Perioperative complications and risk factors in neuromuscular scoliosis surgery

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OBJECTIVE High rates of perioperative complications are associated with deformity correction in neuromuscular scoliosis. The current study aimed to evaluate complications associated with surgical correction of neuromuscular scoliosis and to characterize potential risk factors.

METHODS Data were retrospectively collected from a single-center cohort of 102 consecutive patients who underwent spinal fusions for neuromuscular scoliosis between January 2008 and December 2016 and who had a minimum of 6 months of follow-up. A subgroup analysis was performed on data from patients who had at least 2 years of follow-up. Univariate and multivariate regression analyses, as well as binary correlational models and Student t-tests, were employed for further statistical analysis.

RESULTS The present cohort had 53 boys and 49 girls with a mean age at surgery of 14.0 years (± 2.7 SD, range 7.5–19.5 years). The most prevalent diagnoses were cerebral palsy (26.5%), spinal cord injury (24.5%), and neurofibromatosis (10.8%). Analysis reflected an overall perioperative complication rate of 27% (37 complications in 27 patients), 81.1% of which constituted major complications ($n = 30$) compared to a rate of 18.9% for minor complications ($n = 7$). Complications were predicted by nonambulatory status ($p = 0.037$), increased intraoperative blood loss ($p = 0.012$), increased intraoperative time ($p = 0.046$), greater pelvic obliquity at follow-up ($p = 0.028$), and greater magnitude of sagittal profile at follow-up ($p = 0.048$). Pulmonary comorbidity ($p = 0.001$), previous operations ($p = 0.013$), history of seizures ($p = 0.046$), diagnosis of myelomeningocele ($p = 0.046$), increase in weight postoperatively ($p < 0.005$), and increased lumbar lordosis at follow-up ($p = 0.015$) were identified as risk factors for perioperative infection.

CONCLUSIONS These results suggest that in neuromuscular scoliosis, patients with preexisting pulmonary compromise and greater intraoperative blood loss have the greatest risk of experiencing a major perioperative complication following surgical deformity correction.

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KEYWORDS scoliosis; neuromuscular; cerebral palsy; complications; outcomes; spine

PEDIATRIC patients with neuromuscular conditions present with disproportionately high rates of scoliotic spinal deformities.² Such pathologies frequently present with a left primary thoracolumbar curve affecting pelvic obliquity and shoulder disequilibrium.¹² These specific deformities are challenging to control through non-invasive measures such as bracing because of deformity progression.^{13,20} Definitive treatment for this population involves placement of posterior, anterior, or combined anterior-posterior segmental instrumentation with fusion to restore both coronal and sagittal alignment. However, surgery in these patients has been associated with higher incidences of infection, pseudarthrosis, and limited postoperative mobility.⁴

Complication rates of spinal fusion procedures in this pediatric population range between 24% and 75%, with a mean of approximately 33.1%.¹² Compared with other types of scoliosis, neuromuscular scoliosis (NMS) possesses the highest rate of complications, followed by congenital (10.6%) and idiopathic (6.3%) scoliosis.¹⁶ Such disparity has classically been attributed to higher rates of medical comorbidities in patients with NMS, as well as comparatively poor nutritional status resulting in compromised bone integrity, decreased mobility, poor personal hygiene, and extended hospital stays.^{14,15}

Previous research has identified seizures, sacropelvic fixation, increased body mass index, age at surgery, decreased pulmonary status, increased operative time, in-

ABBREVIATIONS ASA = American Society of Anesthesiologists; NMS = neuromuscular scoliosis; SCI = spinal cord injury; SSI = surgical site infection; TBI = traumatic brain injury.

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creased intraoperative blood loss, cognitive impairment, nonambulatory status, and primary curve magnitude as significant risk factors for the development of a major complication.^{1,3,4,10–13,16} As such, the objective of this study was to further characterize and evaluate significant risk factors associated with complications related to spinal fusion procedures performed in pediatric patients with NMS. Given the consistently high rates of complications in this population, further investigation might continue to help in the medical management of pediatric NMS, reduce the frequency of readmission, and improve patient safety and outcomes in the future.

Methods

A retrospective chart review of all patients who underwent surgical deformity correction for NMS at Shriners Hospitals for Children–Philadelphia between January 2008 and December 2016 was undertaken. Radiographic data and medical charts were reviewed for all patients. Radiographic data were collected at three seminal time points: preoperative, immediately postoperative, and last follow-up. Documented radiographic parameters included primary curve magnitude, compensatory curve magnitude, maximal thoracic kyphosis, maximal proximal kyphosis (upper instrumented vertebra + 2 vertebrae cephalad), maximal lumbar lordosis (T12–L5), pelvic obliquity, shoulder imbalance, Risser classification, and sagittal profile (sagittal displacement of C-2 from sacrum in an upright position). All data were collected by a single trained individual to ensure consistency across measurements and were validated through random spot checks by a fellowship-trained pediatric spine surgeon.⁶ Exclusion study criteria were the absence of any critical time point specified above, diagnosis inconsistent with NMS, and minimum follow-up time less than 6 months after surgery.

Complications were identified by review of medical records. Major complications were defined as those which prolonged the expected hospitalization, required rehospitalization, caused lasting neurological deficit, or necessitated reoperation. Conversely, minor complications constituted those which were resolved by contemporaneous intraoperative modifications or other nonoperative management. Both categories of complications were substratified by salient physiological characteristics consistent with relevant previous studies.⁹

Respiratory complications were divided into respiratory arrest and aspiration pneumonia, both of which were classified as major complications. Similarly, cardiovascular events, such as hemodynamic instability and increased intraoperative blood loss, were deemed as major complications.

Infectious wound complications were identified as deep or superficial. As such, deep infections were deemed major complications, whereas superficial infections not requiring reoperation were classified as minor. We routinely employ a standardized infection control protocol, including both gram-positive and -negative intravenous coverage in conjunction with intrawound vancomycin and tobramycin.

Neurological complications including intraoperative

durotomy and neuromonitoring changes without clinical sequelae were considered minor complications. Conversely, complete loss of neuromonitoring signals at any juncture was deemed a major complication as was development of any new neurological deficit postoperatively.

Instrumentation failure and progression of scoliotic deformity were both considered major complications. The subset of patients presenting with pseudarthrosis was further analyzed for the purposes of elucidating potential risk factors thereof. Finally, unplanned staged procedures were deemed major complications, as reoperation was inherently necessary.

The total sample of 102 patients was distributed into two groups: those with and those without perioperative complications. These groups were subsequently stratified to identify individuals whose charts possessed 2-year follow-up data, and a subcohort was established for additional analysis. A 1-year follow-up subcohort was also created and analyzed; however, this was not included due to a lower sample size and statistical results that were reflective of both already-analyzed cohorts.

Patients were divided into a complication cohort and a control cohort and then compared using univariate and multivariate regression, as well as Student t-tests. Clinical variables (i.e., diagnosis, comorbidities, nonambulatory status, cognitive status, fusion to the pelvis, seizures, interbody fusion, spasticity, halo-femoral traction, rod material, and staged procedures) were separately studied using binary correlational analyses and Pearson coefficients. All statistical analyses were performed at significance level 0.05 using IBM SPSS 23.0 software (2015).

Results

A total of 102 patients (53 boys and 49 girls) were identified and included in this study. The most prevalent diagnoses observed were cerebral palsy (27%), spinal cord injury (SCI)/traumatic brain injury (TBI) (25%), and neurofibromatosis (11%). Within the present cohort, 40 patients were cognitively delayed (39%), 77 were nonambulatory (76%), and 8 had a history of seizures (8%). The average age at surgery was 14.0 ± 2.68 years, with an average of 2.53 ± 1.97 years of follow-up. Pelvic fixation was performed in 92 patients (90%), 25 had staged procedures (25%), and the average operative time was 9.58 ± 2.43 hours. Most patients underwent posterior correction, whereas 3 patients received combined posterior-anterior spinal fusion. Our cohort also included 44 (43%) patients with implanted devices, the most common of which were gastrostomy/jejunostomy tubes (30%), tracheostomies (30%), and CSF shunting devices (18%). Complete lists of patient diagnostic information and operative metrics are presented in Tables 1–3.

The mean preoperative spinal curve was $78.4^\circ \pm 28.8^\circ$, with patients experiencing an average of 49% correction at 180-day follow-up ($39.1^\circ \pm 44.4^\circ$ of correction). Similarly, the mean preoperative compensatory curve was $47.1^\circ \pm 14.9^\circ$, with 24% average correction at 180-day follow-up ($11.2^\circ \pm 20.9^\circ$ correction). The mean pelvic obliquity was $11.8^\circ \pm 9.7^\circ$, with 43% average correction ($5.02^\circ \pm 10.1^\circ$ correction). The distribution of radiographic parameters

TABLE 1. Primary demographic profile of cohort by diagnosis

Diagnosis	No. of Pts (%)	No. of Males (%)	No. w/ Complications (%)	p Value
Cerebral palsy	27 (26.5)	14 (51.9)	6	0.107
Myelomeningocele	10 (9.8)	5 (50.0)	4 (40.0)	0.337
Arthrogryposis	8 (7.8)	1 (12.5)	4 (50.0)	0.364
SCI/TBI	25 (24.5)	14 (56.0)	7 (28.0)	0.436
Neurofibromatosis	11 (10.8)	7 (63.6)	2 (18.2)	0.360
Muscular dystrophy	5 (4.9)	4 (80.0)	2 (40.0)	—
Primary contributory genetic/syndromic conditions	27 (26.5)	14 (51.9)	7 (25.9)	0.855
Spinal muscular atrophy	1 (1.0)	0 (0.0)	0 (0.0)	—
Total	102 (100)	53 (52.0)	27 (26.5)	—

Pts = patients; — = does not apply.

and their respective magnitudes of change are reported in Table 4.

There were 37 documented complications in 27 patients in the overall cohort (27% prevalence). Major adverse events represented 81% of total complications (n = 30), with the remaining 19% classified as minor (n = 7). The most prevalent major complications were deep wound infection (n = 11) and pseudarthrosis (n = 6). Collectively, these accounted for 57% of major complications. Other major complications in the series were decubitus ulcers (n = 3), hemodynamic instability (n = 2), respiratory arrest (n = 1), aspiration pneumonia (n = 1), instrumentation prominence (n = 1), instrumentation malplacement (n = 1), neuromonitoring loss (n = 1), and adjacent-level subluxation (n = 1). Intraoperative durotomy was the most frequently documented minor complication (n = 5), followed by neuromonitoring alerts (n = 1) and superficial wound infection (n = 1). There was no mortality. The distributions of major and minor complications by subcategory are presented in Tables 5 and 6, respectively.

The additional subcohort of patients whose records contained 2-year follow-up data was composed of 60 patients (29 boys and 31 girls). In this group, the mean age at surgery was 14.0 ± 2.7 years, and the most frequent diagnoses were SCI/TBI (25%), cerebral palsy (22%), and neurofibromatosis (12%). There were 22 complications in 16 patients (27% prevalence). Surgical site infection (SSI) was the most commonly documented major complication (32%), followed by pseudarthrosis (23%) and instrumentation prominence (14%). Incidental durotomies comprised 14% of adverse sequelae in this subcohort and were the most frequently encountered minor complications therein.

Patient characteristics not associated with significantly increased risk of major general complications were diagnosis, age at surgery (p = 0.548), cognitive status (p = 0.467), pulmonary comorbidity (p = 0.673), seizures (p = 0.852), presence of implanted devices (p = 0.111), type of implanted device (p = 0.458), and nonambulatory status (p = 0.489). Similarly, operative characteristics not significantly associated with complications included fusion to the pelvis (p = 0.816), staged procedures (p = 0.672), use of intrawound vancomycin (p = 0.655), halo-femoral traction (p = 0.719), interbody fusion (p = 0.163), number of levels fused (p = 0.684), implant density (p = 0.586), osteotomies

(p = 0.613), quantity of intravenous fluid administered (p > 0.9), albumin quantity administered (p = 0.062), and number of previous operations (p = 0.457).

Factors identified as significant predictors of major complications were increased pelvic obliquity at follow-up (p = 0.028), increased intraoperative blood loss (p = 0.001), increased operative time (p = 0.046), and use of cobalt-chrome instrumentation (p = 0.045). Within the subcohort of patients whose charts contained 2-year follow-up data, greater magnitude of sagittal profile at follow-up (p = 0.048), nonambulatory status at follow-up (p = 0.037), and increased intraoperative blood loss (p = 0.012) were significantly associated with experiencing a major adverse event.

As the single most prevalent category of overall complications, SSI accounted for 32% of total adverse sequelae (n = 12). Eleven such patients experienced deep wound pathology, whereas one infection was considered superficial. The most frequently encountered offending organisms were *Escherichia coli* (42%), *Proteus mirabilis* (25%), and *Staphylococcus aureus* (17%). Gram-negative bacteria represented 58% of identified infectious organisms, while

TABLE 2. Additional clinical information

Diagnosis	No. of Pts (%)	No. of Males (%)	No. w/ Complications (%)	p Value
Cognitively delayed	40 (39.2)	19 (47.5)	8 (20.0)	0.467
Pulmonary comorbidity	5 (4.9)	2 (40.0)	3 (60.0)	0.673
Seizures	8 (7.8)	4 (50.0)	3 (37.5)	0.852
Nonambulatory	77 (75.5)	21 (27.3)	27 (35.1)	0.489
G/J tube	13 (29.5)	7 (53.8)	5 (38.5)	0.458
CSF shunt	8 (18.1)	4 (50.0)	3 (37.5)	0.126
Baclofen pump	1 (2.3)	0 (0.0)	1 (100.0)	0.722
Tracheostomy	13 (29.5)	5 (38.5)	4 (30.8)	0.743
Myringotomy tubes	3 (6.8)	1 (33.3)	1 (33.3)	0.703
Other implanted device	6 (13.6)	2 (33.3)	3 (50.0)	0.091
Total	102 (100)	53 (52.0)	27 (26.5)	—

G/J tube = gastrostomy-jejunostomy tube.

TABLE 3. Operative characteristics

Characteristic	Total	No. w/ Complications (%)	Significance
Fused to pelvis (%)	92 (90.2)	27 (29.3)	0.816
Pts w/ staged ops (%)	25 (24.5)	10 (0.4)	0.672
Pre-vancomycin (%)*	67 (65.7)	18 (26.9)	0.655
Post-vancomycin (%)*	64 (62.7)	21 (32.8)	0.655
Halo-femoral traction (%)	19 (18.6)	5 (26.3)	0.719
TLIF (%)	19 (18.6)	7 (36.8)	0.163
Mean levels fused (SD)	16.02 (4.88)	—	0.684
Mean implant density (%)†	1.74 (1.06)	—	0.586
Mean no. osteotomies (SD)	4.14 (4.30)	—	0.613
Mean EBL (SD), ml	1613.10 (1065.89)	—	0.003
Mean IVF (SD), ml	4179.09 (2047.60)	—	—
Mean albumin (SD), ml	822.02 (464.29)	—	0.062
Mean cell saver (SD), ml	518.57 (442.26)	—	0.730
Mean time (SD), mins	9.58 (2.43)	—	0.046
Mean no. related reops	0.66 (2.18)	—	—
Mean no. previous ops	2.27 (1.97)	—	0.457
Mean FU (SD), yrs	2.53 (1.66)	—	0.486
Mean age (SD), yrs	14.04 (2.68)	—	0.548

EBL = estimated blood loss; FU = follow-up; IVF = intravenous fluid; TLIF = transforaminal lumbar interbody fusion.

Values are reported as the number of patients (%) or mean (SD). Boldface type indicates statistical significance.

* Pre- and post-vancomycin represent the times before and after routine intrawound vancomycin powder was applied intraoperatively.

† Mean implant density is the average number of points of fixation per level (i.e., 0–2 depending if 0–2 screws were used at each level).

16.67% were gram positive and 17% presented with mixed polymicrobial pathology. One patient presented with unidentified pathology.

Risk factors most significantly associated with SSI within the 180-day follow-up window included pulmonary comorbidity ($p = 0.007$), residual lumbar lordosis at follow-up ($p = 0.003$), and increase in weight from preoperative to follow-up ($p = 0.010$). Additional factors identified as significant at this juncture were history of myelomeningocele closure ($p = 0.046$), seizures ($p = 0.046$), history of previous operations ($p = 0.013$), greater postoperative thoracic kyphosis ($p = 0.026$), and greater postoperative shoulder imbalance ($p = 0.028$). Notably, use of halo-femoral traction trended toward significance in regression models ($p = 0.055$). Factors remaining significant within the 2-year follow-up cohort included pulmonary comorbidity ($p = 0.001$), increased lumbar lordosis at follow-up ($p = 0.015$), and increase in weight from preoperative to follow-up ($p < 0.001$).

Pseudarthrosis was documented in 6 patients within the general cohort (6% prevalence), constituting the second largest subcategory of major complications for which reoperation was required (Fig. 1). Pseudarthrosis was significantly correlated with SCI ($p = 0.003$), preoperative primary curve magnitudes between 50° and 64° ($p = 0.045$), and increased follow-up time ($p = 0.018$) in the general 6-month cohort. Within the subcohort of patients with 2-year follow-up records, SCI remained a significant positive predictor of pseudarthrosis ($p = 0.005$). In addition, follow-up height ($p = 0.045$) and follow-up curve ($p = 0.049$) were inversely correlated with development of

nonunion at this juncture. Lower weight at follow-up ($p = 0.051$) also trended toward the significance threshold within this analysis.

Discussion

The surgical management of pediatric NMS remains a challenge for practitioners. Current literature approximates perioperative complication rates at 33% (range 17%–74%).^{7,9,14} Management of these cases is frequently compounded by poor personal hygiene, limited mobility, nutritional insufficiency, and cognitive/developmental delays within this population.⁷

Several authors have reported direct relationships between greater primary curve magnitudes, seizures, antiseizure medications, American Society of Anesthesiologists (ASA) classification, nonambulatory status, and sacroiliac fixation and an increased incidence of major perioperative complications.^{3,7,9,12,14,19} Previous investigators have reported no significant difference between staged and unstaged procedures with respect to overall complications.¹² Tsirikos et al.¹⁹ corroborated this observation, stating that staged procedures may offer patients with NMS safer results compared to single-stage procedures. However, further research is required to identify variables with respect to risk factors for general complications in this population.

Our analysis of 102 patients largely reflects evidence in support of previous investigations with respect to findings in the literature. Intraoperative blood loss showed a strong positive correlation with occurrence of major com-

TABLE 4. Summary of clinical and radiographic metrics

Metric	Preop Mean (SD)	p Value	Postop Mean (SD)	p Value	FU Mean (SD)	p Value	Δ' Mean (SD)	p Value	Δ'' Mean (SD)	p Value	Δ Mean (SD)	p Value
Weight (kg)	39.68 (15.66)	0.604	39.84 (15.61)	0.267	47.86 (21.18)	0.375	0.114 (1.10)	0.933	-0.88 (25.98)	0.470	3.44 (12.65)	0.548
Height (cm)	136.93 (23.58)	0.556	137.52 (24.46)	0.899	148.90 (18.21)	0.323	0.264 (2.09)	0.866	-15.12 (84.14)	0.738	34.90 (57.18)	0.576
Curve (°)	78.44 (28.78)	0.948	31.48 (21.32)	0.816	27.93 (15.74)	0.697	-33.31 (37.35)	0.767	-5.88 (26.38)	0.439	-39.11 (44.43)	0.204
Compensatory curve (°)	47.13 (14.89)	0.573	22.78 (13.02)	0.764	20.06 (10.55)	0.155	-11.15 (20.86)	0.349	-1.62 (12.30)	0.746	-11.15 (20.86)	0.349
Thoracic kyphosis (°)	43.66 (27.09)	0.211	37.33 (17.29)	0.026	37.52 (17.35)	0.098	-1.11 (31.91)	0.416	-1.07 (23.56)	0.831	-2.35 (36.66)	0.790
Proximal kyphosis (°)	12.42 (9.21)	0.252	11.49 (6.94)	0.150	11.60 (7.87)	0.365	-0.82 (10.38)	0.911	0.85 (10.06)	0.616	-0.03 (12.57)	0.470
Lumbar lordosis (°)	35.32 (20.91)	0.412	35.42 (13.13)	0.553	38.43 (14.32)	0.519	4.40 (26.04)	0.509	1.36 (20.82)	0.645	5.66 (28.04)	0.220
Pelvic obliquity (°)	11.80 (9.66)	0.939	5.84 (4.73)	0.401	5.14 (4.74)	0.0026	-3.92 (9.77)	0.342	-1.18 (6.36)	0.927	-5.02 (10.09)	0.227
Shoulder balance (°)	7.12 (6.47)	0.131	4.77 (3.71)	0.028	3.86 (2.80)	0.428	-2.16 (6.86)	0.899	-0.41 (4.84)	0.305	-2.53 (6.58)	0.931
Sagittal profile (mm)	13.70 (55.73)	0.127	9.22 (55.72)	0.357	14.53 (55.98)	0.265	-5.47 (60.94)	0.993	4.61 (65.52)	0.918	-1.21 (58.18)	0.436

Δ = comparison of preoperative to last follow-up; Δ' = comparison of preoperative to postoperative; Δ'' = comparison of postoperative to follow-up. Boldface type indicates statistical significance.

plications within both cohorts analyzed ($p < 0.01$). In our cohort, increased pelvic obliquity ($p = 0.026$) and cobalt-chrome rods ($p = 0.045$) were significantly associated with complications. While pelvic obliquity has been classically cited as a major factor related to adverse outcomes, the use of cobalt-chrome rods might predispose patients to increased risk of instrumentation-related complications. This association, however, was not observed to influence pseudarthrosis rates in our cohort. Consistent with previous investigations, analysis of the group with 2-year follow-up data showed that increased magnitude of sagittal profile at follow-up ($p = 0.037$) and nonambulatory status at follow-up ($p = 0.041$) were risk factors for complications. As previously reported, nonambulatory individuals and those with global coronal or sagittal misalignment were at significantly heightened risk for complications. In addition, staged procedures were not found to be more likely than single-staged procedures to result in complications ($p = 0.661$). Our analyses were unable to corroborate previous reports of seizures ($p = 0.867$), sacroiliac fixation ($p = 0.331$), or larger curve magnitudes ($p = 0.428$) as statistically significant risk factors for major complications in this series.

Infectious complications experienced by this demographic tend to require extended courses of antibiotics, as well as a series of operative wound debridements, and potentially complete reinstrumentation of spinal arthrodesis.¹ Current estimations of the prevalence of wound infections within the NMS population range between 6% and 20%.¹⁴ Patients with NMS present most frequently with gram-negative infections (47%–60% of cases); however, *S. aureus* is the single most commonly isolated organism.^{7,18}

In previous investigations, such infectious complications have consistently been attributed to increased implant density, fusion to the pelvis, residual postoperative curve magnitude, longer operative times, neurogenic bowel/bladder dysfunction, body mass index > 95th percentile, degree of cognitive impairment, use of allograft bone tissue, and presence of gastrostomy/jejunostomy tubes or ventriculoperitoneal shunts.^{1,3,5,8,15,17,18,21} Ultimately, nutritional depletion has been additionally linked to slow wound healing and immunological compromise, contributing to heightened risk for infection.⁵

In the present cohort, pulmonary comorbidity ($p = 0.001$), increase in weight from preoperative to follow-up ($p < 0.01$), and residual lumbar lordosis at follow-up ($p = 0.015$) were the most reliable and consistent risk factors for SSI. These factors reached significance in both cohorts and are vastly consistent with related studies. Within the general cohort, additional factors significantly related to SSI included history of myelomeningocele ($p = 0.046$), seizures ($p = 0.046$), residual postoperative thoracic kyphosis ($p = 0.026$), residual postoperative shoulder imbalance ($p = 0.028$), and history of previous operations ($p = 0.013$). These results were not replicated in analysis of the 2-year cohort which may simply lack a sufficient number of patients. Previously reported risk factors of heightened implant density ($p > 0.9$) and fusion to the pelvis ($p = 0.847$) were not significant in our series.

Previous investigation into risk factors for pseudarthrosis within pediatric NMS is sparse. Previously reported

TABLE 5. Major complications by category

Comp	Category		Comp	Subcategory	
	No. (%)	% of Total Comps		No. (%)	% of Total Comps
Respiratory	2 (6.7%)	5.4	Respiratory arrest	1 (3.3%)	2.7
Instrumentation	10 (33.3%)	27.0	Aspiration pneumonia	1 (3.3%)	2.7
			Pseudarthrosis	6 (20%)	16.2
			Instrumentation prominence	3 (10%)	8.1
			Instrumentation malplacement	1 (3.3%)	2.7
Wound	14 (46.7%)	37.8	Deep wound infection	11 (36.7%)	29.7
Neurological	1 (3.3%)	2.7	Decubitus	3 (10%)	8.1
			Neuromonitoring loss	1 (3.3%)	2.7
Progression	1 (3.3%)	2.7	Adjacent-level subluxation	1 (3.3%)	2.7
Cardiovascular	2 (6.7%)	5.4	Hemodynamic instability	2 (6.7%)	5.4
Total	30	81.1			81.1

Comp = complication.
There were 31 surgeries in 102 patients (37 complications observed in 27 patients).

risk factors for pseudarthrosis were implant infections, sacropelvic fixation, and age less than 13 years at surgery.¹⁵ Our analyses associate SCI as a risk factor for pseudarthrosis in this population. This result was significant at the $p < 0.01$ threshold in both 6-month and 2-year follow-up cohorts. All SCI patients presenting as such had evidence of nonunion below their respective levels of injury. This might be secondary to increased mechanical stress exerted upon instrumentation as a result of stress differential due to neurogenic hypotonia observed below the vertebral levels of injury. Within the 6-month cohort, smaller curves (50° – 64°) ($p = 0.045$) and increased follow-up time ($p = 0.018$) were associated with pseudarthrosis. Furthermore, significant inverse relationships were identified at the 2-year follow-up juncture with preoperative weight ($p = 0.018$), height at follow-up ($p = 0.049$), and residual curve at follow-up ($p = 0.045$). Lower preoperative weight and lower height at follow-up likely are indirectly reflective of poor nutritional status and younger age, consistent with previous literature. With respect to lesser primary curve magnitudes at follow-up, this result may be a function of initial operative hypercorrection, exceeding the corrective capacity of the instrumentation. Further investigation is required to corroborate these results and support the

proposed mechanisms of instrumentation failure. Factors not associated with pseudarthrosis in either cohort were infection ($p = 0.509$), pelvic fixation ($p = 0.302$), age ($p = 0.365$), and implant density ($p = 0.452$). These results continue to inform our practice and helped us develop our

TABLE 6. Minor complications by category

Comp	Category		Comp	Subcategory	
	No. (%)	% of Total Comps		No.	% of Total Comps
Neurological	6 (85.7)	16.2	Dural injury	5	13.5
Wound	1 (14.3)	2.7	Neuromonitoring inconsistency	1	2.7
			Superficial wound infection	1	2.7
Total	7	18.9			18.9

FIG. 1. Anteroposterior (upper) and lateral (lower) radiographs of a 16-year-old girl with SCI diagnosed with pseudarthrosis 2 years postoperatively.

current standardized protocol through a multidisciplinary conference.

Limitations of the present study include small sample sizes with respect to pseudarthrosis and infections. As such, statistical analyses might be underpowered to detect true statistically significant risk factors. In addition, the retrospective nature of this investigation limited our inferences and conclusions based upon accuracy and completion of patient records within the center's primary database. Specifically, Scoliosis Research Society outcome scores, nutritional information, and ASA classifications were unable to be collected due to these limitations.

Conclusions

Our results suggest that within this population, patients with greater magnitudes of pelvic obliquity who experience greater volumes of intraoperative blood loss are at increased risk of experiencing a major perioperative complication. Individuals with preexisting respiratory compromise and increased residual postoperative lumbar lordosis are at greater risk of perioperative infections. History of previous operations, myelomeningocele, seizures, and postoperative weight gain were also significantly associated with infectious complications. Lastly, patients with SCI were found to have a greater risk of pseudarthrosis. Adverse sequelae related to surgical deformity correction in NMS are highly prevalent and remain a critical avenue for continued clinical improvement.

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Disclosures

Dr. Pahys is consultant for DePuy Synthes, Globus Medical, and Zimmer Biomet. Dr. Samdani is consultant for DePuy Synthes, Globus Medical, Ethicon, Zimmer Biomet, Misonix, and Stryker. Dr. Hwang is on the speakers' bureau with NuVasive, is a consultant for NuVasive, and owns stock in Auctus.

Author Contributions

Conception and design: Hwang. Acquisition of data: Toll. Analysis and interpretation of data: Toll. Drafting the article: Toll. Critically revising the article: all authors. Reviewed submitted version of manuscript: Hwang, Toll. Approved the final version of the manuscript on behalf of all authors: Hwang. Statistical analysis: Toll. Administrative/technical/material support: Hwang, Samdani. Study supervision: Hwang.

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