

Neuromuscular Scoliosis: Comorbidities and Complications

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Study Design: Single-center, retrospective cohort study conducted from 2013 to 2017.

Purpose: To determine the risk factors for surgical complications in neuromuscular scoliosis based on known patient comorbidities.

Overview of Literature: The concept of neuromuscular scoliosis includes a wide variety of pathologies affecting the neuromuscular system. Complications are numerous and are often difficult to predict.

Methods: A retrospective analysis of a single-center database was conducted from 2013 to 2017. Inclusion criteria were patients aged <25 years, diagnosis of neuromuscular scoliosis, and history of posterior fusion deformity surgery. A total of 64 patients (mean age, 15 years; 63% females) were included in this study. Clinical, radiological, and laboratory parameters in the preoperative, intraoperative, and postoperative settings were analyzed. Univariate analysis was performed using Student t-test for continuous variables, and a chi-square test was used for noncontinuous variables. Multivariate analysis was performed to identify predictors of major, mechanical, and total complications.

Results: Complications were found in 44% of patients, with 46.9% consisting of major complications, and 84.4% being early complications. Univariate analysis revealed that the presence of perinatal comorbidities, independent of other comorbidities, increased the risk for complications ($p=0.029$). Preoperative hypoglycemia, high number of instrumented levels, longer surgical time, use of an all-screw construct, lower preoperative pelvic obliquity, postoperative lower kyphosis, high thoracic spinopelvic angle (as measured by T9 spino-pelvic inclination), absence of deep drain, and use of superficial drain were associated with postoperative complications (all $p<0.05$). Logistic regression demonstrated that comorbidities, longer surgical time, hypoglycemia, and absence of deep drains are predictors of complications. Independent variables that predicted major complications were the number of levels fused, postoperative kyphosis ($p=0.025$; odds ratio [OR], 1.074), and high screw density ($p=0.014$; OR, 4.380).

Conclusions: Complications in neuromuscular scoliosis are increased by comorbidities, long surgical time, and inadequate correction. Preventative measures to decrease these complications include appropriate preoperative patient preparation and surgical planning.

Keywords: Scoliosis; Complications; Comorbidity; Perinatal

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Introduction

The concept of neuromuscular scoliosis includes a wide variety of pathologies associated with both the nervous and muscular systems [1]. With such a heterogeneous group of disorders, it is difficult to establish guidelines for preoperative planning, surgery, and postoperative treatment. Although patients are evaluated individually, identifying the shared characteristics can be valuable for treatment algorithms.

It is difficult to anticipate the complications in neuromuscular scoliosis surgery, with rates being reported from 6.3% to 50.0% [2-14]. The Scoliosis Research Society morbidity and mortality database for neuromuscular scoliosis reported a rate of 13%–16% between 2004 and 2007. This rate dramatically decreased to 4% between 2012 and 2015,

and the authors primarily attributed this reduction to a two-fold decrease in infection rate.

Over the past 20 years, there have been insufficient, quality studies reporting the associations between neuromuscular scoliosis complications and controllable parameters, including ambulatory status, diagnosis of myelomeningocele, curve magnitude severity, instrumentation type, estimated blood loss, and pulmonary comorbidities [2-7,9-13,15] (Table 1). None of the published reports addressed the potential impact of perinatal comorbidities.

The Barker hypothesis proposes transgenerational epigenetic inheritance these changes might occur in as early as one generation [16]. Later life outcomes such as lower test scores, psychiatric diseases, and epilepsy have been associated with perinatal circumstances [16]. We hypothesized that epigenetic inheritance and perinatal

Table 1. Articles that studied the correlation between known parameters and complications in neuromuscular scoliosis

Variable	No. of studies	Reference	Our study
Demographics			
Age >13 yr	2	[9,12]	No, low Risser yes
Nonwhite race	1	[7]	Not analyzed
Family income	1	[7]	No, same results public/private hospital
Comorbidities			
≥1 known comorbidity	2	[7,9]	Yes
Pulmonary comorbidity	3	[2,4,12]	No
Known diagnosis: MMC or Duchenne	4	[2,9,10,15]	Yes
Weight under 5% or over 95%	2	[2,9]	No
Epilepsy	1	[2]	No
Previous surgery	1	[2]	No
Non-ambulatory	4	[2,9,11,13]	Yes
Curves characteristics			
Curve magnitude	4	[3,9,11,12]	No
Curve rigidity	1	[3]	No
Pelvic obliquity	2	[2,9]	No
Surgery related			
No. of levels instrumented	1	[7]	Yes
One versus double staged surgery	1	[15]	No
Type of instrumentation	4	[5,6,9,10]	No
Osteotomies	1	[6]	No
Surgical time	2	[2,9]	Yes
Blood loss	3	[2,7,9]	Yes
Inadequate reduction (LL or PO)	1	[2]	Yes, for major complications

LL, lumbar lordosis; PO, pelvic obliquity; MMC, Myelomeningocele.

comorbidities could potentially be related to complications in neuromuscular scoliosis surgery. Therefore, the present study was conducted to investigate the association between perinatal comorbidities, preoperative evaluation, surgical parameters, and postoperative complications in neuromuscular scoliosis.

Materials and Methods

This study was approved by the ethics committee for evaluation (approval no., 383/2019). Informed consent was obtained from all individual participants included in the study. A single-center retrospective analysis was conducted using the data of patients operated between August 2013 and October 2017. Inclusion criteria were patients aged <25 years, a diagnosis of neuromuscular scoliosis, and a past surgical history of a posterior spinal fusion. Exclusion criteria were history of revision spine surgery or use of growth-guided systems. Data were collected from patient charts.

1. Preoperative evaluation

All patients underwent the same preoperative evaluation protocol consisting of a cardiac, pulmonary, psychological, and laboratory assessment. Data pertaining to perinatal morbidity were collected, including pregnancy characteristics, type of delivery, gestational weeks at birth, maternal diseases during pregnancy, birth weight, and birth size.

The following parameters concerning the current physical condition were evaluated: gait, preoperative and postoperative height and weight, comorbidities, previous surgeries, sports practiced, presence of thelarche in girls and increase in testicular volume in boys, age at menarche in girls or voice change in boys, use of preoperative brace, allergies, and use of medications. All patients underwent preoperative laboratory testing, including hematocrit (Ht, expressed as %), hemoglobin (Hb, g/dL), and platelet count (100,000 platelets/field); coagulation analysis comprising activated partial thromboplastin time (seconds) and prothrombin time (%); and a biochemical analysis of blood urinary nitrogen and glucose (both in mg/dL).

Patients were evaluated by a pediatric cardiologist using a bidimensional echocardiogram to search for any malformations. Ejection fraction was measured in patients when an adequate acoustic window permitted it. When possible, spirometry with and without a β_2 -sympathomimetic agent was performed to measure forced expiratory volume dur-

ing the first second (FEV1). When spirometry was not possible due to mental or physical issues, thoracic anteroposterior and lateral X-rays, along with clinical evaluation, were used for preoperative assessment. Other respiratory parameters analyzed in this study were the use of nocturnal external respiratory aids such as bilevel positive airway pressure (BiPAP) and the number of lower respiratory tract infections (LRTI) per year in the preoperative and postoperative period.

All patients underwent a complete urinalysis and culture test. The number of urinary tract infections (UTIs) per year was recorded. If the urine culture test result was positive or the patient had previous urine culture tests, the colonizing bacterial type was evaluated. If a culture had $\leq 80,000$ colonies/field, it was considered as colonization and was left untreated.

Neurological evaluation was also performed when possible. Patients with epilepsy were preoperatively administered escitalopram for 3 days to avoid seizures related to neuromonitoring unless they were already taking this drug. The number of preoperative and postoperative seizures and the number and type of anticonvulsants taken were also recorded.

A psychological evaluation was performed on all complying patients to identify situations that would be contraindicated for surgery and to provide support and recommendations for families and patients. In general, three sessions were performed, including two before surgery and one postoperatively.

Preoperatively, an anesthesiologist evaluated all patients 1 month before surgery and classified the patients according to the American Society of Anesthesiologists (ASA) physical status classification [17]. Preoperative temperature ($^{\circ}\text{C}$), blood pressure (mm Hg), heart rate (bpm), and oxygen saturation (%) were also recorded.

Imaging evaluation was performed preoperatively, immediately postoperatively, and at 2-year follow-up and included full-length anteroposterior and lateral radiographs as well as preoperative bending and traction films to evaluate the curve flexibility. Radiographic parameters of interest included skeletal maturity assessed using the Risser scale, curve magnitude (Cobb angles), apical vertebral rotation assessed using the Raimondi method, pelvic obliquity (PO), cervical lordosis, thoracic kyphosis (TK), lumbar lordosis, pelvic incidence, sacral slope, pelvic tilt, sagittal vertical axis, T1 Spino-pelvic inclination, and T9 spino-pelvic inclination (T9SPI) [18-20]. All measure-

ments were performed in Surgimap ver. 2.2.14.1 (Nemaris Inc., New York, NY, USA).

Details regarding the following intraoperative parameters were collected: blood pH, PCO₂ (partial pressure of carbon dioxide, mmH₂O), PO₂ (partial pressure of oxygen, mmH₂O), Ht/Hb, screw density, type of rod material, type of derotation technique, osteotomies, surgical time (from skin incision to the placement of the dressing), intraoperative bleeding, number of red blood cells (RBCs), plasma and platelet transfusions, and the use type and dosage of vasoactive drugs. Neuromonitoring data were analyzed regarding baselines, endlines, and any alerts.

Postoperative parameters evaluated in this study included length of stay (LOS) at each unit, admission to the intensive care unit (ICU) with or without mechanical ventilation, airway status (intubated or extubated), Ht, Hb, platelets, and C-reactive protein at postoperative days 1, 3, and 7. Postoperative transfusions were also evaluated. Postoperative bleeding was evaluated by measuring the drain output and the number of drain days.

Early complications were defined as complications that occurred in the perioperative period up to 12 months postoperatively. Complications classified after this time period were considered as late complications. Major complications were defined as those that pose a risk to the patient's life, and mechanical complications were any of those related to the osteosynthesis material.

2. Statistical analysis

Univariate analysis was conducted to compare patients who sustained a complication versus those who did not using a chi-square or a two-tailed Student *t*-test. Similar analyses were conducted for major and mechanical complications. Statistically significant parameters identified in the univariate analysis were then used in a binary logistic regression to examine the variables with the largest impact associated with the likelihood of developing complications. Statistical analysis was conducted using IBM SPSS ver. 19.0 (IBM Corp., Armonk, NY, USA), and the level of significance was set at 0.05.

Results

1. Demographics

A total of 64 consecutive patients were included in this

Table 2. Primary diagnosis

Diagnosis	No. of frequency
Neuropathics	
First motoneuron	
Cerebral palsy	20
Chiari type I	4
Siringomyelia	3
Intradural tumors	2
Spinocerebellar ataxia	1
Spinal cord trauma	2
Second motoneuron	
Charcot–Marie–Tooth	1
Spinal atrophie type II	3
Congenital hypothyroidism	6
Mixed	
Tetherd cord	2
Myelomeningocele	8
Myopathic	
Duchenne syndrome	1
Central core disease	1
Collagenopathies	
Marfan syndrome	3
Ehler–Danlos syndrome	7

study, with a follow-up time of 24 months. The majority of cohort consisted of female patients (62.5%), with a mean age at surgery of 15 years (range, 8–25 years). Motor neuron pathologies accounted for 50% of the cohort, with cerebral palsy being the most common diagnosis in this group (Table 2).

In total, 51.6% of the patients were treated in the public system, and 48.4% were treated in the private system by the same surgical team and primary surgeon. Preoperative weight (mean, 45.49±44.48 kg) significantly increased (mean, 51.45±15.17 kg) at 2-year follow-up ($p=0.030$), as did mean height (preoperative, 135.09±44.49 cm; 2-year follow-up, 148.74±33.81 cm; $p<0.001$).

2. Complications

The mean complication rate was 44.4% (28 patients with 32 complications), and early complications accounted for 84.4% of all complications (Table 3). Among patients with complications, 7.7% had a surgical site infection (3.1%

Table 3. Complications

Complication	Rate (%)
Superficial infection	3.13
Deep infection	4.7
Occipital pressure sore	1.6
Bilateral pneumonia	4.7
Minor pneumothorax/atelectasis	4.7
Varicella	1.6
Intraoperative screw pullout repositioned during same surgery	1.6
Unidentified fever for 2 days	4.7
Incidental durotomy	3.13
Hypovolemic shock	4.7
Tongue biting	1.6
Postoperative convulsions	3.13
Paraparesis (complete recovery 3 weeks)	1.6
Postoperative paralytic ileum	1.6
Late complications	
Proximal screw pullout due to proximal junctional kyphosis	3.13
Pedicle fracture due to traumatic accident	1.6
Nonunion	3.13

superficial and 4.7% deep), and 4.7% were diagnosed with pneumonia. Vancomycin and amikacin were the most commonly used antibiotics in infected patients. Among patients with deep infection, one was diagnosed with varicella and received extended treatment with acyclovir. Two incidental durotomies were repaired during surgery without further complications.

Major complications were found in 49.9% of patients, with all complications occurring in the early period (i.e., before 1 year). Among these patients, three recuperated from hypovolemic shock, 9.4% were due to respire, and two patients had status epilepticus. There were no deaths in this series. Late complications were all mechanical in nature and observed in 7.8% of patients; two of these were nonunions requiring revision, and both were myelomeningoceles with sacroiliac nonunion and underwent anterior lumbar interbody fusion with good results.

In total, 63% of patients had normal baselines in the four extremities, and 8% had only readable somatosensory evoked potential (SSEP) and motor evoked potential (MEP) in the upper extremities. All other patients had either absent, altered, or incomplete lines in the upper and lower extremities. A total of 10 patients had intraoperative

neuromonitoring alerts, of which four were perfusion-related and spontaneously recuperated upon increasing the blood pressure, whereas two were minor alerts during detethering that recuperated immediately after the completion of this part of procedure. Among the remaining four alerts, three patients had a decrease in MEP in one lower extremity, primarily anterior tibialis and adductor hallucis longus with no clinical postoperative consequence, and one patient with Ehlers–Danlos syndrome had a complete loss of lower extremity SSEP and MEP. Partial improvement was observed after activation of the intraoperative protocol (<50% at final follow-up), but the patient woke up paraparetic (M2 right lower extremity and M3 left lower extremity), with complete recovery at 3 weeks.

3. Clinical evaluation

1) Perinatal characteristics

In total, 78.5% of the mothers had normal pregnancies, 54.8% of deliveries where eutocic, 41.9% were C-sections, and 3.2% required the use of forceps. Delivery occurred at a mean of 37.9 weeks (range, 26–41 weeks), with a mean birth weight of 3,186 g (range, 1,040–4,280 g) and a mean size of 48.2 cm (range, 32–54 cm). Furthermore, 33.3% of patients had no perinatal pathologies. A prenatal diagnosis of pathology involving the central nervous system (myelomeningocele) was found in 14% of mothers. The most common perinatal conditions besides morphological alterations of the spinal canal (seven patients) were genopathies, prematurity, and perinatal pneumonias.

2) Comorbidities

At least one comorbidity was found in 93.75% of patients, whereas 56% of them had three or more comorbidities, with a maximum of 10 comorbidities.

3) Previous surgery

In total, 62.5% of patients had undergone previous surgeries, 46.9% had undergone fewer than three surgeries, and 15.7% had undergone more than four surgeries.

4) Current health

A total of 73.8% of patients underwent surgery post menarche or voice change at a mean age of 12.8 years. Of those premenarchial patients, 17.7% had already undergone thelarche or displayed secondary sexual characteristics at a mean age of 10.27 years. No allergies were found in

70.8% of patients, whereas 18.5% were allergic to latex (all myelomeningocele cases), 4.6% were allergic to penicillin, and 3% had other allergies. There were no sports activities in 85.9% of patients, whereas 32.3% of them had undergone a previous treatment with a brace.

5) Cardiac evaluation

No cardiac alterations were found in 73.4% of patients. Among those with morphological findings, the majority were mild tricuspid insufficiencies. Ejection fraction could be measured in only 15/64 patients, with the mean value being $71.53\% \pm 14.78\%$. Two patients had life-threatening malformations, including one patient who had a severe aortic dilatation with mitral valve reflux and cava dilatation with Marfan syndrome that required evaluation by a cardiothoracic surgeon; however, no cardiac surgery was recommended at that point and posterior spine fusion was subsequently authorized. The other patient had cardiac insufficiency due to cor pulmonale secondary to a 144° curve magnitude that required permanent digoxin to maintain cardiac function.

6) Bronchopulmonary evaluation

Standard spirometry evaluation could be completed in 29.7% of patients, with the mean FEV1 being $73.16\% \pm 17.58\%$. Preoperatively, 60% of patients had more than three episodes of LRTI a year, of whom 15.6% required domiciliary nocturnal BiPAP. Postoperatively, 8.1% of patients presented with an LRTI, and the difference between the preoperative and postoperative number of LRTIs was significantly different ($p < 0.000$).

7) Urological evaluation

Recurrent lower UTIs before surgery were found in 21.5% of patients; 69% of these patients had three or fewer UTIs per year, whereas 31% had up to six UTIs per year. After surgery, the UTI prevalence was 12.5%, with 75% of these patients having fewer than three UTIs per year and 25% having up to five UTIs per year; this decrease was significantly different ($p = 0.015$). In particular, 77.77% of the identified bacteria were Gram-negative.

8) Neurological evaluation

Preoperatively, 15.6% of patients suffered from one to four seizures per month. Of these patients, 20% were under anticonvulsant treatment, with 54% being treated with valproic acid, and all of them were under multi-pharma-

logical treatment. Postoperatively, 6.3% of patients still experienced seizures but at a maximum rate of once per month ($p = 0.007$).

9) Psychological evaluation

Psychiatric evaluation was performed in 71.9% of patients, and no psychotic or personality disorders were diagnosed. Although all patients undergoing psychiatric evaluation exhibited anxiety symptoms, no surgery was suspended or rescheduled due to psychological pathology.

10) Anesthesia

In total, 54.7% of patients had ASA 2, and 20.3% had ASA 3. Antibiotic prophylaxis with cefazolin was implemented in 96.6% of patients, whereas 3.4% received clindamycin. Vasoactive drugs were required to maintain hemodynamic stability in 34.4% of patients, of which phenylephrine was used in 25% of patients, epinephrine or norepinephrine in 28%, and 3% of them required the addition of dopamine.

11) Surgical technique

A total of 833 levels were instrumented. Titanium rods were used in 54.7% of patients, and CrCo rods were used in 40.6% of patients. In three patients, one rod of each material was placed. Screw placement was primarily a low-density screw technique (in 72.6% of patients). In 29.6% of patients, the instrumentation was performed to the pelvis. In 53.1% of patients, the coplanar technique was used for derotation, whereas apical rotation was used in 46.9% of patients. Osteotomies were performed in 40% of patients; 81% of these were classified as Schwab 2 [21]. Eight patients were simultaneously detethered, and no postoperative fistulas were formed. The mean surgical time was 217.4 ± 90.7 minutes.

12) Surgical correction

A total of 69% of patients had Risser scale scores of III to V. The mean preoperative maximum Cobb angle was $65.7^\circ \pm 25.5^\circ$, and by $11.2^\circ \pm 16.5^\circ$ and $18.9^\circ \pm 12.7^\circ$, respectively, on bending and traction films (both with $p < 0.001$). The maximum Cobb angle was corrected to $33.9^\circ \pm 23.6^\circ$ ($p < 0.001$) postoperatively, with a slight loss of correction at 2 years ($3.2^\circ \pm 8.3^\circ$, $p = 0.026$). PO was also significantly corrected ($p = 0.017$) and maintained at 2 years. In the sagittal plane, TK was significantly decreased from $41.0^\circ \pm 28.5^\circ$ to $34.1^\circ \pm 17.4^\circ$ ($p = 0.015$), with no further change at 2-year follow-up (Table 4).

13) Bleeding

Operative laboratory parameters were normal in all patients, with a mean Ht/Hb of 40.35%/13.26 g/dL, which

decreased to 30.88%/10.51 g/dL during the surgery and stabilized at 28.64%/9.9 g/dL in the postoperative period and 30.16%/12.44 g/dL at discharge (Table 5). Total blood

Table 4. Pre- and postoperative radiographic measurements

Measurement	Preoperative	Postoperative	Correction	p-value	2-yr FU	% Correction at 2-yr FU	p-value
Max Cobb (°)	65.7±25.5	30.6±22.2	-33.9±14.2	0.000	33.9±23.6	3.2±8.3	0.026
Bending (°)	56.1±28.2	-	11.2±16.5	0.000	-	-	-
Traction (°)	50.91±25.9	-	18.9±12.7	0.000	-	-	-
Pelvic obliquity (°)	12.34±16.88	6.54±10.14	-3.5±10.2	0.017	6.3±8.7	0.3±6.8	0.772
Apical vertebral rotation (°)	18.9±12.5	10.5±11.1	-7.5±13.1	0.000	11.2±10.7	1.1±8.7	0.461
Lordosis cervical (°)	13.74±13.5	17.6±17.0	1.7±15.2	0.405	14.5±13.6	-5.2±16.3	0.041
Thoracic kyphosis (°)	41.0±28.5	34.1±17.46	8.4±24.5	0.015	33.8±19.57	0.9±9.3	0.507
Lordosis lumbar (°)	54.6±19.85	51.89±15.2	-3.9±15.28	0.066	49.1±16.1	-2.4±12.1	0.190
Sacral slope (°)	35.6±11.13	35.0±10.67	-2.1±6.7	0.836	34.0±8.1	0.5±6.1	0.821
Pelvic incidence (°)	46.1±21.56	48.9±16.0	-2.9±6.5	0.495	47.3±14.8	-1.0±6.2	0.533
Pelvic tilt (°)	13.2±11.62	13.87±10.3	-0.6±6.9	0.760	14.0±11.6	0.3±7.0	0.750
Sagittal vertical axis (mm)	26.75±39.3	28.8±46.5	2.4±59.8	0.766	34.0±39.8	5.1±50.0	0.493
T9SPI (°)	11.5±11.0	8.3±8.8	-2.9±12.2	0.085	9.1±7.5	-0.5±8.5	0.702
T1SPI (°)	2.0±6.8	3.4±7.0	1.3±7.9	0.206	5.1±5.1	1.7±8.8	0.303

Values are presented as mean±standard deviation. Bold type is considered statistically significant. FU, follow-up; SPI, spino-pelvic inclination.

Table 5. Laboratory parameters pre- to postoperative

Variable	Preoperative	Intraoperative	Postoperative	At discharge
Hematocrit (%)	40.35±3.49	30.88±4.85	28.64±4.8	30.16±4.11
Hemoglobin (g/dL)	13.26±1.4	10.51±1.58	9.9±1.74	12.44±12.52
Platelets (thousand/field)	273.610±72.23	-	-	-
APTT	30.39±3.57	-	-	-
Prothrombin (%)	84.33±26.95	-	-	-
Glucose (mg/dL)	87.61±8.35	-	-	-
Blood urinary nitrogen (mg/dL)	14.43±4.72	-	-	-
Temperature (°C)	36.06±1.37	-	35.9±0.99	-
MAP (mm Hg)	110.31/63.34	-	102.61/57.07	-
Heart rate (bpm)	84.74±18.72	-	-	-
Saturation O ₂ (%)	98.26±1.48	-	-	-
PH	-	7.35±0.09	-	-
PCO ₂ (mmH ₂ O)	-	41.67±7.9	-	-
PO ₂ (mmH ₂ O)	-	9.63±66.70	-	-
C-reactive protein day 1 (mg/L)	-	-	9.0±7.5	-
C-reactive protein day 3 (mg/L)	-	-	115.65±88.96	-
C-reactive protein day 7 (mg/L)	-	-	81.90±54.21	-

Values are presented as mean±standard deviation or number. Bold type is considered statistically significant.

PCO₂, partial pressure of carbon dioxide; PO₂, partial pressure of oxygen; APTT, activated partial thromboplastin time; MAP, medial arterial pressure.

Table 6. Bleeding

Variable	Mean±standard deviation	Min–max
Intraoperative bleeding (mL)	938.89±668.016	150–4,000
Total drain debit (mL)	405.36±387.47	0–1,875
Total blood loss (mL)	1,423.21±866.35	175–4,425
Intraoperative transfusions	1.09±0.937	0–1
Postoperative transfusions	0.43±0.47	0–3

loss volume, including drain output, was 1,423.21±866.35 mL (Table 6). In 54.6% of patients, intravenous tranexamic acid (TXA) was used, and in 82.8% of patients, topical TXA was used (Table 7). Intraoperatively, 44 patients were transfused with RBCs, nine patients were transfused with platelets, and 14 patients were transfused with plasma. Postoperatively, 23 patients required RBC transfusions, and none required additional plasma or platelets (Table 6). Superficial drains were used in 48 patients, deep drains were used in 12 patients, and no drain was used in 16 patients. The mean number of days of drain use was 3.19 with a maximum of 7 days.

14) Hospitalization

A total of 26.6% of patients were sent to the ICU while intubated, of whom eight were mechanically ventilated after detethering to avoid Valsalva maneuver. Another 32.3% of patients were sent directly to the intermediate care unit. The mean length of hospital stay was 3.5 days.

4. Risk analysis

Patients with and without overall complications were compared using univariate analysis based on all the above-described preoperative, intraoperative, and postoperative parameters (Table 7). In terms of demographic data, there were no significant differences between patients with or without complications. The number of comorbidities was significantly higher in patients with complications (mean of 4.0 versus 2.5, $p=0.009$).

Patients with complications were more likely to have a history of perinatal comorbidities ($p=0.029$), independent of other comorbidities; no other perinatal parameters were statistically significant. The laboratory findings revealed that patients with complications had a significantly lower preoperative glycemia (84.7 versus 89.9 g/dL, $p=0.016$).

Intraoperatively, patients with more number of complications had more levels instrumented ($p=0.044$), longer surgical time ($p=0.012$), presence of an all-screw construct ($p=0.010$), absence of a deep drain ($p=0.003$), or use of superficial drain ($p=0.021$). Osteosynthesis material, simultaneous detethering, and use of osteotomies were not significant. Total bleeding was almost significant with a p -value of 0.065.

Patients with complications had a smaller preoperative PO ($p=0.050$), smaller postoperative kyphosis ($p=0.035$), larger flattening of TK ($10.8^\circ\pm 27.7^\circ$ versus $6.3^\circ\pm 21.6^\circ$), and higher postoperative T9SPI ($p=0.043$) (Table 8).

In the multivariate logistic regression analysis, presence of comorbidities ($p=0.026$; odds ratio [OR], 1.423), lower preoperative glycemia ($p=0.003$; OR, 0.865), longer surgical time ($p=0.020$; OR, 1.007), and absence of a deep drain ($p=0.017$; OR, 0.124) were identified as independent predictors for the presence of complications. For major complications, the independent predictors were the number of levels fused ($p=0.046$; OR, 1.311) and lower postoperative kyphosis ($p=0.025$; OR, 1.074). Finally, a high screw density ($p=0.014$; OR, 4.380) was the only independent predictor of mechanical complications.

Discussion

The best defense against complications is to prevent them. In a study of 2,154 patients with neuromuscular scoliosis, the overall complication rate was 33.1%–40.1%, an unacceptable value for any surgical procedure [7,14], indicating that it is necessary to assess patients in advance to obtain all pertinent information that might impact a complication. Patient history must begin before the patient is even born, including the mother's pregnancy and birthing circumstances. We did not find any study analyzing the association between perinatal characteristics and complications; however, our findings support the importance of perinatal pathologies in the incidence of surgical complications in neuromuscular scoliosis. In a retrospective study that evaluated the cause of complications in 7,252 children with neuromuscular scoliosis aged >5 years, 59% of them were found to have more than four comorbidities, which correlated with a higher incidence of surgical complications [22]. Similarly, in our study, the presence of four or more comorbidities served as an independent predictor of complications.

Conditions strongly associated with longer hospital-

Table 7. Risk assessment for complications

Variable	Category	With complication	No complication	p-value
Demographic	Age (yr)	14.86±2.44	15.44±4.36	0.498
	Sex (male:female)	11:14	25:14	0.093
	Preop weight (kg)	45.06±14.88	45.93±16.90	0.840
	Preop size (cm)	148.8±15.4	146.7±19.14	0.730
	Hospital (public/private)	18/10	15/21	0.369
	No. of comorbidities	3.96±2.5	2.47±1.6	0.009
	Previous surgeries (yes/no)	19/9	21/15	0.302
	Thelarche age (yr)	9.75±2.5	10.57±1.13	0.464
	Menarche age (yr)	12.65±1.7	12.93±1.7	0.589
	Preop brace (yes/no)	12/16	9/27	0.107
	Allergies (yes/no)	8/20	10/26	0.320
	Ambulatory status (yes/no)	16/12	24/11	0.250
	No. of seizures (/mo)	0.5±1.2	0.28±0.9	0.390
	No. of UTI (/yr)	0.9±1.5	0.3±1.1	0.095
	No. of LRTI (/yr)	1.0±1.7	0.67±1.5	0.458
	No. of patients (ASA I/II/III)	4/17/7	12/18/6	0.207
	Perinatal	Birth weight (kg)	3.176±739	3194±596
Birth size (cm)		48.23±4.8	48.07±3.83	0.873
Delivery (wk)		37.62±2.9	38.17±2.6	0.436
Pathological pregnancy (normal/pathological)		6/31	6/20	0.273
Delivery (eutocic/c-section)		16/9	18/17	0.609
Perinatal pathology (no/yes)		14/13	28/8	0.029
Laboratory	Preop glycemias (mg/dL)	84.7±8.2	89.9±7.9	0.016
	Preop blood bitrogen (mg/dL)	15.75±5.0	13.4±4.3	0.055
	Hematocrit preop (%)	40.4±4.2	40.3±4.2	0.973/0.908
	Hemoglobin preop (g/dL)	13.3±1.8	13.27±1.1	-
Surgical	Rod material (titanium/CrCo/both)	19/7/2	16/19/1	0.074
	All screws/low density	23/5	24/12	0.010
	No. of instrumented levels	13.93±2.9	12.31±3.3	0.044
	LIV to pelvis (yes/no)	8/28	11/17	0.458
	Surgical technique (VCA/AD)	13/15	21/15	0.244
	Osteotomies Schawb (1–6)	0/11/2/0/0/0	0/11/2/1/0/0	0.592
	Simultaneous dethethering (yes/no)	4/24	4/32	0.495
	Surgical time (min)	245.0±80.2	189.7±86.7	0.012
	Bleeding (mL)	1,112±865	800±418	0.065
	Use of intravenous TXA (yes/no)	17/19	18/10	0.134
	Use of topical TXA (yes/no)	29/7	24/4	0.296
	No. of transfusions—red blood cells	3±2.0	1.75±1.2	0.123
	No. of transfusions—platelet	2.88±2.9	3.7±3.1	0.700
	Hematocrit (%)	27.6±5.7	29.5±3.9	0.170
Hemoglobine (g/dL)	9.5±2.0	10.23±1.4	0.092	

(Continued on next page)

Table 1. Continued

Variable	Category	With complication	No complication	<i>p</i> -value
	pH	7.3	7.3	0.578
	PO ₂ (mmH ₂ O)	111.9	86.5	0.298
	pCO ₂ (mmH ₂ O)	40.7	42.7	0.465
	Drain (superficial)	17	11	0.021
	Drain (deep)	10	18	0.003
	Intensive care unit	4.65	2.29	0.178
	Intensive treatment unit	3.16	1.26	0.108
	Medical-surgical unit	6.77	3.55	0.094
	Mechanical ventilation (yes/no)	7/18	7/26	0.578

Values are presented as mean±standard deviation or number, unless otherwise stated. Bold type is considered statistically significant.

Preop, preoperative; Postop, postoperative; UTI, urinary tract infections; LRTI, lower respiratory tract infections; ASA, American Society of Anesthesiologists; LIV, lower instrumented vertebra; VCA, vertebral coplanar alignment; AD, apical derotation; TXA, tranexamic acid; PCO₂, partial pressure of carbon dioxide; PO₂, partial pressure of oxygen.

Table 8. Radiological parameters and their complication risk

Variable	Preoperative			Postoperative		
	With complications	Without complications	<i>p</i> -value	With complications	Without complications	<i>p</i> -value
Risser (0–V)	3/5/1/1/8/10	3/2/6/3/11/11	0.362	-	-	-
Curve magnitude (°)	69.7±27.7	62.3±23.3	0.271	34.8±22.6	26.9±21.7	0.186
Apical vertebral rotation (°)	19.7±14.3	18.2±10.8	0.668	12.3±12.4	9.1±10.0	0.301
Pelvic obliquity (°)	7.27±8.4	16.8±21.0	0.050	8.4±12.5	5.1±8.0	0.220
Cervical lordosis (°)	13.2±11.9	14.2±14.9	0.782	16.6±16.6	18.4±17.4	0.683
Thoracic kyphosis (°)	40.9±31.8	41.2±25.7	0.976	28.9±15.2	38.2±18.1	0.035
Lumbar lordosis (°)	53.4±22.8	55.7±17.0	0.670	49.4±14.2	53.8±15.8	0.267
Sacral slope (°)	37.4±11.0	34.1±11.2	0.265	36.1±11.8	34.2±9.8	0.491
Pelvic incidence (°)	49.9±20.4	43.16±22.3	0.230	45.9±14.5	48.4±15.1	0.815
Pelvic tilt (°)	16.04±11.8	10.9±11.2	0.085	13.6±13.4	14.3±10.4	0.565
Sagittal vertical axis (mm)	28.1±29.9	25.5±46.7	0.812	43.6±32.2	26.3±44.2	0.364
T9 spino-pelvic inclination (°)	10.4±11.6	12.4±10.6	0.505	10.4±6.8	8.2±8.0	0.043
T1 spino-pelvic inclination (°)	0.9±7.3	3.0±6.5	0.265	5.3±5.8	4.9±4.5	0.091

Values are presented as number or mean±standard deviation, unless otherwise stated. Bold type is considered statistically significant.

izations and readmission include bladder dysfunction, epilepsy, and chronic respiratory insufficiency [20]. Although our numbers do not support this completely, neurogenic bladder is also very common and predisposes to renal damage [23]. Wounds and dressings get easily contaminated with colonized urine, which increases the risk of infection and prevents the wound from healing. In our study, 35% of patients with myelomeningocele self-catheterized, and 54% had vesicoureteral reflux with UTI in the preoperative evaluation [23].

Two patients presented with seizures in the immediate postoperative period, with one patient having a past history of Rett syndrome. Interestingly, this increased the LOS in the ICU [24]. Hence, we recommend checking anticonvulsant plasmatic levels in advance.

A good preoperative evaluation and preparation is mandatory in patients with respiratory failure undergoing surgery. Patients who present with inadequate ventilatory mechanics due to hypotonicity, spasticity, or trunk shortening have a high incidence of pneumonia during

their lives at a rate of 8.0 for every 100 patients [25,26]. Importantly, our study findings support that the number of LRTIs in patients decreased to 51.9% after surgery. This decrease is significant as it is associated with important increases in the overall quality of life and life expectancy.

To expand more on the improvement of quality of life after surgery, our results disclosed significant decreases in the incidences of UTI, LRTI, and epilepsy after the surgery. These decreases relieve patients and parents of significant non-scoliosis-related issues; a stable spine allows for better hygiene, easier access to catheterization (leading to a decreased risk of developing UTIs), better ventilation and less gastroesophageal reflux, and therefore less incidence of LRTIs. We can only theorize regarding the significant decrease in seizures, but a vicious position is painful and stressful. We hypothesize that the relief caused by surgery probably diminishes the reactive threshold to trigger a seizure.

Cardiac sequelae stemming from neuromuscular pathologies include cardiac malfunctions due to primary myocardial alterations or collagen quality. High-magnitude curves are associated with increased deterioration of diastolic function. Due to the curve magnitude, the cardiac evaluation oftentimes may be incomplete. In one study, only 49.3% of patients were able to undergo an appropriate echocardiogram, with 33% of them undergoing surgery suffering from a minor cardiac-related complication after surgery [27]. In our patient series, 100% of them underwent an echocardiogram, but ejection fraction (EF) could be measured in only 23% of them. We did not find any correlation between the curve magnitude/rotation and the ability to measure the EF. Importantly, we found that curves $>80^\circ$ were associated with an EF $<60\%$, thus providing further evidence of the importance of preventing neuromuscular patients from reaching such levels of deformity.

Myocardial stress correlates with poor nutrition, and poor nutrition has been shown to correlate with complications, poor surgical results, and greater length of hospital stay [28]. Due to hypotonia or spasticity, deglutition capacity is diminished and therefore serves as a significant obstacle to adequate weight gain [15]. Furthermore, we found that a lower preoperative glycemia is a predictor of complications, even if it is not in hypoglycemia levels. This point must be considered when scheduling surgeries as patients generally fast for long hours and reach the surgery at low glycemic levels. Conversely, obesity has

also been correlated with increased risk for complications in the literature. In our country, 60% of children are overweight or obese, which correlates with a higher complication rate, poor healing, and high levels of inflammatory mediators [28].

Nonambulatory patients have been reported to have a higher prevalence of postoperative complications [11]. We did not find this association in our study; however, all patients with myelomeningocele who had early complications were nonambulatory, whereas those with late complications were ambulatory. Potentially, mechanical loading is more important in ambulatory patients, and immobility predisposes nonambulatory patients to early complications.

Preoperative curve magnitude increased the risk for complications. Fusion to the pelvis, a higher number of levels, and a longer surgical time are associated with longer lengths of hospital stay [11,24]. Although we did not find an association between curve magnitude or rigidity and an increased risk for complications, we believe that this principle holds true, as rigid, bigger curves tend toward longer surgical times and more bleeding, and our study demonstrated that surgical time is a predictor of complications.

Poor or excessive reduction increases the risk for major complications. We found that excessive correction of kyphosis was a predictor of major complications and that unbalanced patients with higher T9SPI values were also at risk. We also found that rigid all-screw constructs predicted the presence of mechanical complications. These patients are typically osteoporotic, and reductions must be adequate and not perfect, as too much expectation may compromise the result of the surgery.

Although in this patient series osteotomies and detethering were not associated with the development of complications, Cognetti et al. [6] reported the opposite result. Considering that $<20\%$ of the osteotomies included more than one column in our series, we believe that osteotomies increase the surgical time and bleeding and therefore correlate with a major complication-driven event. Detethering during the same surgical time does not add comorbidity; in a study performed on 3,682 pediatric patients who were detethered, there was no increase in the incidence of complications compared with patients undergoing scoliosis surgery without this added procedure [29].

Patients with neuromuscular scoliosis demonstrated

increased blood loss compared with their adolescent idiopathic scoliosis counterparts [30]. We found that the use of deep drains served as a protective factor for these patients. Therefore, we specifically recommend the use of deep drains in patients with myelomeningocele where dead space after closure remains an issue.

There were some uncommon complications in our patient series, which included small pox in a hospitalized, vaccinated patient, thereby demonstrating how immunosuppressed these patients are after such a major surgery. One patient also suffered a tongue laceration due to malpositioned buccal protection. This finding reveals that we must always be prepared for the unexpected.

Although quality of life measures were not a primary outcome for these children, a decrease in the rate of infections, better ability to eat, better ventilatory parameters, less pain, and a stable spine all make us consider surgery as an efficient method to improve the lives of both children and caretakers, despite the risk of complications.

Based on our study findings, we state that there are important factors that must be considered to reduce the probability of developing complications in patients with neuromuscular scoliosis. In the preoperative setting, obtaining a global patient history and developing a good preoperative plan that considers reduction in terms of established thresholds are key. Intraoperatively, achieving an adequate kyphosis with a balanced center of mass and a low PO, while at the same time decreasing the surgical time and blood loss, can further reduce the probability of developing complications.

Conclusions

Complications in neuromuscular scoliosis are increased by perinatal comorbidities, long surgical times, and inadequate correction. Appropriate patient preparation and surgical planning are the preventive measures to decrease these complications.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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