<td>Sussman et al[34]</td>
<td>25</td>
<td>Cerebral palsy</td>
<td>L-rod</td>
<td>1 hardware failure; 1 deep wound infection Complications rate: 11% 3 neurologic deficits 10 other</td>
<td></td>
</tr>
<tr>
<td>1997</td>
<td>Frischhut et al[19]</td>
<td>41</td>
<td>Various</td>
<td>29 L-rod, Luque-Galveston, CDI and ISOLA; 12 Harrington instrumentation</td>
<td>3 deep wound infections Complications rate: 7%</td>
<td></td>
</tr>
<tr>
<td>1997</td>
<td>Marchesi et al[25]</td>
<td>25</td>
<td>Duchenne muscular dystrophy</td>
<td>L-rod with sacral screws</td>
<td>14 hardware problems; 7 cases of pseudarthrosis; 3 neurologic deficits Complications rate: 35%</td>
<td></td>
</tr>
</tbody>
</table>

**Table 4 Decade 1990-1999**

Most significant works published between 1990 and 1999. CDI: Cotrel-Dubousset instrumentation.

Unit-rod for segmental spinal fixation (late 1980s)

The unit-rod (U-rod) technique was developed in the late 1980s by Bell, Moseley and Koreska from Canada[19].

This technique uses a U-shaped, double, prebent rod, and it is a modification of Luque’s segmental instrumentation technique, which, in contrast, must link together two single L-shaped rods[20-22].

The distal portion of the U-rod is inserted into both iliac wings, while the middle and proximal portions are wired to sub-laminar wires threaded through the spinal canal at each vertebral level, from the upper thoracic (T1-T2) to the lower lumbar (L4-L5) spine. Sub-laminar wires are progressively twisted around the U-rod from caudal to cephalad to provide gradual deformity correction.

U-rod instrumentation has become a common, standard technique and the primary instrumentation system for the treatment of pediatric patients with neuromuscular spine deformities and pelvic obliquity (Tables 4 and 5). The technique is simple to apply, it is less expensive than most other systems, and it can achieve good deformity correction and a low reoperation rate[19].

Sub-laminar band technique (late 2000s)

The sub-laminar band devices and technique were first described in 2009 by Mazda et al[28] from France. The technique is also known as the universal clamp technique (Table 5).

The technique of placing sub-laminar bands is similar to Luque’s wire technique. However, while Luque’s wires

are made of steel or titanium alloy, the bands with this technique are made of acrylic or polyester material. The bands are supple and, once inserted, cannot be inadvertently pushed into the canal.

The sub-laminar system is composed of a connector, a band-locking set screw, a polyester or acrylic band and, depending on the manufacturer, a rod-locking set screw.

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Today, band-only and hybrid constructs, with lumbar transpedicular screws, thoracic sub-laminar bands and pedicle-transverse hooks at the upper end of the curve, have become widely used and have been shown to provide good correction of spinal deformities, as well as reduced operating time, radiation exposure, and blood loss, compared to all-screw constructs. 
Canavese F et al. Surgical treatment of neuromuscular scoliosis

Table 5  Decade 2000-2011

<table>
<thead>
<tr>
<th>Decade-Year of publication</th>
<th>Authors</th>
<th>Patients (n)</th>
<th>Neuromuscular condition</th>
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<th>Complications (number of patients)</th>
<th>Outcome/Complications</th>
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<tbody>
<tr>
<td>2000-2011</td>
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<tr>
<td>2000</td>
<td>Yazici et al[25]</td>
<td>47</td>
<td>Various</td>
<td>ISOLA-Galveston</td>
<td>2 deep wound infections; 2 hardware removals; 4 cases of pseudarthrosis; 1 pseudarthrosis repair</td>
<td>ISOLA-Galveston instrumentation is as safe and effective as other types of instrumentation</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Complications rate: 19%</td>
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<tr>
<td>2009</td>
<td>Modi et al[20]</td>
<td>52</td>
<td>Cerebral palsy</td>
<td>U-rod and pedicle screws</td>
<td>2 deaths; 1 neurologic deficit; 17 respiratory complications (atelectasia, pneumonia, hemoptoxia)</td>
<td>U-rod with pedicle screws provides good frontal and sagittal plane correction, as well as pelvic obliquity improvement (56% correction)</td>
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<td>Complications rate: 38%</td>
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<td></td>
<td>1 case of blindness; 1 death; 16 respiratory complications (atelectasia, pneumonia, pneumothorax)</td>
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<td></td>
<td>Complications rate: 64%</td>
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<tr>
<td>2010</td>
<td>Nectoux et al[21]</td>
<td>28</td>
<td>Cerebral palsy</td>
<td>Luque-Galveston, U-rod</td>
<td>1 death; 4 respiratory failure; 2 neurological deficits; 1 ileus; 2 cases of atelectasia; 3 UTI's; 7 cases of coccydynia; 1 rod dislodgement</td>
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<tr>
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<td></td>
<td></td>
<td>Complications rate: 64%</td>
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</tr>
<tr>
<td>2010</td>
<td>Modi et al[22]</td>
<td>27</td>
<td>Spinal muscular atrophy and Duchenne muscular dystrophy</td>
<td>U-rod and pedicle screws</td>
<td>1 death; 4 respiratory failure; 2 neurological deficits; 1 ileus; 2 cases of atelectasia; 3 UTI's; 7 cases of coccydynia; 1 rod dislodgement</td>
<td>Although flaccid neuromuscular scoliosis can be corrected well with U-rod and posterior-only pedicle screws, there is a high rate of associated complications</td>
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<td>Complications rate: 77%</td>
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<td></td>
<td></td>
<td>Complications rate: 6%</td>
<td></td>
</tr>
<tr>
<td>2011</td>
<td>La Rosa et al[24]</td>
<td>84</td>
<td>Cerebral palsy</td>
<td>Universal clamps, hooks and L-rod</td>
<td>5 respiratory complications</td>
<td></td>
</tr>
</tbody>
</table>

Most significant works published between 2000 and 2011.

instrumentation.

Band-only instrumentation (Figure 1) is a construct characterized by two bilateral claws at the upper instrumented vertebra (one per side) and sub-laminar bands as thoracic and lumbar anchorages. Band-only instrumentation should be preferred in non-ambulatory patients.

The hybrid construct (Figure 2) consists of two bilateral claws at the upper instrumented vertebra (one per side), multiple transpedicular screws as distal anchorages and sub-laminar bands between the upper claws and distal screws. Hybrid instrumentation can be used in both ambulatory and non-ambulatory patients.

In cases of severe pelvic obliquity, iliac screws can be added to both constructs. Moreover, Ponte’s posterior osteotomies can be performed at and around the apex for rigid curves (less than 30% reduction on bending films).

**Screws and claws**

Instrumentation is performed with the PASS® LP side connection segmental system (MEDICREA, Neyron, France), using 5.5 mm titanium (Ti) or cobalt-chrome (Co-Cr) rods, pedicle screws, auto-stable claws, cross-links and various rod-anchorage connectors locked by nuts.

Transpedicular screws can be inserted with the free-hand technique, and they are mostly placed at the lumbar level.

Auto-stable claws consist of a main pedicular hook and a counter-hook, which can be placed under the lamina or above the transverse process of the upper instrumented vertebra (thoracic region). Upper claws and lumbar screws should be placed before band insertion.

**Sub-laminar band insertion**

Sub-laminar fixation is performed with the LigaPASS® system (MEDICREA, Neyron, France), which consists of a titanium alloy connector, a rod-locking set screw, a polyester band and a band-locking set screw.

A portion of the ligamentum flavum must be removed from each intervertebral space. Once the canal is opened, the bands can be placed from caudal to cephalad.

Each band ends with malleable Ti leads. The malleable Ti end is contoured by creating a small bend at the tip that will emerge on the cephalad side of the lamina. Contouring the malleable Ti leads helps to slide the band under the lamina from caudal to cephalad, with a very low risk of damaging the thecal sac.

If two bands must be slid under the same lamina, the second band placement can be facilitated using the first band as a guide. The second band should be inserted between the first band and the lamina. By doing so, the thecal sac is protected throughout the whole insertion maneuver of the second band. Moreover, insertion is easier
self-stable band tensioning.

The reduction is performed sequentially by progressively tensioning all the bands with the tension pulleys. This process gradually translates the spine toward the rods and reduces the deformity by sharing forces among all the implants. The tension applied to each band can be assessed by observing the strain gauge on the pulley. Maximum reduction is achieved when the band connector is seated on the vertebra. Once the desired reduction is achieved, the band is locked within the connector by tightening the band-locking set screw. At this point, the remaining screws and upper claws can also be locked.

WHEN TO OPERATE ON A PATIENT WITH NEUROMUSCULAR SCOLIOSIS

**Indications for and goals of surgical treatment**

In neuromuscular scoliosis, bracing is usually not effective, and surgery becomes the primary treatment option. The type of spinal stabilization is influenced by the age of the patient, the severity of the deformity, the ambulatory status, and the underlying neuromuscular condition.

Posterior instrumentation for neuromuscular deformity treatment should be segmental and low-profile, with sound pelvic purchase if needed. In all cases, fitness for surgery and psychological status should be assessed prior to surgery, as the results can be gratifying if...
patients are properly selected.

Surgical treatment is indicated in large curves (> 50°) and in curves progressing beyond skeletal maturity. However, puberty can begin earlier or, more frequently, later in patients with neuromuscular disease (than the puberty of children with idiopathic curves). Depending on the neuromuscular disease, the rate of progression of the scoliotic deformity during pubertal growth spurt can increase by 2° to 4° per month, especially in patients who are wheelchair-bound. Scoliosis continues to progress beyond skeletal maturity at a rate of approximately 1° to 2° per year if the curvature is greater than 50° at the end of growth, compared to approximately 0.5° to 1° per year for curves of less than 50°.[1,6,30]

In addition, neuromuscular curves are responsible overall for a greater decrease in lung volumes compared to idiopathic curves, which, in contrast, are characterized by normal muscle function.[27-29]

Sleep-disordered breathing, with or without nocturnal hypercapnic hypoventilation, is a common complication of respiratory muscle weakness in children and adolescents with neuromuscular disorders (Table 2). Nocturnal hypercapnic hypoventilation is a sign of respiratory muscle fatigue and a poor prognosis. It is recommended to perform a polysomnographic evaluation, searching for sleep-disordered breathing in patients with neuromuscular compromise and spinal deformities. Children with neuromuscular scoliosis are at risk for sleep-disordered breathing when the inspiratory vital capacity is less than 60%, and PaCO₂ is greater than 40 mmHg.[6]

Overall, the indications for surgery are: (1) A significant curve resulting in functional disturbance and/or cardio-respiratory compromise; (2) A progressive spinal deformity not controllable with orthosis; (3) A small curve with inevitable progression; and (4) Painful deformities.

The goals of surgical treatment are: (1) To prevent curve progression; (2) To maintain the spine balanced on the coronal and sagittal planes, with a level and upright trunk position; (3) To provide a balanced and comfortable sitting position to reduce repositioning; (4) To reduce pain; (5) To reduce the discomfort caused by the impingement of the ribs against the iliac crest on the concave side of the curve; (6) To maximize patients’ health and function; and (7) To maintain walking ability in ambulatory patients.

Although spinal surgery can restore proper spinal alignment, it has some potential disadvantages. In particular, spinal fusion and instrumentation can adversely affect those patients with neuromuscular disorders who have developed functional compensation techniques requiring a short and mobile trunk. Moreover, surgery stops any further growth over the fused segments, and it can accentuate hip deformity.[1,6,30]

**Hip dislocation, pelvic obliquity and the extent of instrumented fusion**

A large number of patients with neuromuscular scoliosis have involvement of the sacrum and subsequent pelvic obliquity. However, patients with neuromuscular scoliosis can develop pelvic obliquity from other sources, such as hip joint and other lower extremity contractures, which will eventually affect the lumbar spine. Furthermore, deformity progression can interfere with trunk stability.[32,33]

It is important to assess hip motion and contracture carefully in any patient with neuromuscular spinal deformity. Hip contracture and dislocation can secondarily deform the spine dynamically when the patient attempts to accommodate the hip deformity while sitting.

In cases of unilateral dislocation, pelvic obliquity increases spine deformities and can cause ischemic pressure sores and loss of sitting position. In such situations, hip surgery is recommended. The choice of surgical procedure depends on the morphology of the femoral head and the presence of necrosis and degenerative cartilage changes. The current recommendations are to reconstruct the hip whenever it is possible. Otherwise, a total hip prosthesis or a femoral head resection can be considered. For patients who present with scoliosis and hip dislocation, hip surgery is usually performed before spinal fusion unless pelvic obliquity is caused by the spine deformity. The goal of orthopedic surgery in non-ambulatory patients is to achieve a sitting position with a level pelvis and an upright trunk position.[32,33,34]

Instrumentation and fusion should be extended to the pelvis in non-ambulatory patients with pelvic obliquity. In contrast, instrumented fusion can stop at L5 or above when the patient is still ambulatory and shows minimal or no signs of pelvic obliquity. Small amounts of pelvic obliquity (less than 10° to 15°) are compatible with comfortable sitting. In contrast, larger fixed obliquities are not compatible with comfortable sitting and must be corrected surgically or, if not fixed, with wheelchair modifications.[34-36].

**COMPLICATIONS OF SURGERY**

Surgical treatment of neuromuscular spine deformities is more complex than the treatment of idiopathic scoliosis.[37-40]. Complex reconstruction can be necessary to obtain satisfactory outcomes. However, the post-surgical complication rate is higher in neuromuscular scoliosis patients, compared to patients with idiopathic scoliosis. The Scoliosis Research Society Morbidity and Mortality Committee reported an infection rate of 5.5% for neuromuscular cases compared to 1.4% in idiopathic patients and a new neurological deficit rate of 1.03% vs 0.73%, respectively.[31,41]. These rates are often due to the presence of multiple comorbidities. Chronic cardiovascular disease as a consequence of a severe scoliotic deformity can lead to complications such as hypoxemia, hypercapnia, cor pulmonale, and pulmonary hypertension. A preoperative forced vital capacity less than 30% is strongly predictive
of pulmonary complications, and a significant association between restrictive lung disease and increased pulmonary complications has been reported.\(^{[16,18,22,29]}\)

The nutritional status of patients with neuromuscular disorders is extremely important, as nutritional depletion has been associated with increased complication rates.\(^{[33,34,36,37]}\)

Complications can be divided into early and late. Early complications are those diagnosed immediately after or within 4 to 6 wk from the index surgery. In contrast, late complications are diagnosed more than 6 wk after the index surgery.

Early post-operative complications include infections, cardio-respiratory, neurologic and nutritional issues, prolonged ileus, constipation, fluid overload, skin breakdown, bleeding and death. Late post-operative complications include chronic infections, non-union, coccygodynia, crankshaft phenomena, implant-related issues, loss of correction and inadequate correction.\(^{[20,21,25,36,37]}\)

**Application of the VAC system**

The VAC system consists of a polyurethane foam sponge with open pores, 400 µm to 600 µm in size, a connecting tube and a plastic sealant. After thorough lavage and removal of all macroscopic contamination, de-vitalized tissue and loose bone grafts, the VAC sponge is cut and fitted into the wound. The plastic sealant is used to cover the sponge and is applied several centimeters beyond the margins of the wound to create an airtight seal. A cruciate incision is made in the plastic sealant covering the sponge, through which a suction tube is inserted and fixed. The tubing is connected to a negative pressure device. The sponge is compressed at sub-atmospheric pressure (-125 mmHg), continuously or intermittently. “Controlled negative pressure” is used to evacuate edema from the wound, increase blood flow, decrease bacterial load and increase the formation of granulation tissue. The system also assists the debridement of necrotic tissue and acts as a sterile barrier.\(^{[33,34]}\)

Intra-operative debridement should involve thorough lavage and removal of all macroscopic contamination, de-vitalized tissue and loose bone grafts. No attempt should be made to remove grafts that are partially or fully fused. Intra-operative specimens for bacteriological culture must be obtained before application of the VAC system.\(^{[33,43]}\)

Canavese et al.\(^{[40]}\) treated 14 patients with early post-operative infections in which removal of the implant was undesirable because fusion had not been achieved. These authors had no patients who required removal of hardware and no loss of correction at an average of 44 mo of follow-up.

**DISCUSSION/CONCLUSION**

In patients with neuromuscular disease, the likelihood and severity of scoliosis increase with the degree of neuromuscular involvement. There is little doubt that segmental instrumentation techniques have revolutionized the care of patients with neuromuscular scoliosis by providing lasting correction, significant relief of pain, and restoration of quality of life and sitting positions. Moreover, continuous evolution in segmental instrumentation has increased the percentage of successful surgical corrections.

However, it must be stressed that although neuromuscular scoliosis can be well corrected with different constructs (hooks, screws, sub-laminar bands, U-rods, L-rods), there is a high rate of associated complications.\(^{[33,34,48]}\) The complication rates have increased with time, and an increasing number of complications have been reported in the recent literature. This can be explained by the improvement in complication recording but also that more severe patients are now operated. The evidence of such complications should never be underestimated by the treating surgeon, and the rate of such complications is particularly high in patients with flaccid neuromuscular scoliosis, i.e., spinal muscular atrophy and Duchenne muscular dystrophy.\(^{[22]}\)
The literature regarding the surgical management of spinal deformities in neuromuscular disorders has suggested that bilateral instrumentation and fusion to either L5 or the sacrum are the most effective, and multiple fixation points, such as sub-laminar wires or bands, are preferred [23,24,36,38,43]. In our opinion, instrumentation of the pelvis is indicated in non-ambulatory patients with pelvic obliquity. Fixation of the pelvis can be obtained with iliac screws, while hybrid instrumentation (screws, hooks, sub-laminar bands) or band-only instrumentation can be used for deformity correction. Fusion to the sacrum should be avoided in patients with residual walking ability.

In contrast, ambulatory patients should be fused to L5 at most with hybrid constructs (screws as distal anchorage, hooks and sub-laminar bands as proximal anchorage).

Restoring the sagittal balance of the spine is one of the most challenging goals in scoliosis surgery. Sub-laminar bands have been demonstrated to provide good deformity correction on both the coronal and sagittal planes [46]. Moreover, the operative time, bleeding and radiation exposure are reduced, with a low rate of early or late surgical complications.

The state of knowledge regarding neuromuscular scoliosis is a dynamic process, so a current literature review was mandatory. The somewhat large bibliography for this subject reflects the many opinions and findings presented here.

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P- Reviewers: Aota Y, Lykissas MG  S- Editor: Wen LL  L- Editor: A  E- Editor: Lu Y