SANAMED
2024; 19(3): 367–372
ISSN-1452-662X

DOI: 10.5937/sanamed0-52708
UDK: 616.711-007.5-089
ID: 159951113
Review article

MINIMALLY INVASIVE BIPOLAR FIXATION FOR THE TREATMENT OF NEUROMUSCULAR SCOLIOSIS-MILADI's TECHNIQUE

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Primljen/Received:12. 08. 2024. Prihvaćen/Accepted: 4. 12. 2024. Published online first: 16. 12. 2024.

Abstract: This paper presents the minimally invasive bipolar technique, also known as Miladi's technique, for the treatment of neuromuscular scoliosis. This approach involves bipolar spinal fixation extending from T1 to the pelvis. Proximal fixation is achieved using laminar and pedicular hooks configured as claws, while distal fixation employs iliosacral connectors and screws. The proximal and distal anchors are connected by a bilateral double-rod sliding construct, allowing for correction of spinal curvature and pelvic obliquity. This technique demonstrates reduced morbidity and complication rates compared to traditional methods.

Keywords: neuromuscular scoliosis, minimally invasive technique, iliosacral screws.

INTRODUCTION

Neuromuscular scoliosis is caused by diseases of the nervous system (brain, spinal cord, motor neurons) or muscular system of varying etiologies. The most common causes include cerebral palsy, Duchenne muscular dystrophy, myelomeningocele, spinal muscular atrophy, Friedreich's ataxia, and spinal cord injury (1). Vertebral deformity is progressive in most patients, particularly in those with severe neurological and systemic diseases (1).

While vertebral deformities appear similar across different etiologies, the specific clinical characteristics of each condition must be considered. The deformity often manifests at an early age, frequently resulting in trunk imbalance. The progression of spinal deformity is influenced by the patient's age, severity of motor injury, and curve magnitude. In patients with spastic quadriplegia aged 12 years, it has been observed that curves of ≤ 40 degrees progress more slowly (2, 3, 4). Associated problems such as intellectual disability, digestive disorders, and cardiac issues may also aggravate the clinical condition (5).

The outcomes of neuromuscular scoliosis progression are consistent across different etiologies. The deformity can impair positioning for daily care, sitting, standing, and ambulation in those capable of walking. Over time, it may lead to pain, skin lesions, and respiratory and cardiovascular complications (6, 7).

Conservative treatment options have limited effectiveness in managing neuromuscular scoliosis but are initially employed to provide external support for trunk balance in sitting positions for patients with flexible curves (8). Long-term success with bracing is rare. However, improvements in sitting balance, Cobb angle, and care facilitation have been reported with the use of three-point and molded braces (9).

Surgical treatment is indicated for progressive deformities accompanied by trunk imbalance or pelvic obliquity, which affect sitting or standing balance. In spinal muscular atrophy, early surgical intervention may be warranted to address increasing deformity and respiratory restriction caused by bracing (10).

In the past, combined anterior and posterior approaches were commonly used, but the posterior approach is now preferred. For patients with pelvic obliquity, spinal fixation typically extends from T1-T2 to the pelvis. In patients without pelvic obliquity and with flaccid or nonspastic paralysis, fixation may end at L5 (11, 12, 13). However, surgical correction of neuromuscular scoliosis carries significant risks. Among 8975 patients undergoing surgical correction for spinal deformity, neuromuscular scoliosis was the only group with recorded deaths within the first postoperative month (14).

The drawbacks of limiting trunk growth and its impact on lung development have driven the evolution of growth-sparing techniques. Although such tech-

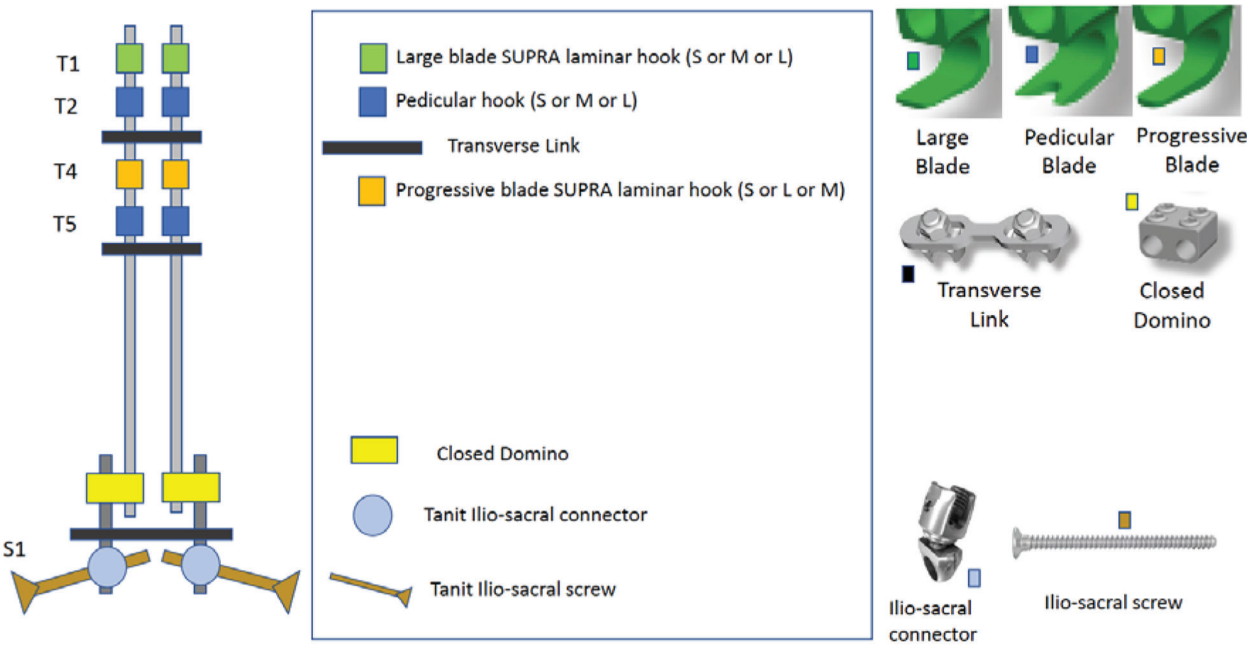

Figure 1. *Illustration of the assembly of the bipolar system and its components (Source: EUROS)*

niques allow for spinal growth, they are associated with high complication rates, including screw malposition, rod breakage, hook migration, screw pullout, infection, and skin issues, requiring reintervention in 40% to 60% of cases (15, 16).

The bipolar technique (Figure 1), a minimally invasive, fusionless method for neuromuscular scoliosis, was first described by Miladi in 2018 (16). This technique offers an alternative approach with reduced surgical morbidity and lower risks of mechanical and infectious complications (16, 17). It has since been expanded to address other deformities, including kyphosis and early-onset scoliosis. In young children, the technique enables effective correction of spinal deformities while preserving spinal growth through a device coupled to the rods (16, 17).

Bipolar operative technique

The patient is operated on under traction, with proximal traction applied using a skull clamp and distal traction applied to the legs. In patients with pelvic obliquity, the traction is asymmetric. The distal traction applies 10% to 15% of the patient's body weight.

The construct extends proximally from T1 to the sacrum. Proximal fixation is achieved using hook-claws on each side (laminar and pedicular hooks) (Figure 2). In some cases, pedicular screws may also be used, depending on the surgeon's preference. The proximal construct includes fixation of the first thoracic vertebra.

Distal fixation is performed using an iliosacral connector and iliosacral screw (Figure 3). The iliosacral connector is inserted into the sacrum laterally to the L5-S1 joint and proximal to the first posterior sacral foramina. A transmuscular paramedian (Wiltse) approach is employed following a short midline lumbopelvic incision to expose the posterior sacral cortex and the site for connector insertion on both sides. After placing the connector into the sacrum, the iliosacral screw is inserted percutaneously from the posterior part of the iliac bone in an oblique posterior-to-ante-

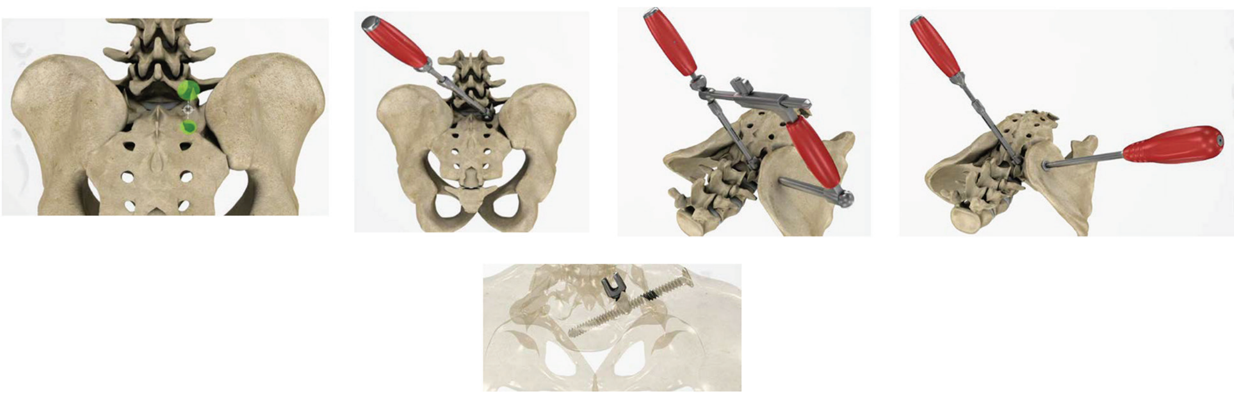

Figure 2. *Drawing illustrating the placement of the iliosacral connector and screw (Source: EUROS)*

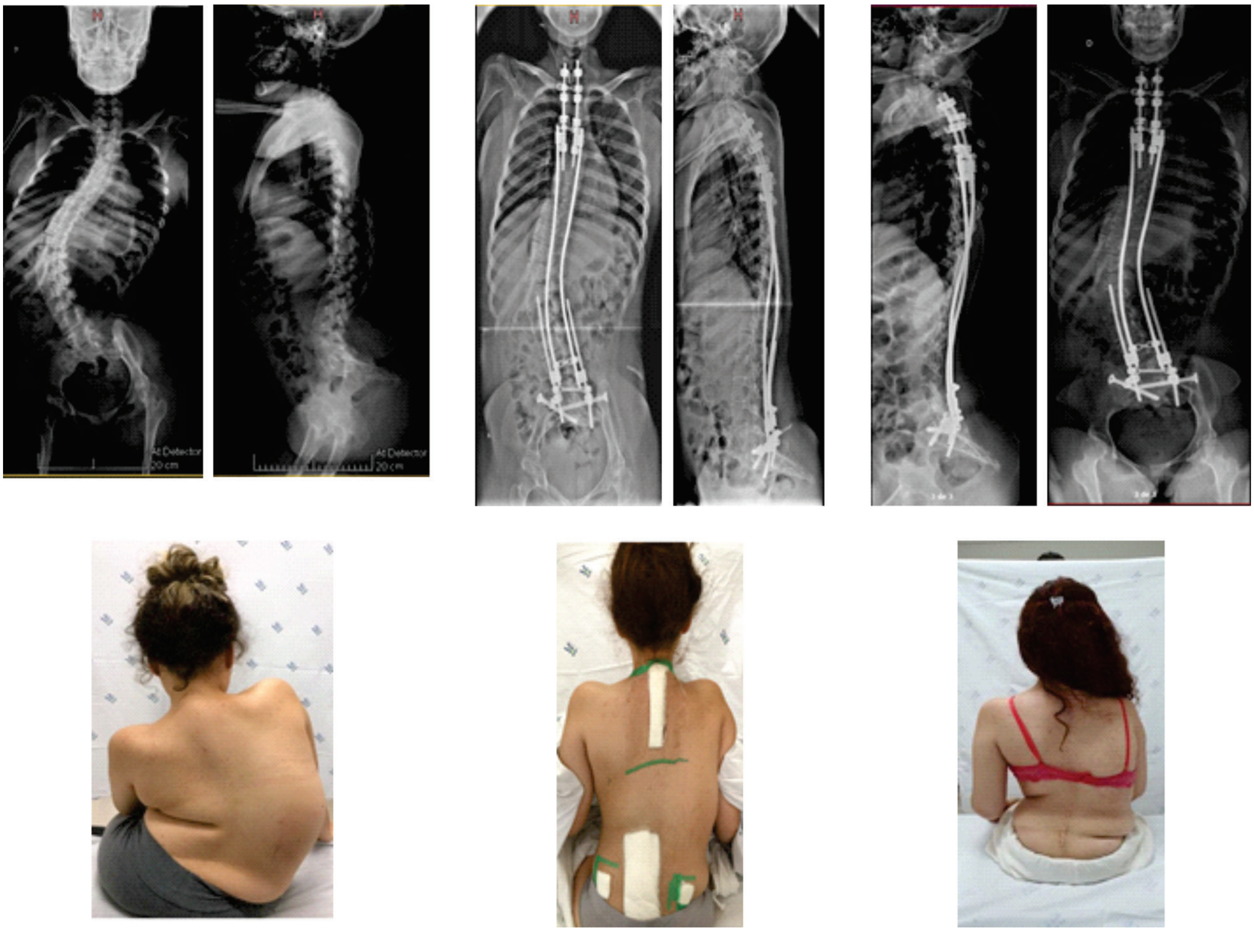

Figure 3. *Radiographs and photos of a 15-year-old female patient with progressive spinal amyotrophy. From left to right: preoperative, immediate postoperative, and 1-year follow-up (Source: author's own archive)*

rior direction using a guide. A 7 mm screw extending from the external iliac to the vertebral body of S1 is placed inside the deep ring of the connector. The iliosacral screw provides strong and stable fixation, and the connector's low profile allows its use in very young and thin patients.

The proximal and distal constructs are connected using two rods. The proximal rod is positioned medially, while the distal short rod is placed laterally. These rods are connected by a side-to-side domino (Figure 1). The rod on the concave side is inserted first, and deformity correction is achieved through progressive rod distraction at the domino, which connects the proximal and distal short rods. Before insertion, the rod should be contoured to accommodate the sagittal and coronal planes.

The rod on the convex side is inserted after the concave rod. Pelvic obliquity can be corrected by applying distraction on the concave side rod or compression on the convex side rod.

The rods on the concave and convex sides are further stabilized using three cross-link devices. Two cross-links are placed on the proximal rod, and one is placed on the distal rod near the iliosacral connectors. This configuration provides strong and stable fixation while allowing for future rod lengthening (Figure 3).

Problems related to neuromuscular spinal deformities

Treating neuromuscular spinal deformities is challenging and often associated with high complication rates. Spinal deformities typically manifest early and progress in most patients despite conservative treatments. Factors such as frailty, underlying clinical conditions, and osteoporosis contribute to the high incidence of complications. Treatment is particularly difficult in children under 10 years of age, as preserving spinal growth is crucial for lung development. Techniques like growing rods were developed for this age group but are associated with numerous complications (18-21).

To reduce complications and morbidity in the surgical treatment of neuromuscular scoliosis, Miladi developed the bipolar technique (16, 17). This technique offers greater stability compared to traditional methods, with lower morbidity and complication rates, and allows for growth without the need for additional surgeries (22). The NEMOST device enables spinal development without requiring further surgeries (23).

Miladi et al. reported the outcomes and complications of 100 consecutive patients with neuromuscular scoliosis who underwent minimally invasive fusionless surgery between 2011 and 2015 (16). The Cobb angle was corrected by 63%, and pelvic obliquity improved by 83%. Complications included wound infections, implant dislodgement, superior mesenteric artery syndrome, and pneumonia (2, 12, 16). The results demonstrated significant correction of spinal deformities and pelvic obliquity with a lower complication rate, avoiding the need for final arthrodesis (16). A high rate of spontaneous fusion was observed on CT (computed tomography) scans at the end of the lengthening period in patients undergoing bipolar minimally invasive fusionless surgery (5).

Long-term follow-up in patients with spinal muscular atrophy who underwent minimally invasive fusionless surgery showed preserved spinal and thoracic growth without compromising respiratory function. Definitive fusion was not required at the end of growth, and significant deformity correction was achieved (5, 15).

Pelvic obliquity, the fixed angulation of the pelvis relative to the horizontal axis in the frontal plane, is a common issue in patients with spinal deformities. It can interfere with sitting posture (24). Pelvic fixation is often necessary in non-ambulatory patients, especially when pelvic obliquity exceeds 15 degrees or when lumbar curvatures are present, to achieve coronal and sagittal balance (25). Several techniques for pelvic fixation have been developed, all of which carry mechanical complications (26). The pelvic extension of minimally invasive fusionless surgery originated from the ileo-sacral screw of the Cotrel-Dubousset system (22). Fixation is further enhanced by using the Wiltse approach, introducing the connector into the sacrum, and fixing it with a percutaneous screw inserted through the iliac and sacrum (S1) without violating the sacroiliac joint (Fig. 3). This fixation method, encompassing S1 and two cortices of the ilium, results in a high rate of pelvic obliquity correction (61%) and significantly reduces the rates of lumbosacral pseudarthrosis (0-0.65%) (17, 22).

Pelvic obliquity correction is more effective in patients undergoing minimally invasive fusionless surgery compared to traditional open procedures due to the repeated surgeries for lengthening (16, 17). The sacral alar iliac screw provides better correction of pelvic obliquity compared to traditional techniques, although it does not significantly affect lumbar curve correction (17, 22). Screw malposition was reported in 3.4% of cases, leading to root irritation and necessitating revision (17, 22). The deep placement of the ilio-sacral screw, along with its low profile, reduces the risk of implant prominence, reported in 11% of iliac screw fixation cases (Modi), as well as skin ulceration and postoperative pain when sitting (17, 22). The rod connection in the center of the screw, aligned perpendicularly to the iliac crest, crossing both cortices and ending in the S1 body, may explain the absence of screw pullout. This method offers lower mechanical complication rates compared to other pelvic fixation techniques (15).

When comparing fusionless surgery to standard fusion surgery in neuromuscular scoliosis, both methods achieved similar curve corrections, but fusionless surgery resulted in significantly fewer complications and reduced intraoperative blood loss (27).

One common complication of growth-sparing techniques is rod breakage, which occurs in 15%-42% of cases (5, 12, 15). Rod breakage can lead to pain, loss of correction, and skin rupture, necessitating re-intervention. The bipolar technique, however, has a lower rate of rod breakage (6.9%) in neuromuscular deformities, with a mean follow-up of 5.2 years. The rate of rod failure is higher in ambulatory, dystonic, and hyperactive patients, and a four-rod construct is recommended to reduce rod breakage (5, 12, 15, 24).

CONCLUSION

The bipolar technique for the surgical treatment of neuromuscular scoliosis enables the achievement of a balanced, stable spine, prevents deformity progression, and allows for growth. This minimally invasive approach offers fewer complications and better deformity correction than traditional techniques.

Conflict of Interests: The authors declare no conflicts of interest related to this article.

Funding: No

Authors' Contributions: All authors have contributed equally

Note: Artificial intelligence was not utilized as a tool in this study.

Sažetak

MINIMALNO INVAZIVNA BIPOLARNA FIKSACIJA ZA LEČENJE NEUROMIŠIĆNE SKOLIOZE-MILADI TEHNIKA

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Ovaj rad predstavlja minimalno invazivnu bipolarnu fiksaciju, poznatu i kao Miladi tehnika, za lečenje neuromišićne skolioze. Ovaj pristup uključuje bipolarno fiksiranje kičme od T1 do karlice. Proksimalna fiksacija se postiže korišćenjem laminarnih i pedikularnih kukica koje su oblikovane kao kandže, dok distalne fiksacije koriste ilio-sakralne konektore i šrafove. Proksimalna i distalna sidra su povezana bilateralnim dvostrukim kliznim konstrukcijama, što omogućava korekciju krivljenja kičme i pelvične nagnutosti. Ova tehnika pokazuje smanjeni morbiditet i stopu komplikacija u poređenju sa tradicionalnim metodama.

Ključne reči: neuromišićna skolioza, minimalno invazivna tehnika, ilio-sakralni šrafovi.

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How to cite this article: Defino LA H, Defino P M, Dorigão T. Minimally Invasive Bipolar Fixation for the Treatment of Neuromuscular Scoliosis – Miladi’s Technique. Sanamed. 2024; 19(3): 367-372. doi: 10.5937/sanamed0-52708.