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COMPLICATIONS IN PEDIATRIC NEUROMUSCULAR SPINAL DEFORMITY SURGERY: A COHORT STUDY OF 45 PATIENTS AND RISK FACTOR ANALYSIS

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ABSTRACT

Objective: Neuromuscular spinal deformity (NMSD) is a complex, progressive condition that affects children with disorders such as cerebral palsy, muscular dystrophy and spinal muscular atrophy. These children often experience significant functional limitations and an increased risk of surgery. This study aims to classify intraoperative and postoperative complications in pediatric NMSD surgery and identify related risk factors.

Materials and Methods: We retrospectively reviewed 45 pediatric patients who underwent surgical correction for NMSD between June 2020 and December 2024. We collected demographic, clinical, and surgical data. Complications were categorised as either intraoperative or postoperative. Logistic regression analysis was performed to identify risk factors associated with complications.

Results: Of the 45 patients (53% female; mean age: 11.7 years), 13 underwent growth-friendly procedures and 32 underwent definitive posterior spinal fusion. Intraoperative complications occurred in 37.8% of cases, primarily due to excessive bleeding (n=14). Postoperative complications were observed in 55.6% of patients, with the most frequent being infections (n=16), respiratory issues (n=12), and implant problems (n=9). The presence of a ventriculoperitoneal shunt, a history of previous spinal surgery, non-ambulatory status, pelvic fixation, and longer operative times were all significantly associated with higher complication rates.

Conclusion: Children with NMSD are at considerable risk during and after spinal surgery due to their underlying health conditions. Our findings emphasise the importance of recognising risk factors early on to improve outcomes. While surgical correction can offer substantial functional and postural advantages, a personalised, multidisciplinary care approach is essential to minimise complications and facilitate recovery in this vulnerable group.

Keywords: Neuromuscular spinal deformity, pediatric spine surgery, surgical complications, risk factors, posterior spinal fusion

INTRODUCTION

Scoliosis, defined as a three-dimensional deformity of the spine, is typically identified by a Cobb angle exceeding 10 degrees on the coronal plane[1]. Among its various forms, neuromuscular spinal deformities represent the second most frequent subtype[2]. This condition is commonly associated with underlying neuromuscular disorders, such as cerebral palsy, muscular dystrophies, or spinal muscular atrophy, which interfere with motor control and muscle tone.

In contrast to idiopathic scoliosis, curves in neuromuscular scoliosis patients tend to present earlier and often progress rapidly[3]. These deformities are usually more extensive and rigid, posing greater surgical challenges. Untreated cases can lead to deterioration in sitting balance, difficulty in mobility, and severe cases, compromise of respiratory and cardiac functions[4].

The extent of spinal curvature and its progression are closely related to the nature of the underlying neuromuscular disease. As such, surgical planning must be individualized, taking into account the patient's functional capacity, ambulatory status, and systemic health[5]. Although recent improvements in spinal instrumentation have enhanced the correction potential and overall outcomes[6], complication rates-especially in the perioperative period-remain high, necessitating a collaborative, multidisciplinary care model[7]. These complications result in longer stays in hospital and intensive care, placing a heavy burden on healthcare resources[8].

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The primary goals of surgery in this context include curve correction, enhancement of sitting and standing balance, pain reduction, and improved pulmonary function and quality of life[9]. Despite these objectives, intraoperative and postoperative complications continue to be a pressing concern. In our study, we aimed to classify these complications and analyze the risk factors for neuromuscular spinal deformity.

MATERIALS AND METHODS

The study was approved by the Clinical Research Ethics Committee of the University of Health Sciences Türkiye, Başakşehir Çam and Sakura City Hospital (decision number: 213, date: 27.03.2024), and was conducted in accordance with the principles outlined in the Declaration of Helsinki. Written informed consent was obtained from all participating patients and their legal guardians before data collection.

Pediatric patients diagnosed with neuromuscular spinal deformity who underwent surgical correction between June 2020 and December 2024 were retrospectively reviewed. Inclusion criteria consisted of complete documentation across preoperative, intraoperative, and postoperative phases, along with a minimum of six months of follow-up following surgery.

Collected demographic variables included age, sex, and ambulatory status. The underlying etiologies were categorized as central nervous system (CNS), peripheral nervous system, muscular, or mixed in origin. Operative data covered the surgical approach (posterior or anterior), type of instrumentation-either growth-friendly surgery (GFS) or posterior spinal fusion (PSF)-and additional interventions such as pelvic fixation or spinal osteotomies. Comorbidities were also recorded, including the presence of ventriculoperitoneal (VP) shunts and previous spinal surgery history related to spinal anomalies (e.g., tethered cord release, diastematomyelia surgery, or myelomeningocele repair). Intraoperative data included surgical duration, estimated blood loss, dural injury, and neurological events.

All patients were treated under a standardized surgical protocol. This included the administration of intravenous tranexamic acid (TXA) at induction, the use of prophylactic topical vancomycin, and the application of autograft material before wound closure. Surgical strategies were individualized based on curve characteristics, patient age, and progression rate. Growth-friendly techniques employed included Magnetic Expansion Control (MAGEC) rods, Shilla guidance systems, traditional growing rods, and other expandable constructs. For fusion cases, posterior spinal arthrodesis was the standard technique, supplemented with osteotomies where necessary. Pelvic fixation was performed when required. This was based on the status of the patient and the severity of the Cobb curvature and pelvic obliquity degree. Intraoperative neuromonitoring (motor-evoked potential, somatosensory evoked potentials, and electromyography) was routinely utilized.

Complications were stratified into intraoperative and postoperative events. Intraoperative complications were defined as excessive blood loss (≥30% of estimated blood volume), dural tears, and neurologic injury. Postoperative complications were further divided into early (within six weeks) and late (beyond six weeks) and categorized into three subtypes: infectious (superficial or deep SSI), respiratory (e.g., pneumonia, prolonged intubation, atelectasis, pneumothorax), and implant-related issues (e.g., screw loosening, breakage, rod migration, skin erosion).

Statistical Analysis

Statistical analysis was performed using SPSS version 27.0. The normality of data was evaluated with both Kolmogorov-Smirnov and Shapiro-Wilk tests. Normally distributed continuous variables were analyzed using the independent-samples t-test, while non-normally distributed data were evaluated with the Mann-Whitney U test. Categorical data were assessed via chi-squared or Fisher's exact tests as appropriate. Multivariate logistic regression was applied to identify factors independently associated with complication risk. A p-value of less than 0.05 was considered statistically significant.

RESULTS

A total of 45 pediatric patients underwent surgical correction for neuromuscular spinal deformity. Among them, 24 (53%) were female and 21 (47%) were male. The average age at the time of surgery was 11.7 years (range: 8-18 years), with a mean postoperative follow-up duration of 27.5 months (range: 7-48 months).

Etiology

The distribution of underlying diagnoses was as follows:

- **CNS disorders:** Cerebral palsy (n=13), syringomyelia (n=1), Chiari malformation (n=2), hydrocephalus (n=1), autism spectrum disorder (n=1), transverse myelitis (n=1).
- **Mixed central-peripheral etiology:** Myelomeningocele (n=19).
- **Peripheral neurological disorders:** Polyneuropathy (n=2), Friedreich's ataxia (n=1), spinal muscular atrophy type I (n=1).
- **Muscular disorders:** Myopathy (n=3).

Radiological and Surgical Parameters

The mean preoperative coronal Cobb angle was 55° (range: 30°-90°). Mean thoracic kyphosis (T5-T12) was 38° (range: 15°-70°), and mean lumbar lordosis (L1-S1) was 42° (range: 10°-70°). Four patients with myelomeningocele with lumbar kyphosis underwent kyphectomy, while the remaining 41 cases underwent scoliosis correction. Following surgery, the average Cobb angle improved to 10° (range: 0°-15°), with thoracic kyphosis reduced to 35° (range: 15°-50°) and lumbar lordosis to 40° (range: 10°-70°).

A posterior-only surgical approach was used in 44 out of 45 cases (97.7%), with a single myelomeningocele patient, who underwent anterior surgery. GFS were applied in 13 patients and included: MAGEC rods (n=7), Shilla rods (n=2), traditional growing rods (n=2), and sliding systems (n=2). PSF was performed in 32 cases. Among these, 18 patients underwent spinal osteotomy, and 21 required pelvic fixation using iliosacral or sacral alar-iliac screw instrumentation.

Complications

Overall complications were observed in 25 patients (55.6%). Intraoperative events occurred in 17 cases (37.8%) and included excessive bleeding (n=14), dural tears (n=2), and one transient neurological deficit. A total of 40 postoperative complications were recorded: surgical site infections (SSI) in 16 patients, respiratory issues in 12, and implant-related complications in nine. Rare complications included VP shunt dysfunction (one patient), gastrointestinal ileus (one patient), and cardiac arrest resulting in death (one patient).

The management of SSI involved treating five patients with intravenous antibiotics and wound care on the ward, eight patients with both treatment and surgical debridements in the operating room, and three patients were transferred to the intensive care unit (ICU) due to wound site-related sepsis. Respiratory complications included pneumonia (n=5), prolonged intubation (n=4), pneumothorax (n=2), and atelectasis (n=1). Implant-related problems were screw loosening or breakage (n=4), rod fracture (n=1), and soft-tissue erosion/skin breakdown (n=4). Some individuals experienced multiple complications (Figure 1).

Risk Factor Analysis

Patients with intraoperative complications were, on average, significantly older than those without (13.3 vs. 10.8 years, p=0.033). No association was found between complications and sex or deformity magnitude in either the coronal or sagittal plane (p>0.05). PSF procedures were linked with a significantly higher intraoperative complication rate compared to GFS (p=0.008).

Longer operative time was associated with both intraoperative (p=0.049) and postoperative complications (p=0.003). Higher intraoperative bleeding also correlated with increased complication rates (p<0.001 intraoperative; p=0.034 postoperative). These patients also required more transfusions (p=0.003 intraoperative; p=0.030 postoperative). Postoperative complications led to extended hospitalization (p<0.001) and prolonged ICU stays (p=0.036).

Pelvic fixation was found to significantly increase the likelihood of postoperative complications [odds ratio (OR): 3.2, p=0.009]. Other independent predictors were non-ambulatory status (OR: 2.9, p=0.033), the presence of a VP shunt (OR: 4.5, p=0.007) and previous spinal surgery (OR: 2.6, p=0.045).

DISCUSSION

Neuromuscular spinal deformities present significant challenges to surgical correction due to their complex interplay with musculoskeletal deformities and systemic comorbidities[10]. Neuromuscular patients frequently exhibit multi-organ involvement, thereby increasing perioperative risk[7]. It is imperative that these vulnerabilities are recognised and addressed in order to facilitate safe surgical planning, intraoperative management, and postoperative care. Surgical correction of neuromuscular scoliosis has been shown to be associated with a high complication rate, ranging from 17 to 74%[11].

The study found that 55.6% of patients experienced surgical complications. The most common intraoperative event was excessive bleeding, followed by dural tears and neurological injuries. Postoperatively, 40 complications were documented, primarily involving SSIs, respiratory problems, and implant-related issues. Infections ranged from superficial to deep SSIs and sepsis. Respiratory complications included pneumonia, atelectasis, prolonged intubation, and pneumothorax. Implant-related issues included rod fractures, pedicle screw loosening or breakage, and skin irritation due to hardware prominence.

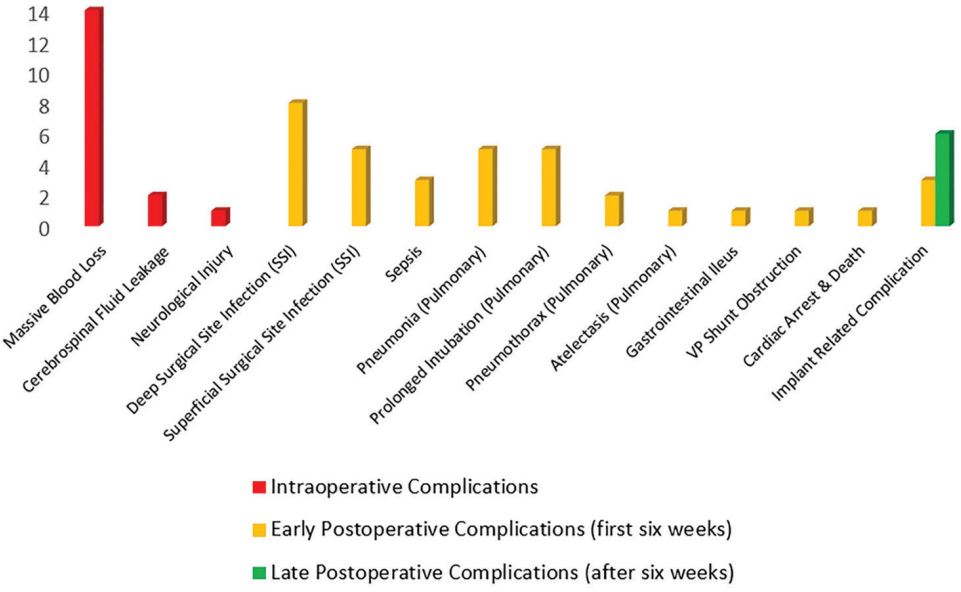

Figure 1. This illustrates the number of patients who experienced intraoperative and postoperative complications

Less common but clinically significant complications included VP shunt obstruction, gastrointestinal ileus and cardiac arrest/death. Several patients experienced multiple complications.

The study identifies risk factors associated with complications, including non-ambulatory status, VP shunt presence, previous spinal surgery history, and pelvic fixation use. Older age also correlates with increased intraoperative complications. The findings emphasize the need for comprehensive preoperative risk stratification for preventive measures. Complications in patients with prolonged surgeries, higher intraoperative bleeding, and blood transfusions result in longer ICU and hospital stays, highlighting the need for comprehensive risk stratification.

Previous studies have linked severe spinal deformities (e.g., Cobb ⩾50°, hyperlordosis, thoracolumbar kyphosis) with higher complication rates[12-14], but our data did not show a significant correlation between coronal or sagittal deformity and overall complications.

Although there was a difference in age at the initial surgery, PSF may be more effective than GFS at managing deformity. Although GFS patients experience greater spinal growth, they also encounter more complications and require additional surgeries[15]. However, GFS has several benefits, including improved lung health, better correction of deformities and an enhanced quality of life[16]. Furthermore, GFS has been associated with less blood loss, shorter surgeries, and faster recovery times[17]. Our research shows that GFS reduces bleeding during surgery much more effectively than PSF. However, GFS did not reduce the rate of complications after surgery compared to PSF.

Patients with neuromuscular disease are at high risk of extensive blood loss due to factors such as older age, increased fusion length, prolonged procedures and reduced bone mineral density[18-20]. Coagulopathies, often caused by antiepileptic drugs or an underlying condition, can also increase the risk of bleeding[21]. Bleeding often necessitates blood transfusions and extended hospital stays[22]. Perioperative blood transfusions also increase the risk of wound infection[23]. Topical and systemic TXA, hemostatic matrixes, and fibrin glues have been reported to effectively reduce bleeding[24,25]. In addition, a dual-surgeon approach has been demonstrated to reduce operative time, blood loss, complication rates and hospital stays[26]. In our study, excessive bleeding was associated with longer operative times, higher transfusion requirements, and longer stays in the ICU and hospital. Our data also showed that older patients experienced a higher amount of intraoperative bleeding. Postoperative complications were significantly associated with longer operative times and higher blood loss.

Patients who have undergone spinal surgery or intrathecal procedures are at a higher risk due to the presence of dural adhesions, altered anatomy, and compromised tissue planes[27]. Dural tears can lead to cerebrospinal fluid leakage, pseudomeningoceles, arachnoiditis, and wound infection[28]. Two patients with myelomeningocele in our cohort recovered without complications after their dural tears were repaired during surgery.

Preoperative computed tomography and magnetic resonance imaging imaging of the entire spine, as well as intraoperative neuromonitoring, are essential for ensuring neurological protection[29,30]. In our cohort, one non-ambulatory patient with myelomeningocele experienced transient hip flexor weakness which resolved within three months after surgery.

Malnutrition is common among neuromuscular patients due to feeding difficulties, gastrointestinal dysmotility, and increased metabolic requirements[31]. Low serum albumin and prealbumin levels can hinder wound healing and increase the risk of infection[32]. Poor nutritional status can also exacerbate respiratory muscle weakness and delay healing[33]. Percutaneous endoscopic gastrostomy tube feeding is often necessary to meet these patients' caloric requirements and prevent aspiration[34].

Patients with neuromuscular conditions are at a higher risk of infection following spinal fusion. Reported rates are 6-15% for patients with cerebral palsy and 8-42% for those with myelodysplasia. SSIs result in increased patient morbidity, the need for multiple operations, prolonged hospital stays and significant financial costs[35]. A study found that wound infection in children treated surgically for neuromuscular spinal deformity was associated with increased body weight after surgery, residual lumbar lordosis, pulmonary comorbidity, a history of myelomeningocele repair, seizures and previous operations[36]. The presence of a VP shunt prior to corrective surgery significantly increases the likelihood of a wound infection[37]. Our cohort confirms this, with a high incidence of postoperative complications in VP shunt patients. One case also required surgical shunt revision in the early postoperative period. The management of SSI involved treating five patients with intravenous antibiotics and wound care on the ward, eight patients with both treatment and surgical debridements in the operating room, and three patients were transferred to the ICU due to wound site-related sepsis.

Respiratory complications are particularly prevalent in this population due to weakened musculature and impaired thoracic mechanics[38]. These complications can include pneumonia, pneumothorax, atelectasis and pleural effusion, as well as the need for prolonged mechanical ventilation[39]. Patients with conditions such as Duchenne muscular dystrophy and spinal muscular atrophy are particularly susceptible to respiratory problems following surgery for spinal deformity[40,41]. Our findings were consistent with those reported in the literature, with pneumonia, prolonged intubation, atelectasis and pneumothorax being the most common postoperative respiratory issues. Although perioperative pulmonary rehabilitation has been shown to reduce the risk of respiratory complications[42], limited cooperation may hinder recovery and increase the risk of complications.

Patients with non-ambulatory status are more susceptible to implant-related issues, such as rod fractures, screw loosening and implant migration, partly due to poor bone quality[43]. Furthermore, non-ambulatory patients often have pelvic obliquity and hip dislocation, which impair sitting balance

and quality of life[44,45]. Of the 45 patients in our study, 23 had hip dislocation; all of these patients had an underlying neuromuscular condition, primarily myelomeningocele or cerebral palsy. Although pelvic fixation can improve alignment and function, it increases surgical complexity and the risk of complications[46,47]. Our data confirmed higher postoperative complication rates in non-ambulatory patients and in those requiring pelvic fixation. Several patients required revision surgery due to rod or screw breakage or loosening, as well as soft tissue irritation and skin breakdown. Figure 2 shows the postoperative complications related to the implant in a non-ambulatory patient with myelomeningocele and a VP shunt, who underwent lumbar kyphectomy and pelvic fixation. The patient is still being followed up and treated.

Although less common, gastrointestinal complications can arise from the use of narcotic analgesics and reduced motility[48]. One patient developed postoperative paralytic ileus, which was managed conservatively.

Cardiac complications are also a concern, particularly in patients with muscular dystrophy[49,50]. One patient in our cohort with type 4 collagen myopathy experienced cardiac arrest after surgery and subsequently died from multi-organ failure in the ICU. This case emphasises the importance of thorough cardiac evaluation prior to surgery.

Study Limitations

This study has several limitations. Its retrospective design and relatively small sample size limit the generalisability of our findings. Additionally, variability in follow-up duration and the lack of consistent data on nutritional status and pulmonary function further limit the ability to assess specific risk factors.

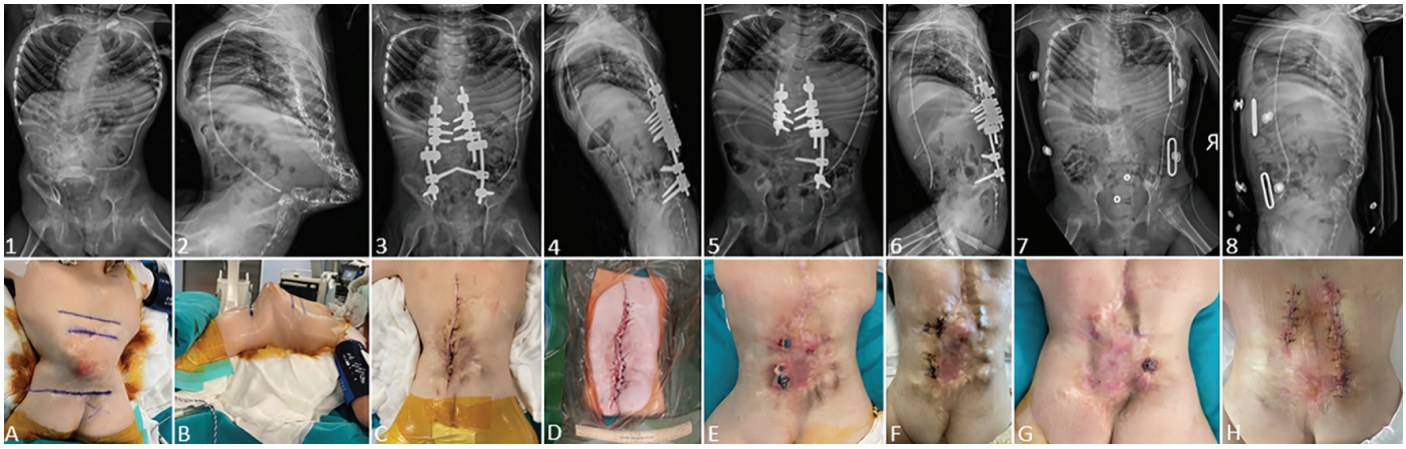

Figure 2. (1) and (2) show X-ray images of a patient with myelomeningocele taken before deformity surgery. (3) and (4) show X-ray images taken after the first surgical debridement. (5) and (6) show the results of the second surgical debridement, which involved implant removal due to exposure. (7) and (8) show the X-rays taken after the third surgical debridement, when all the implants were removed due to exposure. (A) and (B) show photographs of the patient's skin before the initial deformity surgery. (C) and (D) are photographs of the patient's skin before (C) and after (D) the first surgical debridement at 3 weeks after index surgery. (E) and (F) are photographs of the patient's skin before (E) and after (F) the second surgical debridement at 4 months after index surgery. (G) and (H) are photographs of the patient's skin before (G) and after (H) third surgical debridement at 6 months after index surgery

CONCLUSION

This study highlights the complex and multifactorial nature of surgical complications in neuromuscular scoliosis. Non-ambulatory status, pelvic fixation, VP shunts, and previous spinal surgery significantly increase the risk of postoperative complications. Comprehensive preoperative assessment, multidisciplinary management, and careful surgical planning are critical in reducing morbidity and improving outcomes in this vulnerable population. Future prospective studies are needed to validate these findings and refine perioperative risk models.

Ethics

Ethics Committee Approval: The study was approved by the Clinical Research Ethics Committee of the University of Health Sciences Türkiye, Başakşehir Çam and Sakura City Hospital (decision number: 213, date: 27.03.2024).

Informed Consent: Written informed consent was obtained from all participating patients and their legal guardians before data collection.

Footnotes

Authorship Contributions

Surgical and Medical Practices: Y.Ö., K.A., A.V.Ö., M.B.B., Concept: M.B.B., Design: Y.Ö., Data Collection or Processing: Y.Ö., Analysis or Interpretation: K.A., Literature Search: Y.Ö., A.V.Ö., Writing: Y.Ö.

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