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Clinical Study

Incidence and risk factors of postoperative neurologic decline after complex adult spinal deformity surgery: results of the Scoli-RISK-1 study

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Abstract

BACKGROUND CONTEXT: Significant variability in neurologic outcomes after surgical correction for adult spinal deformity (ASD) has been reported. Risk factors for decline in neurologic motor outcomes are poorly understood.

PURPOSE: The objective of the present investigation was to identify the risk factors for postoperative neurologic motor decline in patients undergoing complex ASD surgery.

STUDY DESIGN/SETTING: This is a prospective international multicenter cohort study.

PATIENT SAMPLE: From September 2011 to October 2012, 272 patients undergoing complex ASD surgery were prospectively enrolled in a multicenter, international cohort study in 15 sites.

OUTCOME MEASURES: Neurologic decline was defined as any postoperative deterioration in American Spinal Injury Association lower extremity motor score (LEMS) compared with preoperative status.

METHODS: To identify risk factors, 10 candidate variables were selected for univariable analysis from the dataset based on clinical relevance, and a multivariable logistic regression analysis was used with backward stepwise selection.

RESULTS: Complete datasets on 265 patients were available for analysis and 61 (23%) patients showed a decline in LEMS at discharge. Univariable analysis showed that the key factors associated with postoperative neurologic deterioration included older age, lumbar-level osteotomy, three-column osteotomy, and larger blood loss. Multivariable analysis revealed that older age (odds ratio [OR]=1.5 per 10 years, 95% confidence interval [CI] 1.1–2.1, p=.005), larger coronal deformity angular ratio [DAR] (OR=1.1 per 1 unit, 95% CI 1.0–1.2, p=.037), and lumbar osteotomy (OR=3.3, 95% CI 1.2–9.2, p=.022) were the three major predictors of neurologic decline.

CONCLUSIONS: Twenty-three percent of patients undergoing complex ASD surgery experienced a postoperative neurologic decline. Age, coronal DAR, and lumbar osteotomy were identified as the key contributing factors.

Keywords: Adult spinal deformity; American Spinal Injury Association (ASIA) neurologic exam; Lower extremity motor score (LEMS); Multicenter study; Multivariate analysis; Neurologic complications; Predictor; Risk factor; Spinal deformity surgery; Spinal osteotomy

Introduction

The reported prevalence of adult spinal deformity (ASD) in the general population ranges from 2% to 32% [1–3]. The impact of ASD on a patient's quality of life can be debilitating, and in our aging world, increased numbers of patients with ASD are predicted. Thus, the burden of ASD on healthcare resources is substantial. However, advancing technical sophistication in spine surgery has enabled surgical correction of severe complex ASD with the use of pedicle screw fixation and complex osteotomies. Nevertheless, no ASD surgery is without an inherent risk of complications. Among these, deterioration of neurologic function is one of the most devastating complications [4].

Despite the existence of numerous previous reports regarding the rates of neurologic deficits in ASD surgery, most of these have several limitations, including retrospective study design, a limited number of cases included, incomplete follow-up rates, heterogeneity in patient cohorts and surgical procedures, and non-standardized outcome measures. As a result, there is significant inconsistency in the reports of neurologic outcomes after surgical correction for ASD. The Scoli-RISK-1 study was an international multicenter cohort study designed and performed to prospectively collect data on the neurologic complications associated with surgical correction of complex ASD. Previously, we reported on lower extremity motor function before and after surgical correction of complex ASD and demonstrated that a decline in neurologic function after complex ASD surgery was more frequently observed than previously reported [5].

Identifying the risk factors for neurologic deficits in ASD surgery is also important to understand the risk profile for individual patients and to help surgeons undertake precautions or make safer patient care decisions. For instance, spinal osteotomy for rigid deformity is generally believed to be a high-risk procedure, and the severity of the deformity has also been found to be predictive of intraoperative spinal cord monitoring events in a recent study [6]. Only a few modern studies in the literature have documented the risk factors [6–17]. The objective of the present study was to elucidate the risk factors associated with neurologic decline after surgical correction of complex ASD.

Materials and methods

Patient selection and surgical procedure

Data from the Scoli-RISK-1 study were used for the present investigation [5]. Key inclusion criteria were patients between 18 and 80 years of age and having a diagnosis of ASD with an apex of the major deformity in the cervicothoracic or the thoracolumbar region between C7 and L2 inclusive. To focus

on high-risk events, we enrolled patients based on the procedure performed. For the present study, the procedure was defined as complex ASD surgery when one or more of the following criteria were met: corrective surgeries for a curvature with a major Cobb angle of ≥80° in the coronal or the sagittal plane; corrective osteotomies for congenital spinal deformity; corrective osteotomies for revision of spinal deformity (any type); three-column osteotomy (3CO, ie, pedicle subtraction osteotomy, vertebral column resection [VCR]) between C7 and L5 inclusive; reconstruction for myelopathy caused by spinal deformity; and deformity reconstruction with concomitant spinal cord decompression for ossification of the ligamentum flavum or ossification of the posterior longitudinal ligament. Patients with a history of substance dependency or psychosocial disturbance, active malignancy, active bacterial infection, recent history of significant spinal trauma or malignancy, complete long-term paraplegia, pregnancy, prisoners, and institutionalized individuals were excluded.

Nine spinal deformity centers in North America, three in Europe, and three in Asia participated. The respective ethical committees or institutional review boards at all participating sites granted study approval. All patients provided informed consent before enrollment. The study is registered with clinicaltrials.gov as NCT01305343. Enrollment of 272 consecutive patients was performed from September 2011 to October 2012 by 44 surgeons. Seven patients lacked neurologic status data at baseline or at discharge and thus were excluded from the analysis. The surgical approach, instrumentation, and corrective maneuvers were at the discretion of the operating surgeon.

Neurologic and radiographic measurements

An American Spinal Injury Association (ASIA) neurologic examination was performed by an ASIA-certified examiner within 6 weeks before surgery and at hospital discharge. The lower extremity motor score (LEMS) evaluates motor function as a sum of scores for each of five lower extremity muscle groups: hip flexors (L2), knee extensors (L3), ankle and toe dorsiflexors (L4), great toe extensor (L5), and plantar flexors (S1). Each group is rated on a scale of 0 (no motor function) to 5 (full motor function), and the LEMS has a maximum of 50 points (25 points per side). It has been demonstrated to be correlated to ambulatory function measured with gait analysis in patients with incomplete spinal cord injury [18]. To ensure as accurate a neurologic assessment as possible, every effort was made to adequately control pain.

Preoperative upright coronal and sagittal global spine x-rays were performed in all patients, and radiographic parameters, including Cobb angle, thoracic kyphosis, and lumbar lordosis, were measured. In addition, the acuteness of the focal kyphotic or scoliotic angulation was measured as the deformity angular ratio (DAR) [19]. The DAR is a unitless number calculated as the Cobb angle of the maximum curve divided by the number of vertebral levels involved. A similar measurement was previously reported as the "Harrington factor" [20]. Sagittal DAR is calculated in the same manner. In the present investigation, we used the maximum DAR among the values from each coronal curve as a patient's "coronal" DAR when multiple curves existed, and the DAR calculated from the maximum kyphosis as a patient's "sagittal" DAR to represent the acuteness of the spinal deformity.

Statistical analysis

Patients were divided into two groups: those who experienced a decline in LEMS at discharge in comparison with their preoperative status, and those who had the same or improved LEMS. When a patient underwent staged procedures and had multiple discharges, the last discharge was chosen as the point of investigation for neurologic status. Identification of factors associated with a decline in LEMS was performed in two steps. For the first step, 10 candidate variables were investigated using univariable logistic regression models. These candidates were selected based on clinical relevance and previous literature [6–17]. In the second step, all these variables were entered in a multivariable logistic regression model using backward selection with a retention criterion of p-value of less than .25. Adjusted odds ratios (ORs) with 95% confidence intervals (CIs) were calculated. The association between the spinal levels with neurologic decline tested in LEMS and the lumbar osteotomy levels was assessed by a mixed effects logistic regression model with a random effect at the patient level. A p-value of less than .05 was considered statistically significant for all analyses. The statistical analysis was performed using the software SAS version 9.4 (SAS Institute Inc., Cary, NC, USA).

Results

A total of 265 patients who had LEMS at discharge were included in the analysis. The mean age at surgery was 56.8 years old (standard deviation 15.4, range 18–81). There were 180 women (68%) and 85 men (32%). The most common indication for inclusion in the present study was 3CO (n=201, 76%), followed by revision of deformity requiring osteotomy (n=161, 61%), primary coronal or sagittal deformity with major Cobb angle of ≥80° (n=77, 29%), congenital deformity (n=12, 5%), myelopathy caused by spinal deformity (n=12, 5%), and ossification of the ligamentum flavum or ossification of the posterior longitudinal ligament (n=5, 2%). Lumbar osteotomy was performed in 194 patients (73%), with 90 undergoing at least one osteotomy in high lumbar spine down to L2, and thoracic osteotomy was performed in 113 patients (43%). Demographic data are summarized in Table 1. Of the total number of patients, 199 (75%) had LEMS=50 preoperatively, whereas 66 (25%) had LEMS<50. The median number of days that elapsed between surgery and discharge was 9.0 days (interquartile range 7.0–16.0). At discharge, 61 patients (23%) showed a decline in LEMS from preoperative status. Among these patients, we identified 7 cases in which surgical intervention was required for neurologic

Table 1
Demographics data

	Mean (SD), n (%)	Range Minimum–maximum
Age (y)	56.8 (15.4)	18–81
Female	180 (67.9)	
Race		
White or Caucasian	209 (79.2)	
East Asian	49 (18.6)	
Black or African American	2 (0.8)	
Native American	1 (0.4)	
Other	3 (1.1)	
Smoker	25 (9.5)	
Diagnosis (inclusion criteria)		
Three-column osteotomy	201 (75.8)	
Revision osteotomy	161 (60.8)	
Cobb angle≥80°	77 (29.1)	
Congenital deformity	12 (4.5)	
Deformity-related myelopathy	12 (4.5)	
OPLL or OLF	5 (1.9)	
Preoperative neurologic deficit	66 (24.9)	
Previous history of spine surgeries	165 (62.3)	
Coronal DAR	5.2 (4.3)	0.3–17.4
Sagittal DAR	6.1 (3.5)	1.1–23.7
Levels involved in surgery	11.7 (4.0)	3–23
Osteotomy		
Lumbar	194 (73.2)	
Thoracic	113 (42.6)	
Surgical approach		
Posterior only	203 (76.6)	
Anterior-posterior	62 (23.4)	
Total estimated blood loss (cc)	2,000 (1,400,3,100)*	180–12,000

SD, standard deviation; OPLL, ossification of posterior longitudinal ligament; OLF, ossification of ligamentum flavum; DAR, deformity angular ratio.

* Values are median (standard deviation or Q1, Q3).

Table 2
The distribution of the lower extremity motor score declines by lumbosacral spinal level

Muscle group with declines	
L2 (hip flexors)	42 (69%)
L3 (knee extensors)	29 (48%)
L4 (ankle dorsiflexors)	21 (34%)
L5 (great toe extensors)	26 (43%)
S1 (ankle plantar flexors)	14 (23%)
Total	61

complications. The distribution of LEMS declines by lumbosacral spinal level is shown in Table 2. Among 305 muscle groups in 61 patients (5 muscle groups [L2–S1] in each patient) with postoperative neurologic decline, 84 muscle groups (28%) had osteotomies at the corresponding spinal levels, of which 43 (51%) had neurologic decline, whereas 89 out of 221 (40%) muscle groups without the osteotomy at the same level had postoperative decline (OR=1.6, 95% CI 0.97–2.8, p=.06) (Table 3). This analysis showed a trend that the osteotomy was associated with the decline in neurologic function at the same spinal level, although the adjusted OR was 1.2 (95% CI 0.7–2.2, p=.47) after the adjustment of the muscle group as a confounder. Twenty of these 61 patients were found to have experienced five points or more of LEMS decline.

Table 3
Association between osteotomy and neurologic decline at each spinal level

	Osteotomy at the level of the corresponding muscle group			
	No	Yes	Unadjusted OR (95% CI)	p-Value
Total number of muscle groups	221	84	1.64 (0.97–2.78)	.064
Without decline, n (%)	132 (60)	41 (49)		
With decline, n (%)	89 (40)	43 (51)		

OR, odds ratio; CI, confidence interval.

Given the numbers of these events encountered in our cohort, a decision was made to first select 10 variables as candidates to avoid overfitting of the final model [21]. Based on clinical relevance and knowledge from the existing literature, the following 10 variables were chosen: age, previous history of spine surgeries, preoperative neurologic deficits, coronal DAR, sagittal DAR, surgical approach (combined anterior and posterior approach vs. posterior-only approach), numbers of spinal levels involved, lumbar-level osteotomy, 3CO, and estimated blood loss [6–17]. Results of univariable analyses are summarized in Table 4. Age, the prevalence of lumber level osteotomy, the prevalence of 3CO, and blood loss were found to differ significantly between the patients with and without neurologic decline.

After using a multivariable logistic regression model with backward elimination, six variables remained in the final model (Table 5). Among these, older age (OR=1.5 per 10 years' increase, 95% CI 1.1–2.1, p=.005), larger coronal DAR (OR=1.1 per 1 unit increase, 95% CI 1.0–1.2, p=.037), and lumbar osteotomy (OR=3.3, 95% CI 1.2–9.2, p=.022) were the three significant predictors of neurologic decline.

A representative case is described in the Figure.

Discussion

Although a new neurologic deficit after ASD surgery has been reported to be relatively uncommon, this large prospective study enabled a thorough assessment of its occurrence in complex ASD surgeries. Our present findings indicated that 23% of the patients undergoing complex ASD surgery experienced a neurologic decline, as measured by LEMS at discharge, in comparison with preoperative status, and that among the many factors investigated in this prospective study, older age, larger coronal DAR, and lumbar-level osteotomy were the key contributing factors.

The reported rate of postoperative neurologic decline after complex ASD surgery in the Scoli-RISK-1 study was higher than that reported in most of the existing literature [5–14,16,17]. The Scoliosis Research Society Morbidity and Mortality Committee reported that new neurologic deficits

Table 4
Comparisons of patients and procedural characteristics between patients with and without postoperative neurologic decline, including results from univariable logistic regression models

	Mean (SD), n (%)					
	Decline in LEMS at discharge					
Prognostic factor	Yes (n=61)	No (n=204)	Details	OR	95% CI	p-Value
Age (y)	62.0 (10.3)	55.2 (16.3)	Per 10 y	1.41	(1.12–1.78)	.003
Previous history of spine surgeries	43 (71)	122 (60)		1.61	(0.87–2.98)	.133
Preoperative neurologic deficit	17 (28)	49 (24)		1.22	(0.64–2.33)	.542
Coronal DAR	6.0 (4.4)	5.0 (4.3)	Per 1 unit	1.05	(0.99–1.13)	.127
Sagittal DAR	5.7 (4.1)	6.3 (3.3)	Per 1 unit	0.95	(0.86–1.04)	.252
Anterior-posterior approach	13 (21)	49 (24)	Versus posterior only	0.86	(0.43–1.71)	.661
Levels involved in surgery	12.5 (3.9)	11.5 (4.0)	Per 1 level	1.06	(0.99–1.14)	.091
Lumbar-level osteotomy	56 (92)	138 (68)		5.36	(2.05–14.00)	<.001
Three-column osteotomy	53 (87)	148 (73)		2.51	(1.12–5.60)	.025
Total estimated blood loss (cc)*	2,500 (2,000,4,000)	2,000 (1,200,3,000)	Per 500 cc	1.09	(1.02–1.17)	.009

SD, standard deviation; OR, odds ratio; CI, confidence interval; LEMS, lower extremity motor score; DAR, deformity angular ratio.
* Values are median (Q1, Q3).

Table 5
Multivariable logistic regression analysis

Prognostic factor	Details	Adjusted OR	95% CI	p-Value
Age	Per 10 y	1.53	(1.13–2.06)	.005
Coronal DAR	Per 1 unit	1.10	(1.01–1.19)	.037
Levels involved in surgery	Per 1 level	1.08	(0.99–1.17)	.091
Lumbar-level osteotomy		3.30	(1.18–9.17)	.022
Three-column osteotomy		2.16	(0.77–6.08)	.143
Total estimated blood loss	Per 500 cc	1.06	(0.97–1.15)	.179

OR, odds ratio; CI, confidence interval; DAR, deformity angular ratio.

after spine surgery, in general, were documented in 1,064 cases (1.0%) in their largest review of 108,419 spinal procedures [22]. In the "high-risk" procedures such as osteotomy, the incidence has been known to be higher because of the direct manipulation of neurologic elements and the acute change in alignment of the spinal canal [23]. For instance, new deficit rates after 3CO have been reported to be 8.6%–40.3%, depending on the study [8,12,24–26]. The Scoli-RISK-1 study has the advantage of a prospective and multicenter design and rigorous documentation of neurologic deficits by ASIA-certified examiners, which enabled us to detect subtle changes that could be potentially missed with a surgeon-reported approach. Our study population also consisted of high-risk patients with ASD undergoing complex spinal procedures, which likely contributed to the relatively high reported rate of new deficits (23%) at discharge.

Only limited numbers of previous studies have discussed the risk factors associated with neurologic deficits after ASD surgeries, partly because a relatively large number of patients are necessary to conduct detailed analyses of these. In terms of patient demographic factors, age, previous history of spine surgeries, and preoperative neurologic deficits have been reported to be associated with a higher likelihood of neurologic complications. Elderly patients are known to have a higher risk of postoperative morbidities in general [27]. Kim et al. reported that patients older than 35 years tended to have higher neurologic deficits after VCR [12]. The neural tissue in elderly patients is thought to have decreased tolerance to insult and recovery after traumatic spinal cord injury compared with younger patients [28]. Revision surgery was also raised as a risk factor in the Scoliosis Research Society Morbidity and Mortality Committee report [22]. Several other studies regarding ASD surgeries have shown higher neurologic complication rates in revision cases than in primary cases [9,15,16]. This finding could be attributed to the altered anatomical landmarks and adhesive scar formation from the previous surgery, which could aggravate the complexity of the surgical procedures. Preoperative neurologic deficits have also been proposed as a risk factor [12,13]. Chronic hypoxia in the spinal cord makes it more vulnerable to ischemic change because of anterior spinal cord artery traction caused by the corrective maneuver.

Severity of spinal deformity clearly contributes to an increase in neurologic risk. For instance, there is a higher risk of neurologic deficits in correction surgery of significant coronal deformities with a Cobb angle of >90° [9,11] or hyperkyphosis [7,9,11–13,17]. Correction of these severe deformities leads to elongation of the spinal cord, which puts spinal cord circulation at risk, or overshortening causing kinking of the spinal cord. Shortening in the lumbar spine can result in iatrogenic foraminal stenosis leading to radiculopathy. In particular, Wang et al. focused on local acuteness of deformity as a risk factor and demonstrated an association between total DAR≥25 or sagittal DAR≥15 and neurologic risk in their consecutive series of 202 patients who underwent posterior VCR [6]. The other common surgical risk factors previously proposed are anterior-posterior (circumferential) procedures [7,9], number of spinal levels involved [10,12,13], use of osteotomy [10,11,14], and larger intraoperative blood loss [12], which all represent increased invasiveness of the surgical procedure.

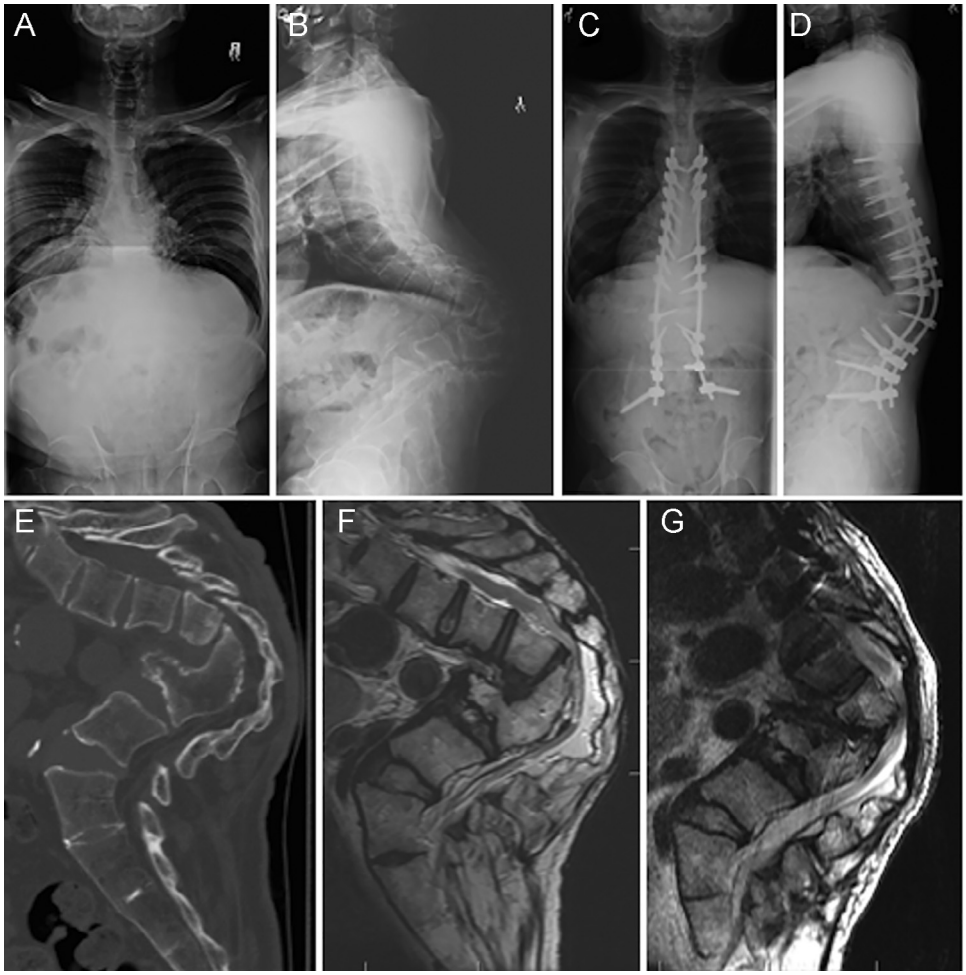

Figure. A 59-year-old man presented with postinfectious kyphoscoliosis (likely caused by treated tuberculosis) associated with fusion of L1–L4 vertebrae and a severe kyphotic deformity with neural compression. Preoperative and 1-year postoperative coronal (A) and sagittal (B) x-rays and computed tomography image (E). The local coronal Cobb angle was 15° (DAR 3.0), and the sagittal Cobb angle was measured as 151° (DAR 30.2). This patient developed intermittent claudication with an LEMS of 47 caused by cauda equina compression at the apex of the deformity as shown by the T2-weighted sagittal magnetic resonance image (F). Decompression in conjunction with deformity correction by posterior T12–L1 vertebrectomy and instrumented fusion from T5 to L2 was performed with preservation of all nerve roots. The estimated intraoperative blood loss was 2,200 cc. Coronal (C) and sagittal (D) x-rays 1 year after surgery are shown. Local sagittal Cobb angle was corrected by 40°, and decompression was confirmed by postoperative magnetic resonance imaging (G). Although no neurophysiological changes were observed intraoperatively, the patient experienced lower limb paresis immediately after the surgery (LEMS 27). After an in-hospital physiotherapy program, neurologic function gradually recovered, and the patient presented at a follow-up appointment at 6 weeks with significant improvement (LEMS 42). There was complete neurologic recovery at the 12 months' postoperative follow-up assessment (LEMS 50). DAR, deformity angular ratio; LEMS, lower extremity motor score.

In light of this previous knowledge, we investigated 10 candidate variables: age, revision surgery, preoperative neurologic deficits, coronal DAR, sagittal (kyphosis) DAR, anterior-posterior surgical approach, osteotomy levels, 3CO, lumbar osteotomy, and blood loss. Among these variables, age, lumbar osteotomy, 3CO, and blood loss were associated with a higher risk of neurologic decline in univariable analysis models, and these findings replicated the results in the existing literature. The multivariable analysis revealed that older age, larger coronal DAR, and lumbar osteotomy were the main risk factors. The present study is one of the few studies to demonstrate the negative impact of old age on neurologic outcome after ASD surgery [12]. Elderly patients should be counseled preoperatively, not only about medical complications but also regarding the neurologic risk associated with complex ASD surgery. High DAR was proven once more to be an important factor in predicting neurologic outcome in ASD surgery [6,19] and a useful indicator, from a practical point of view, to describe the severity of spinal deformity. We expected thoracic-level osteotomy involving the spinal cord to stand out as a risk factor, but, paradoxically, lumbar osteotomy was associated with a higher risk of neurologic decline. Declines in lumbar osteotomy implicate radicular symptoms, typically related to foraminal stenosis by shortening with pedicle subtraction osteotomy, to explain a significant portion of neurologic decline after ASD surgery.

Interestingly, there was a trend that the lumbar-level osteotomy was associated with decline in neurologic function

at the same spinal level as examined in LEMS. However, caution has to be taken on its interpretation because (1) many cases had declines in multiple muscle groups, and (2) a single nerve root issue can cause declines in multiple muscle groups because of the overlap in myotomes. Moreover, the different muscle groups had different risk in terms of neurologic decline. Specifically, L2 was the most commonly affected spinal level as shown in Table 2, whereas osteotomy was the most commonly performed at L2 as well. Therefore, chances are that this association was overrated. Despite all these limitations, our present results still highlighted the impact of lumbar-level procedures on developing neurologic events.

The present study does have several other limitations. First, despite our inclusion criteria with strict definitions of "complex" ASD, the patient cohort studied in Scoli-RISK-1 was still heterogeneous in diagnosis and treatment options. We focused only on "high-risk" ASD surgeries; thus, comparisons with previous studies discussing ASD surgeries should be undertaken with caution. Second, the surgeries investigated in the Scoli-RISK-1 study were all performed by very experienced spinal deformity surgeons in specialized institutions. Therefore, our current results should be interpreted with caution when applied to spinal deformity surgeries in general. Third, we reported only on motor function in lower extremities using the ASIA LEMS component, which means that thoracic radiculopathy or sensory-only deficits were not captured, and these minor deficits might have been underestimated. Also, the reliability of neurologic assessment could have been compromised in some patients, such as those with significant pain, even with the examination by our ASIA-certified examiners. Notably, neurologic declines that existed in the very early postoperative period but resolved at discharge either spontaneously or by surgical intervention were not assessed in the present study, which might have caused a slight underestimation of neurologic events. Lastly, the relative rarity of neurologic decline limited our capability to perform comprehensive screening of the risk factors. It is generally a rule of thumb to use only one variable for 10 events in a multivariable analysis. As the present study is exploratory in nature, we expanded the limit to 10 variables based on knowledge gleaned from the existing literature. There were still many other variables that were recorded in the database but were not included in the present investigation, such as diagnosis of congenital scoliosis or operation duration. For a thorough investigation, examination of large-scale databases such as nationwide studies is warranted.

Conclusions

In conclusion, our prospective, multicenter, observational Scoli-RISK-1 study documented a lower extremity motor decline rate of 23% at discharge after complex ASD surgery. Older age, larger coronal DAR, and lumbar-level osteotomy were risk factors for postoperative neurologic deterioration. These risk factors should be considered in planning ASD surgeries, and this knowledge will be useful for counselling patients preoperatively and can be used as a reference for future studies.

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