Spine

SPINE Volume 36, Number 18, pp 1484–1491

DEFORMITY

Complications in the Surgical Treatment of 19,360 Cases of Pediatric Scoliosis

A Review of the Scoliosis Research Society Morbidity and Mortality Database

Davis L. Reames, MD,* Justin S. Smith, MD, PhD,* Kai-Ming G. Fu, MD, PhD,* David W. Polly, Jr., MD,†‡ Christopher P. Ames, MD,§ Sigurd H. Berven, MD,¶ Joseph H. Perra, MD,‖ Steven D. Glassman, MD,** Richard E. McCarthy, MD,†† Raymond D. Knapp, Jr., MD,‡‡ Robert Heary, MD,§§ Christopher I. Shaffrey, MD,* and Scoliosis Research Society Morbidity and Mortality Committee

Study Design. Retrospective review of a multicenter database.

Objective. To determine the complication rates associated with surgical treatment of pediatric scoliosis and to assess variables associated with increased complication rates.

Summary of Background Data. Wide variability is reported for complications associated with the operative treatment of pediatric scoliosis. Limited number of patients, surgeons, and diagnoses occur in most reports. The Scoliosis Research Society Morbidity and Mortality (M&M) database aggregates deidentified data, permitting determination of complication rates from large numbers of patients and surgeons.

Methods. Cases of pediatric scoliosis (age ≤18 years), entered into the Scoliosis Research Society M&M database between 2004 and 2007, were analyzed. Age, scoliosis type, type of instrumentation used, and complications were assessed.

Results. A total of 19,360 cases fulfilled inclusion criteria. Of these, complications occurred in 1971 (10.2%) cases. Overall complication rates differed significantly among idiopathic, congenital, and neuromuscular cases ($P < 0.001$). Neuromuscular scoliosis had the highest rate of complications (17.9%), followed by congenital scoliosis (10.6%) and idiopathic scoliosis (6.3%). Rates of neurologic deficit also differed significantly based on the etiology of scoliosis ($P < 0.001$), with the highest rate among congenital cases (2.0%), followed by neuromuscular types (1.1%) and idiopathic scoliosis (0.8%). Neur-omuscular scoliosis and congenital scoliosis had the highest rates of mortality (0.3% each), followed by idiopathic scoliosis (0.02%). Higher rates of new neurologic deficits were associated with revision procedures ($P < 0.001$) and with the use of corrective osteotomies ($P < 0.001$). The rates of new neurologic deficit were significantly higher for procedures using anterior screw-only constructs (2.0%) or wire-only constructs (1.7%), compared with pedicle screw-only constructs (0.7%) ($P < 0.001$).

Conclusion. In this review of a large multicenter database of surgically treated pediatric scoliosis, neuromuscular scoliosis had the highest morbidity, but relatively high complication rates occurred in all groups. These data may be useful for preoperative counseling and surgical decision-making in the treatment of pediatric scoliosis.

Key words: pediatric scoliosis, complications, surgery, idiopathic scoliosis, congenital scoliosis, neuromuscular scoliosis. **Spine 2011;36:1484–1491**

Pediatric scoliosis is a heterogeneous collection of spinal deformities, broadly defined as a coronal deviation of the spine of more than 10° in a pediatric patient.[1,2] On the basis of this definition, prevalence has been estimated between 1.5% and 3.0%.[3–6] Among the most common categories of pediatric scoliosis are idiopathic, neuromuscular, and congenital.[1,7–9]

The pathogenesis of pediatric scoliosis may begin *in utero* with complex defects ranging from failures of formation to disruptions of segmentation.[1] Postnatal causes vary from developmental to acquired etiologies, although idiopathic types are by far the most common. The natural history of pediatric scoliosis is highly variable and is dependent on the etiology. In general, neuromuscular scoliosis and congenital scoliosis are more likely to progress and ultimately warrant intervention than adolescent idiopathic scoliosis.[10] Among the latter group, female gender, younger age, and greater curve magnitude at diagnosis are recognized factors associated with a higher rate of curve progression.[6]

From the *Department of Neurosurgery, University of Virginia Medical Center, Charlottesville, VA; Departments of †Orthopedic Surgery; and ‡ Neurosurgery, University of Minnesota, Minneapolis, MN; Departments of §Neurosurgery; and ¶Orthopedic Surgery, University of California, San Francisco, CA; ‖Twin Cities Spine Center, Minneapolis, MN; **Norton Leatherman Spine Center, Louisville, KY; ††Arkansas Spine Center, Little Rock, AR; ‡‡Arnold Palmer Children's Hospital, Orlando, FL; §§Center for Neurological Surgery, UMDNJ, Newark, NJ.

Acknowledgment date: June 15, 2010. First revision date: July 10, 2010. Acceptance date: July 12, 2010.

The manuscript submitted does not contain information about medical device(s)/drug(s).

No funds were received in support of this work. One or more of the author(s) has/have received or will receive benefits for personal or professional use from a commercial party related directly or indirectly to the subject of this manuscript: e.g., honoraria, gifts, consultancies, royalties, stocks, stock options, decision making position.

Address correspondence and reprint requests to Christopher I. Shaffrey, MD, University of Virginia Health Sciences Center, Department of Neurosurgery, PO Box 800212, Charlottesville, VA 22908; E-mail: cis8z@hscmail.mcc.virginia.edu

DOI: 10.1097/BRS.0b013e3181f3a326

A subset of pediatric patients with scoliosis ultimately warrants surgical management. Neurologic deficit, curve progression, pain, cardiopulmonary compromise, and cosmesis are among the indications for scoliosis correction. Recognition of complication rates is critical for patient counseling and quality assurance measures; however, there are relatively few studies available to help guide management. In addition, wide variability is reported for complications associated with operative treatment of pediatric scoliosis, and most of the available reports are limited by relatively small numbers of patients or patient populations from single surgeon or institution experiences.[11–29] Furthermore, many of the currently available reports that document complication rates in pediatric scoliosis surgery are based on cases performed before the widespread use of aggressive osteotomies and pedicle screw instrumentation and may not be reflective of the risks involved with these newer approaches.

The Scoliosis Research Society (SRS) consists predominantly of fellowship trained spine surgeons and pediatric orthopedists who are dedicated to the advancement of care for patients with spinal deformity. One of the unique features of this society is the requirement of its members to submit surgical case data, including morbidity and mortality (M&M). These data have been collected for more than 40 years and have enabled multiple studies that have defined complication rates for spinal procedures.[30–35] The power of this database rests on the vast number of cases submitted, the extensive numbers of surgeons and institutions represented, the spectrum of pathology, and the prospective design.

Our objectives in the present study were 2-fold. First, we used the SRS M&M database to assess the complication rates associated with the surgical treatment of pediatric scoliosis, stratified based on general subtype. Second, we assessed for associations between rates of neurologic injury and surgical factors, such as inclusion of a corrective osteotomy and type of instrumentation used. This study is unique that provides M&M data based on a large multi-institutional series of pediatric scoliosis procedures that reflect newer trends in deformity correction, including the use of aggressive osteotomies and the widespread use of thoracic pedicle screws.

MATERIALS AND METHODS

The SRS M&M database was examined for all cases reported from the years 2004 to 2007, with the inclusion criteria of age ≤18 years and primary diagnosis of scoliosis. Extracted variables included scoliosis type (divided into idiopathic, congenital, neuromuscular, and "other"), occurrence of nonfatal and fatal complications, type of spinal instrumentation used, whether an osteotomy was performed, and if so, the type of osteotomy; and whether the surgery was primary or revision. In addition, for new neurologic deficits, the type of deficit (nerve root, *cauda equina*, partial spinal cord, or complete spinal cord) and the degree of improvement (none, partial, or complete) were extracted. Members were requested to submit operative and perioperative complications, and in general, this represented complications occurring up to at least 30 days after surgery. The category of "other" scoliosis reflects a broad range of subtypes, including post-traumatic, syndromic (Down's, Marfan's, Ehlers-Danlos), neurofibromatosis, non-neurologic tumor, iatrogenic, and bone dysplasias/dwarfism.

This project was submitted to the Hospital for Special Surgery (New York, NY) Institutional Review Board (IRB) and was determined to be exempt from IRB approval based on use of deidentified data (IRB 29045).

Frequency distributions and summary statistics were calculated for all clinical data. For categorical variables, crosstabulations were generated, and Fisher exact and Pearson's χ^2 tests were used to compare distributions. All statistical analyses were 2-sided. $P < 0.05$ was considered significant.

RESULTS

A total of 19,360 cases fulfilled inclusion criteria. Cases were grouped into 4 primary subtypes, including idiopathic, congenital, neuromuscular, and other. Idiopathic cases included infantile (0-3 years, n = 367), juvenile (4–10 years, n = 927), and adolescent (11–18 years, n = 9886). There were 47 cases of idiopathic scoliosis unspecified as to subtype. Congenital cases included mixed types (n = 984), those related to failure of formation (n = 694), failure of segmentation (n = 224), and unspecified (n = 110). Neuromuscular cases included those related to cerebral palsy (n = 1974), myelodysplasia (n = 575), muscular dystrophy (n = 446), spinal muscular atrophy (n = 280), postspinal cord injury (n = 127), Rett syndrome (n = 92), neural tumor (n = 54), Friedrich's ataxia (n = 51), Charcot–Marie–Tooth disease (n = 48), polio (n = 27), and other (n = 983). The remaining 1464 cases were designated as other.

A total of 1971 total complications (10.2%) were reported and are summarized overall on the basis of scoliosis subtype in Table 1. Among the 3 most common types of scoliosis (idiopathic, congenital, and neuromuscular), the total complication rates differed significantly ($P < 0.001$). Neuromuscular scoliosis had the highest overall rate of complication (835/4657 or 17.9%), followed by congenital scoliosis (213/2012 or 10.6%) and idiopathic scoliosis (710/11,227 or 6.3%). Rates of neurologic deficit also differed significantly based on scoliosis etiology ($P < 0.001$), with the highest rate among congenital cases (41/2012 or 2.0%), followed by neuromuscular types (49/4657 or 1.1%) and idiopathic scoliosis (86/11,227 or 0.8%). Significant differences in the incidences of other complications among the subtypes of scoliosis were also demonstrated, including superficial and deep wound infection, pulmonary complications exclusive of pulmonary embolism, hematologic, durotomy, and implant-related complications (Table 1).

Mortality occurred in 26 patients (approximately 1.3 per 1000), with neuromuscular and congenital scoliosis having the highest rates (3 per 1000 each), followed by idiopathic scoliosis (2 per 10,000) (Table 2). Respiratory failure or aspiration was the leading cause of death when all groups were combined, accounting for 8 of the 26 deaths (31%). This was followed by excessive blood loss and sepsis, each accounting

TABLE 1. Complications Associated With the Surgical Treatment of Scoliosis in 19,360 Pediatric Patients

N	Total 19,360	Idiopathic 11,227	Congenital 2012	Neuromuscular 4657	Other* 1464
Total complications†	10.2% (1971)	6.3% (710)	10.6% (213)	17.9% (835)	14.5% (213)
New neurological deficit†	1.0% (199)	0.8% (86)	2.0% (41)	1.1% (49)	1.6% (23)
Death†	0.1% (26)	0.02% (2)	0.3% (6)	0.3% (16)	0.1% (2)
Superficial wound infection†	1.0% (184)	0.5% (61)	1.3% (27)	1.7% (79)	1.2% (17)
Deep wound infection†	1.7% (321)	0.8% (95)	0.9% (18)	3.8% (177)	2.1% (31)
Pulmonary (not embolism)†	1.0% (202)	0.6% (63)	1.1% (23)	1.9% (90)	1.8% (26)
Non-fatal hematologic†	0.5% (93)	0.2% (25)	0.1% (3)	1.2% (57)	0.5% (8)
Durotomy†	0.4% (76)	0.2% (22)	0.4% (8)	0.9% (42)	0.3% (4)
Implant related†	1.5% (296)	1.1% (120)	1.5% (31)	2.1% (100)	3.1% (45)
Deep venous thrombosis‡	0.01% (2)	<0.01% (1)	0.05% (1)	0% (0)	0% (0)
Pulmonary embolus‡	0.04% (7)	0.04% (5)	0% (0)	0.04% (2)	0% (0)
Epidural hematoma‡	0.02% (3)	<0.01% (1)	0% (0)	0.02% (1)	0.1% (1)
Vision deficit‡	<0.01% (1)	0% (0)	0% (0)	0.02% (1)	0% (0)
Peripheral nerve/plexus deficit§	0.5% (89)	0.5% (53)	0.8% (17)	0.3% (15)	0.3% (4)
SIADH‡	0.3% (48)	0.2% (23)	0.15% (3)	0.3% (14)	0.5% (8)
Other complications†	2.2% (424)	1.4% (153)	1.7% (35)	4.1% (192)	3.0% (44)

**Post-traumatic, syndromic (Down Syndrome, Marfans, Ehrler's–Danlos), neurofibromatosis, non-neurological tumor, iatrogenic, bone dysplasias/dwarfism.*

†$P < 0.001$ (Pearson P values comparing idiopathic, congenital, and neuromuscular cases).

‡$P > 0.05$ (Pearson P values comparing idiopathic, congenital, and neuromuscular cases).

§$P = 0.01$ (Pearson P value comparing idiopathic, congenital, and neuromuscular cases).

TABLE 2. Mortality Associated With the Surgical Treatment of Scoliosis in 19,360 Pediatric Patients

	Total N (%)	Idiopathic 11,227	Congenital 2012	Neuromuscular 4657	Other 1464
Total	26 (0.13%)	2(0.02%)	6(0.30%)	16(0.34%)	2(0.14%)
Respiratory failure or aspiration	8		3	4	1
Sepsis	4				
Pneumonia	3	1		2	
Bowel perforation	1			1	
Intraoperative hemorrhage	4		1	3	
Cardiac failure	2	1		1	
Pulmonary embolus	1			1	
TRALI	1		1		
Brainstem herniation	1		1		
Brainstem infarct	1			1	
Fluid overload	1			1	
Unknown	3			2	1

TRALI indicates transfusion-related acquired lung injury.

TABLE 3. New Neurological Deficits and Degrees of Recovery Associated With the Surgical Treatment of 19,360 Pediatric Patients With Scoliosis

	Total 19,360	Idiopathic 11,227	Congenital 2012	Neuromuscular 4657	Other 1464
Neurological deficit	199(1.0%)	86*(0.8%)	411† (2.0%)	49(1.1%)	23(1.6%)
Nerve root deficit	83 (0.4)	36(0.3)	19(0.9)	19(0.4)	9 (0.6)
Complete recovery	55	27	13	12	3
Partial recovery	27	9	5	7	6
No recovery	1	0	1	0	0
Cauda equina deficit	4 (0.02)	0	1 (0.05)	3 (0.06)	0
Complete recovery	1	0	0	1	0
Partial recovery	1	0	1	0	0
No recovery	2	0	0	2	0
Incomplete spinal cord deficit	90 (0.5)	41 (0.4)	17(0.8)	20 (0.4)	12 (0.8)
Complete recovery	59	33	10	11	5
Partial recovery	30	7	7	9	7
No recovery	1	1	0	0	0
Complete spinal cord deficit	18 (0.09)	6(0.05)	3(0.15)	7(0.15)	2(0.1)
Complete recovery	7	3	1	2	1
Partial recovery	6	3	1	1	1
No recovery	5	0	1	4	0

**Three idiopathic scoliosis with deficits not further specified to severity.*

†One congenital scoliosis with deficit not further specified to severity.

for 4 deaths (15%). The remaining deaths were attributed to cardiac causes, pulmonary embolus, brain stem herniation, brain stem infarct, transfusion-related acquired lung injury, and fluid overload. Cause of death was unknown for 3 cases.

New postoperative neurologic deficits were noted in 199 cases (1.0%) (Table 3). All but 3 cases included report of the type of deficit (nerve root, *cauda equina*, or spinal cord) and degree of recovery (complete, partial, or none). The most common deficits were incomplete spinal cord deficit (90/19,360 or 0.5%) and nerve root deficit (83/19,360 or 0.4%), whereas complete spinal cord deficit occurred in 0.09% (18/19,360) and *cauda equina* deficit in 0.02% (4/19,360) (Table 3). Most cases of nerve root deficit (55/83 or 66%) and incomplete spinal cord deficit (60/90 or 67%) experienced complete recovery. Only 1 of 4 (25%) cases of *cauda equina* deficit and 7 of 18 (39%) complete spinal cord deficits had complete recovery. There were 5 patients with complete spinal cord deficit, 2 patients with *cauda equina* deficit, and a single patient each with incomplete spinal cord or nerve root deficit, who did not experience improvement. The remainder of the 195 cases with recorded new deficit experienced a partial recovery.

Associations were identified between type of instrumentation used and the occurrence of new neurologic deficits (Table 4). Cases that included anterior screw-only constructs or posterior wire-only constructs were associated with the highest rates of new neurologic deficit (21/1019 or 2.0% and 7/415 or 1.7%, respectively). Pedicle screw-only constructs (thoracic and/or lumbar) were associated with a significantly lower rate of new neurologic deficits (34/4672 or 0.7%) compared with either anterior screw-only or wire-only constructs ($P < 0.001$). Rates of new neurologic deficit were not significantly different between pedicle screw-only and hook-only constructs ($P = 0.3$).

The rates of new neurologic deficits were statistically similar for cases using thoracic pedicle screw-only constructs and those using lumbar pedicle screw-only constructs (5/1066 or 0.5% and 2/309 or 0.6%, respectively, $P = 0.7$; Table 4). However, the majority of new deficits associated with thoracic pedicle screws were at the spinal cord level, whereas all new deficits reported with lumbar pedicle screw-only constructs were at the nerve root level.

Use of an osteotomy, including Smith-Peterson osteotomy (SPO), pedicle subtraction osteotomy (PSO), or vertebral column resection (VCR), was associated with a 2% rate of new neurologic deficits (Table 5), a rate significantly higher than for cases not including an osteotomy (159/17,382 or 0.9%, $P < 0.001$). Cases including a VCR had the highest rate of new

TABLE 4. New Neurological Deficits Associated With the Surgical Treatment of Pediatric Scoliosis, Stratified Based on Type of Instrumentation Used

	Total	New Neurological Deficits*†‡ N (%)	Nerve Root Deficit	*Cauda Equina* Deficit	Spinal Cord Deficit (Partial)	Spinal Cord Deficit (Complete)
Lumbar pedicle screws only	309	2 (0.6)	2*	0	0	0
Thoracic pedicle screws only	1066	5 (0.5)	2*	0	3*	0
Thoracic and/or lumbar pedicle screws only§	4672	34 (0.7)	10*, 5‡	1*	11*, 5‡	1*, 1‡
Anterior screws only	1019	21¶ (2)	7*,4‡	0	4*, 3†	1‡
Posterior hooks only	1021	4 (0.4)	3‡	0	1*	0
Posterior wires only	415	7 (1.7)	2*	0	1*, 2†	1*, 1†

**Complete recovery.*

†Partial recovery.

‡No recovery.

§Pedicle screw-only constructs (thoracic and/or lumbar) had a significantly lower rate of new neurological deficits compared with anterior-only screw constructs ($P < 0.001$) and posterior wire-only constructs ($P < 0.001$). Pedicle screw-only constructs (thoracic and/or lumbar) had a statistically similar rate of new neurological deficits compared with hook-only constructs ($P = 0.3$).

¶Two new deficits not further specified.

neurologic deficit (13/177 or 7.3%, $P < 0.001$), followed by cases including PSO (8/303 or 2.6%) or SPO (1159/17,382 or 1.1%). Type of neurologic deficit and degree of recovery are shown in Table 5.

Compared with primary procedures, revision surgery was associated with an increased rate of overall complications with surgery for pediatric scoliosis overall ($P < 0.001$) and for the idiopathic scoliosis subtype ($P < 0.001$) (Figure 1).

DISCUSSION

This is the largest study to date comparing complication rates associated with surgical treatment for the major subtypes of

TABLE 5. New Neurological Deficits Associated With the Surgical Treatment of Pediatric Scoliosis, Stratified Based on Whether an Osteotomy Was Performed as Part of the Procedure

	N	Total New Neurological Deficits*†‡ N %	Nerve Root Deficit	*Cauda Equina* Deficit	Spinal Cord Deficit (Partial)	Spinal Cord Deficit (Complete)
No osteotomy	17,382	159‡ (0.9)	62 (0.4)	3 (0.02)	74 (0.4)	17(0.1)
Osteotomy performed§	1978	40¶ (2.0)	21 (1.1)	1 (0.05)	16 (0.8)	1 (0.05)
Smith-Peterson osteotomy	1204	13 (1.1)	4*, 4† (0.7)	0	4*, 1† (0.4)	0
Pedicle subtraction osteotomy	303	8 (2.6)	4*, 1† (1.7)	0	2*, 1† (1.0)	0
Vertebral column resection§	177	13 (7.3)	4* (2.2)	1† (0.6)	3*, 3† (3.4)	1† (0.6)
Anterior corpectomy or discectomy	243	6 (2.5)	1*, 3† (1.6)	0	1*, 1† (0.8)	0
Unspecified	51	0	0	0	0	0

**Complete recovery.*

†Partial recovery.

‡Three new neurological deficits not further specified.

§Inclusion of an osteotomy was associated with a significantly higher total rate of new neurological deficits ($P < 0.001$).

¶One new neurological deficit not further specified.

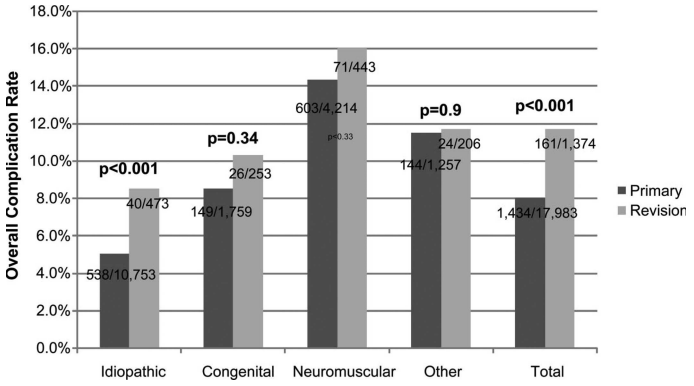

Figure 1. Rates of overall complications associated with the surgical treatment of 19,360 pediatric patients with scoliosis, stratified based on primary *versus* revision surgical status. Complication rates are based on whether any complication occurred in each case and do not account for multiple complications in individual cases.

pediatric scoliosis. This report provides separate complication rates for neuromuscular, congenital, and idiopathic scoliosis and demonstrates significantly different rates of complications among these subtypes. This report also documents the increased complication rates associated with revision surgery and with procedures including corrective osteotomies. In addition, this modern series enables demonstration of the significantly lower rates of neurologic injury associated with pedicle screw-only constructs compared with reconstructions based on anterior screws or posterior wires. Furthermore, the numbers of patients in this study permit estimation of the mortality rates associated with pediatric scoliosis correction. Collectively, these data provide potentially useful information for surgical planning, preoperative patient counseling, and for on-going efforts to improve the safety of patient care.

The overall complication rate for idiopathic scoliosis surgery in the present series was 6.3%, and the mortality rate was 0.02%. These rates are comparable to those reported by Coe *et al*, based on a report from the SRS M&M Committee that focused on 6332 cases of adolescent idiopathic scoliosis (AIS), reported between the years 2001 and 20 03.[30] The overall complication and mortality rates in this series were 5.2% and 0.03%, respectively.

Patil *et al* reported an overall complication rate of 14.9% and mortality rate of 0.17% based on 35,600 pediatric patients surgically treated for idiopathic scoliosis.[36] This study was based on the National Inpatient Sample, an inpatient care database that represents a 20% stratified sample of nonfederal community hospitals in the United States. In another study, by Carreon et al,[37] a 15.4% rate of non-neurologic complications and a 0% mortality rate were reported from 702 pediatric patients surgically treated for AIS. The complication rates are higher in these 2 reports than in the present series. These differences may reflect a lower threshold for classification of "pulmonary" and "postoperative bleeding or hematoma" complications in the study by Patel et al, because the rates of these complications were reported to be 8.1% and 4.1%, respectively. In addition, in the study by Carreon et al,[37] a considerable number of medical complications, such as illeus, diarrhea, and allergic reaction to medications were included in the complication rates, whereas the present study focused primarily on surgical and major medical complications.

The overall complication rate for congenital scoliosis surgery in the present series was 10.6%, and the mortality rate was 0.3%. Few modern reports are available in the literature for comparison, and those available predominantly include fewer than 50 patients,[19–23] a sufficiently small population size in which the presence of a single complication can greatly affect the overall complication rate. Notably, no deaths are reported in these prior series, likely reflective of the small numbers of patients and the relatively rare occurrence of mortality in these cases.

Surgery for neuromuscular scoliosis had the highest overall complication rate (17.9%) and the highest mortality rate (0.34%) in the present series. The number of patients, typically less than 5 0 0[24–29,38–41] and more commonly less than 100,[24–29] in previously reported series of surgically treated neuromuscular scoliosis patients considerably limits the ability of these studies to estimate rates of complications and leads to considerable variation. The overall complication rate in the present series is within the range of these prior studies (0%[27]−33%[39]). Although no cases of mortality are reported in most prior series,[24–29,39] Barsdorf *et al* reported a mortality rate of 1.6% (7 of 437 cases) following surgery for neuromuscular scoliosis, based on the National Inpatient Sample between 1997 and 2003.[38]

The rates at which new neurologic deficits occur in association with scoliosis surgery have not been well defined.[42–44] Notably, some of the earliest estimates were derived based on assessments of the SRS M&M database. In a report from the SRS, MacEwen *et al* were the first to evaluate this complication after the widespread introduction of instrumentation for the correction of scoliosis.[32] They reported a 0.72% rate of neurologic complication for all diagnoses (idiopathic, congenital, and neuromuscular scoliosis).[32] Subsequently, Winter[45] and Coe *et al*,[30] also provided assessments of rates of neurologic injury associated with surgery for scoliosis. In the latter report,[30] based on 6334 cases of AIS, the rate of neurologic injury was 0.5%, which is comparable to the 0.75% for idiopathic scoliosis in the present series. In addition, Diab *et al*.[46] found a 0.69% rate of neural complications in their review of operative treatment of 1301 consecutively treated cases of AIS, and Qiu *et al*.[47] reported new postoperative neurologic deficit rates of 1.06% for AIS (8 of 756), 2.89% for congenital scoliosis (11 of 381), and 3.05% for neuromuscular scoliosis (4 of 131). The rates of the present series are comparable to those of Coe *et al* and Qiu *et al*.

In an effort to assess for potential differences in the rates of new neurologic deficit associated with type of instrumentation used, we assessed these rates in cases that used only a single type of instrumentation, specifically pedicle screws, anterior

screws, hooks, or wires. Pedicle screw-only and hook-only constructs had comparable overall rate of new neurologic deficit. In contrast, anterior screw-only and wire-only constructs had greater than 2-fold higher rates of new neurologic deficit. It is possible that the higher rate of deficit associated with wire-only constructs may result from direct trauma as wires are passed sublaminar, because the majority of these were spinal cord deficits. The higher rate of deficit associated with anterior-only screw constructs may result in part from the relatively steep learning curve involved in placement of anterior screws using thoracoscopic approaches,[48] but this cannot be confirmed based on the database.

In the present series, aggressive osteotomies, including PSOs and VCRs, were associated with higher rates of new neurologic deficits. These osteotomies can offer the potential for powerful correction and are often used in patients with the most complex and rigid deformities. When considering the use of these techniques, it is important to recognize the significantly higher inherent risks of these approaches and provide appropriate preoperative counseling.

The present study has several strengths, most notably the large number of cases that includes representation of the less common subtypes of pediatric scoliosis. Although predominantly fellowship-trained spine surgeons, the contributors represent a broad range of experience levels, enhancing the generalizability of the data. Cases were submitted from multiple institutions that helps to mitigate the effects that specific institutional factors and patient populations may have on the occurrence of complications.

The present study also has some limitations. The study design and analysis were performed retrospectively. There are no methods to determine completeness of data submission, nor the accuracy of the reporting. It is dependent on the efforts of the participants. Therefore, it is possible that the rates of complications in the present study may underestimate the true rates. In addition, the database is primarily designed to capture surgical complications and major medical morbidity, and does not capture parameters that may also be of interest, including radiographic and clinical outcomes.

CONCLUSION

On the basis of 19,360 cases of operatively treated pediatric scoliosis, the overall complication rate was 10.2%, and the overall mortality rate was 0.13% (approximately, 1.3 per 1000). Consistent with prior reports, higher rates of M&M were associated with surgery for neuromuscular and congenital scoliosis when compared with idiopathic scoliosis. Higher rates of new neurologic deficits were associated with the use of anterior screw-only constructs, wire-only constructs, revision procedures, and the use of aggressive osteotomies, including PSOs and VCRs. Collectively, these data provide benchmark rates of M&M for pediatric scoliosis surgery that may prove useful for operative planning, patient counseling, and on-going efforts to improve the safety of patient care.

➢ Key Points

- ❑ Based on 19,360 cases of operatively treated pediatric scoliosis, the overall complication rate was 10.2%, and the overall mortality rate was 0.13% (approximately, 1.3 per 1000).
- ❑ Higher rates of M&M were associated with surgery for neuromuscular scoliosis (17.9% and 0.34%, respectively) and congenital scoliosis (10.6% and 0.30%, respectively), compared with idiopathic scoliosis (6.3% and 0.02%, respectively).
- ❑ Higher rates of new neurologic deficits were associated with revision procedures and with the use of aggressive osteotomies, including PSOs and VCRs.
- ❑ Compared with pedicle screw-only and hookonly constructs, wire-only and anterior screwonly constructs were associated with significantly higher rates of new neurologic injury.
- ❑ These data provide benchmark rates of M&M for pediatric scoliosis surgery that may prove useful for operative planning, patient counseling, and on-going efforts to improve the safety of patient care.

References

1. Smith JS, Abel MF, Shaffrey CI, et al. Decision making in pediatric spinal deformity. *Neurosurgery* 2008;63(suppl 3):54–68.
2. Kane WJ. Scoliosis prevalence: a call for a statement of terms. *Clin Orthop Relat Res* 1977;126:43–6.
3. Asher M, Green P, Orrick J. A six-year report: spinal deformity screening in Kansas school children. *J KansMed Soc* 1980;81:568–71.
4. Lonstein JE, Bjorklund S, Wanninger MH, et al. Voluntary school screening for scoliosis in Minnesota. *J Bone Joint Surg Am* 1982;64:481–8.
5. Roach JW. Adolescent idiopathic scoliosis. *Orthop Clin North Am* 1999;30:353–65, vii-viii.
6. Weinstein SL. Adolescent idiopathic scoliosis: prevalence and natural history. *Instr Course Lect* 1989;38:115–28.
7. Chan G, Dormans JP. Update on congenital spinal deformities: preoperative evaluation. *Spine (Phila Pa 1976)* 2009;34:1766–74.
8. Hedequist DJ. Instrumentation and fusion for congenital spine deformities. *Spine (Phila Pa 1976)* 2009;34:1783–90.
9. Sarwark J, Sarwahi V. New strategies and decision making in the management of neuromuscular scoliosis. *Orthop Clin North Am* 2007;38:485–96, v.
10. McMaster MJ, Singh H. Natural history of congenital kyphosis and kyphoscoliosis. A study of one hundred and twelve patients. *J Bone Joint Surg Am* 1999;81:1367–83.
11. Bridwell KH, Hanson DS, Rhee JM, et al. Correction of thoracic adolescent idiopathic scoliosis with segmental hooks, rods, and Wisconsin wires posteriorly: it's bad and obsolete, correct? *Spine (Phila Pa 1976)* 2002;27:2059–66.
12. Di Silvestre M, Bakaloudis G, Lolli F, et al. Posterior fusion only for thoracic adolescent idiopathic scoliosis of more than 80 degrees: pedicle screws versus hybrid instrumentation. *Eur Spine J* 2008;17:1336–49.
13. Dobbs MB, Lenke LG, Kim YJ, et al. Selective posterior thoracic fusions for adolescent idiopathic scoliosis: comparison of hooks versus pedicle screws. *Spine (Phila Pa 1976)* 2006;31:2400–4.
14. Kim YJ, Lenke LG, Cho SK, et al. Comparative analysis of pedicle screw versus hook instrumentation in posterior spinal fusion of adolescent idiopathic scoliosis. *Spine (Phila Pa 1976)* 2004;29:2040–8.
15. Kim YJ, Lenke LG, Kim J, et al. Comparative analysis of pedicle screw versus hybrid instrumentation in posterior spinal fusion of adolescent idiopathic scoliosis. *Spine (Phila Pa 1976)* 2006;31:291–8.

16. Luhmann SJ, Lenke LG, Bridwell KH, et al. Revision surgery after primary spine fusion for idiopathic scoliosis. *Spine (Phila Pa 1976)* 2009;34:2191–7.
17. Storer SK, Vitale MG, Hyman JE, et al. Correction of adolescent idiopathic scoliosis using thoracic pedicle screw fixation versus hook constructs. *J Pediatr Orthop* 2005;25:415–9.
18. McDonnell MF, Glassman SD, Dimar JR II, et al. Perioperative complications of anterior procedures on the spine. *J Bone Joint Surg Am* 1996;78:839–47.
19. Campbell RM Jr, Smith MD, Mayes TC, et al. The effect of opening wedge thoracostomy on thoracic insufficiency syndrome associated with fused ribs and congenital scoliosis. *J Bone Joint Surg Am* 2004;86:1659–74.
20. Deviren V, Berven S, Smith JA, et al. Excision of hemivertebrae in the management of congenital scoliosis involving the thoracic and thoracolumbar spine. *J Bone Joint Surg Br* 2001;83:496–500.
21. Lenke LG, O'Leary PT, Bridwell KH, et al. Posterior vertebral column resection for severe pediatric deformity: minimum two-year follow-up of thirty-five consecutive patients. *Spine (Phila Pa 1976)* 2009;34:2213–21.
22. Ruf M, Jensen R, Letko L, et al. Hemivertebra resection and osteotomies in congenital spine deformity. *Spine (Phila Pa 1976)* 2009;34:1791–9.
23. Shimode M, Kojima T, Sowa K. Spinal wedge osteotomy by a single posterior approach for correction of severe and rigid kyphosis or kyphoscoliosis. *Spine (Phila Pa 1976)* 2002;27:2260–7.
24. Benson ER, Thomson JD, Smith BG, et al. Results and morbidity in a consecutive series of patients undergoing spinal fusion for neuromuscular scoliosis. *Spine (Phila Pa 1976)* 1998;23:2308–17; discussion 2318.
25. Modi HN, Hong JY, Mehta SS, et al. Surgical correction and fusion using posterior-only pedicle screw construct for neuropathic scoliosis in patients with cerebral palsy: a three-year follow-up study. *Spine (Phila Pa 1976)* 2009;34:1167–75.
26. Modi HN, Suh SW, Hong JY, et al. Treatment and complications in flaccid neuromuscular scoliosis (Duchenne muscular dystrophy and spinal muscular atrophy) with posterior-only pedicle screw instrumentation. *Eur Spine J* 2010;19:384–93.
27. Suh SW, Modi HN, Yang J, et al. Posterior multilevel vertebral osteotomy for correction of severe and rigid neuromuscular scoliosis: a preliminary study. *Spine (Phila Pa 1976)* 2009;34:1315–20.
28. Teli M, Elsebaie H, Biant L, et al. Neuromuscular scoliosis treated by segmental third-generation instrumented spinal fusion. *J Spinal Disord Tech* 2005;18:430–8.
29. Thacker M, Hui JH, Wong HK, et al. Spinal fusion and instrumentation for paediatric neuromuscular scoliosis: retrospective review. *J Orthop Surg (HongKong)* 2002;10:144–51.
30. Coe JD, Arlet V, Donaldson W, et al. Complications in spinal fusion for adolescent idiopathic scoliosis in the new millennium. A report of the Scoliosis Research Society Morbidity and Mortality Committee. *Spine (Phila Pa 1976)* 2006;31:345–9.
31. Coe JD, Smith JS, Berven S, et al. Complications of spinal fusion for scheuermann kyphosis: a report of the Scoliosis Research Society morbidity and mortality committee. *Spine (Phila Pa 1976)* 2010;35:99–103.
32. MacEwen GD, Bunnell WP, Sriram K. Acute neurological complications in the treatment of scoliosis. A report of the Scoliosis Research Society. *J Bone Joint Surg Am* 1975;57:404–8.
33. Fu KG, Smith JS, Polly DW Jr, et al. Morbidity and mortality in the surgical treatment of 605 pediatric patients with isthmic or dysplastic spondylolisthesis. *Spine (Phila Pa 1976)*. In press.
34. Smith JS, Fu KG, Polly DW Jr, et al. Complication rates of three common spine procedures and rates of thromboembolism following spine surgery based on 108,419 procedures: a report of the Scoliosis Research Society Morbidity and Mortality Committee. *Spine (Phila Pa 1976)*. In press.
35. Smith JS, Shaffrey CI, Sansur CA, et al. Rates of infection following spine surgery based on 108,419 procedures: a report from the Scoliosis Research Society Morbidity and Mortality Committee. *Spine (Phila Pa 1976)*. In press.
36. Patil CG, Santarelli J, Lad SP, et al. Inpatient complications, mortality, and discharge disposition after surgical correction of idiopathic scoliosis: a national perspective. *Spine J* 2008;8:904–10.
37. Carreon LY, Puno RM, Lenke LG, et al. Non-neurologic complications following surgery for adolescent idiopathic scoliosis. *J Bone Joint Surg Am* 2007;89:2427–32.
38. Barsdorf AI, Sproule DM, Kaufmann P. Scoliosis surgery in children with neuromuscular disease: findings from the US National Inpatient Sample, 1997 to 2003. *Arch Neurol* 2010;67:231–5.
39. Mohamad F, Parent S, Pawelek J, et al. Perioperative complications after surgical correction in neuromuscular scoliosis. *J Pediatr Orthop* 2007;27:392–7.
40. Sponseller PD, LaPorte DM, Hungerford MW, et al. Deep wound infections after neuromuscular scoliosis surgery: a multicenter study of risk factors and treatment outcomes. *Spine (Phila Pa 1976)* 2000;25:2461–6.
41. Szoke G, Lipton G, Miller F, et al. Wound infection after spinal fusion in children with cerebral palsy. *J Pediatr Orthop* 1998;18:727–33.
42. Pahys JM, Guille JT, D'Andrea LP, et al. Neurologic injury in the surgical treatment of idiopathic scoliosis: guidelines for assessment and management. *J Am Acad Orthop Surg* 2009;17:426–34.
43. Kamerlink JR, Errico T, Xavier S, et al. Major intraoperative neurologic monitoring deficits in consecutive pediatric and adult spinal deformity patients at one institution. *Spine (Phila Pa 1976)* 2010;35:240–5.
44. Vitale MG, Moore DW, Matsumoto H, et al. Risk factors for spinal cord injury during surgery for spinal deformity. *J Bone Joint Surg Am* 2010;92:64–71.
45. Winter RB. Neurologic safety in spinal deformity surgery. *Spine (Phila Pa 1976)* 1997;22:1527–33.
46. Diab M, Smith AR, Kuklo TR. Neural complications in the surgical treatment of adolescent idiopathic scoliosis. *Spine (Phila Pa 1976)* 2007;32:2759–63.
47. Qiu Y, Wang S, Wang B, et al. Incidence and risk factors of neurological deficits of surgical correction for scoliosis: analysis of 1373 cases at one Chinese institution. *Spine (Phila Pa 1976)* 2008;33:519–26.
48. Newton PO, Shea KG, Granlund KF. Defining the pediatric spinal thoracoscopy learning curve: sixty-five consecutive cases. *Spine (Phila Pa 1976)* 2000;25:1028–35.