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Reoperation Rate After Posterior Spinal Fusion Varies Significantly by Lenke Type

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Background: Lenke curve types can vary in their response to treatment. We explored potential differences in reoperation rates, causes, and risk factors among patients with different Lenke types who underwent posterior spinal fusion (PSF) for adolescent idiopathic scoliosis (AIS).

Methods: We studied a multicenter database of patients with AIS who underwent index PSF at ≤21 years of age and had a minimum 2-year follow-up. Baseline and surgical characteristics were collected. Reoperation rates, causes, and risk factors were analyzed by Lenke type.

Results: A total of 3,165 patients were included. The mean age was 14.6 years, and most patients were female (81%) and Caucasian (68%). The mean follow-up period was 4.4 years. A total of 138 patients (4.4%) underwent reoperation. The reoperation rate varied by Lenke type ($p = 0.02$): patients with type-5 curves had the highest reoperation rate (7.2%), and those with type-1 curves had the lowest (3.0%). The most common cause of reoperation was an instrumentation complication. The rate of reoperation due to an instrumentation complication varied by Lenke type ($p < 0.01$). Compared with patients with type-1 curves, those with type-5 curves had significantly higher rates of reoperation due to implant prominence (odds ratio [OR], 11.7; $p = 0.03$), loss of fixation (OR, 3.9; $p = 0.01$), or a broken rod (OR, 7.8; $p = 0.02$) and those with type-3 curves had a significantly higher rate of reoperation due to loss of fixation (OR, 4.37; $p = 0.01$). Independent risk factors for reoperation were a major curve magnitude of ≥60° in patients with type-5 curves (adjusted OR [aOR], 4.18; $p = 0.04$), a major curve correction of ≥40° in patients with type-5 curves (aOR, 3.6; $p = 0.04$), and a lowest instrumented vertebra (LIV) at or above L1 in patients with type-1 curves (aOR, 2.8; $p = 0.02$).

Conclusions: The reoperation rate for patients with AIS who underwent PSF varied by Lenke type. Patients with type-5 curves had the highest reoperation rate, whereas patients with type-1 curves had the lowest. Patients with Lenke type-5 curves had a higher rate of reoperation due to instrumentation complications.

Level of Evidence: Therapeutic Level III. See Instructions for Authors for a complete description of levels of evidence.

Spinal fusion has long been considered the standard approach for the surgical treatment of adolescent idiopathic scoliosis (AIS). It offers a means of correcting spinal deformities that is effective, is relatively safe, and improves the patient's quality of life[1,2]. With the evolution of spinal fusion techniques, posterior spinal fusion (PSF) with segmental spinal instrumentation has become the favored approach[3].

Although PSF is a definitive treatment option, complications, including surgical site infection (SSI), implant dislodgement or breakage, adding-on, curve progression, and neurologic compromise, can still arise, which may necessitate reoperation in certain cases[4,5]. As such, appropriate individualized decision-making hinges on accurate knowledge of the risk profile for each surgical option. The reported reoperation rates for PSF in AIS vary in the literature, ranging from 3% to 14%[4-10]. Dong et al.[4] reported the findings of a single-center, retrospective analysis that included 1,816 patients with a mean follow-up of 8.5 years. They demonstrated that the overall reoperation rate for PSF was 3%, which was lower than the rates for both the anterior and combined anterior-posterior approaches as well as the reported rates in other

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studies[4-10]. However, whether the PSF reoperation rate varies among patients with different curve types remains unknown.

Because Lenke curve types can vary in their response to treatment, accurate knowledge of reoperation rates is important for balancing risks and benefits and providing the most appropriate treatment option to patients. Therefore, we sought to determine the reoperation rate and to assess reoperation causes and risk factors for each Lenke type among patients who underwent PSF for AIS. We hypothesized that the reoperation rate would vary by Lenke type.

Materials and Methods

The study was deemed exempt from institutional review board approval (IRB00326015).

Data Source

A multicenter North American database consisting of 4,946 patients with AIS who underwent PSF from 1995 to 2020 was reviewed. The multicenter registry comprises clinical and operative data from 14 participating academic institutions. All data undergo thorough quality assurance procedures at a central site prior to use for research. Patient radiographs are collected, and trained site coordinators perform all radiographic curve measurements. Routine trainings are held to ensure high inter- and intraobserver reliability.

Study Population and Baseline Characteristics

All patients who were ≤21 years of age at the time of surgery and had a minimum follow-up period of 2 years were included. All patients underwent PSF with segmental spinal instrumentation. Patient demographics; preoperative clinical, radiographic, and surgical data; and major indications for reoperation were recorded. Patients were categorized by their Lenke curve type, as described by Lenke et al. (see Appendix 1)[11]. The rate and causes of reoperation as well as the risk factors for reoperation for each Lenke type were assessed.

Classification of Reoperations

The indications for reoperation were classified as an instrumentation complication, adding-on, a neurologic complication, or deep SSI. Instrumentation complication was subcategorized as a broken rod, a broken screw, loss of fixation to bone, a prominent implant, or inappropriately placed instrumentation during the index surgery that impinges structures such as the aorta or spinal canal. Since many of these findings occur together, the primary complication was selected when multiple reasons for a reoperation were reported. All instances of pseudarthrosis were associated with fixation failures. One patient had proximal junctional kyphosis and 1 patient had distal junctional kyphosis; both were categorized as having adding-on complications. One patient underwent rib resection for scapular pain and prominence and was included in the overall analysis. Two patients underwent reoperation for spondylolisthesis caused by trauma and were excluded. Deep SSI-related reoperations consisted only of infections that required implant removal or revision; irrigation and debridement procedures were not recorded as reoperations since our focus was on structural issues rather than biological ones. Two analyses were performed: one encompassed overall reoperation (i.e., all reoperations), whereas the other focused solely on noninfectious reoperation (i.e., all reoperations other than cases of deep SSI).

Risk Factors for Reoperation

Age, sex, race, preoperative major curve magnitude, preoperative thoracic and lumbar lateral curve magnitudes, lowest instrumented vertebra (LIV), upper instrumented vertebra (UIV), type of construct, and correction of the major curve were analyzed in relation to reoperation rates. The classifications used for race were directly taken from the Harms Study Group database, a multicenter database that includes patient demographic information, including race. Race is identified by the patients themselves, which is recorded in the electronic health record of each participating site and included in the multicenter database. The preoperative major curve of each patient was categorized as <60° or ≥60°. In patients with Lenke type-1 curves, the LIV was categorized as "at or above L1" or "below L1." UIV and LIV levels were utilized to assess whether all structural curves were fused in patients with Lenke types 2, 3, or 6. The type of construct was categorized as pedicle screw or hybrid. Pedicle screw constructs were those in which screws made up at least 80% of the anchors, whereas hybrid constructs had a combination of screws and hooks, with hooks making up the majority of the anchors. Major curve correction was categorized as ≥40° or <40°.

Statistical Analysis

Statistical analyses were performed with use of Stata (version 14.1; StataCorp). Categorical variables are expressed as percentages, and continuous variables are expressed as means and standard deviations. A univariate analysis of each variable was performed with use of a 2-tailed Student t test for continuous variables or with use of a Pearson chi-square test or Fisher exact test for categorical variables. Multivariable logistic regression was utilized to assess age, sex, preoperative major curve, and preoperative thoracic and lumbar lateral curves as independent risk factors for reoperation following index surgery for each Lenke type. Odds ratios (ORs) or adjusted odds ratios (aORs) and 95% confidence intervals (CIs) are presented. The reoperation-free survival curve for each Lenke type was estimated with use of the Kaplan-Meier method, with censoring at the time of the last follow-up, and differences were evaluated with use of the log-rank method. Significance was set at an alpha of <0.05.

Results

Patient Characteristics

A total of 3,165 patients were included, of whom 2,565 (81%) were female and 600 (19%) were male. The mean age at the index surgery was 14.6 years (range, 10 to 21 years). Of the 3,165 patients, 68% were Caucasian, 14% were Hispanic, 13% were African American, 4% were Asian, and 2%

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were of other race. The mean follow-up period was 4.4 years (range, 2.0 to 19.2 years). Patient characteristics for the overall cohort and by Lenke type are shown in Table I.

Reoperation Rate

A total of 138 patients underwent reoperation. The overall reoperation rate was 4.4%. The mean time between index surgery and reoperation was 3.1 years, and time to reoperation did not significantly differ by Lenke type ($p = 0.72$). The rates of reoperation by Lenke type are shown in Table II. Patients with Lenke type-5 curves had the highest overall reoperation rate, followed by those with type 4, type 6, type 3, and type 2, with the lowest rate observed among those with type 1. Reoperation rates varied significantly ($p = 0.02$) by Lenke type and were significantly greater for patients with type 5 (7.2%; $p < 0.01$; OR, 2.49; 95% CI, 1.47 to 4.20) or type 6 (5.4%; $p = 0.04$; OR, 1.84; 95% CI, 1.04 to 3.25) than for those with type 1 (3.0%). Patients with types 1A, 1B, and 1C had similar reoperation rates ($p = 0.29$).

Figure 1 presents the Kaplan-Meier reoperation-free survival curves, stratified by Lenke type. The survival curves differed significantly across Lenke types (log-rank test: $\chi^2 = 13.58$; $p = 0.02$). The reoperation rate for all survival curves began to plateau after 6 years. Patients with Lenke type-1 curves had the lowest rate of reoperation (97% survivability), whereas those with type 5 had the highest rate of reoperation (92.3% survivability). Patients with types 2, 3, 4, and 6 had similar reoperation-free survival estimates, between 94% and 96%.

The noninfectious reoperation rate was 3.0%. After excluding SSI-related reoperations, which accounted for 45 (33%) of 138 reoperations, the differences in reoperation rate among Lenke types remained significant ($p < 0.01$; Table II). Similar to the results for overall reoperation, when considering only reoperations for noninfectious etiologies, patients with Lenke type-5 curves had the highest reoperation rate and those with type 1 had the lowest. The rate of reoperation was significantly higher for patients with type 5 (6.0%) than for those with type 1 (1.9%; $p < 0.01$; OR, 3.10; 95% CI, 1.71 to 5.63) or type 2 (2.8%; $p = 0.01$; OR, 2.23; 95% CI, 1.19 to 4.16), and it was significantly higher for patients with type 3 (4.5%) than for those with type 1 (1.9%; $p = 0.02$; OR, 2.32; 95% CI, 1.15 to 4.65).

Noninfectious Indications for Reoperation

Table III presents the noninfectious reoperation rates for patients with each Lenke type, stratified by the indication for reoperation. The most common noninfectious indication was an instrumentation complication (65 patients [71%]), followed by adding-on (15 patients [16%]) and neurologic complication (12 patients [13%]). Only the rate of reoperation due to an instrumentation complication differed significantly by Lenke type ($p < 0.01$). The rate of reoperation due to an instrumentation complication was significantly higher for patients with Lenke type-5 curves (4.8%) than for those with type 1 (1.3%; $p < 0.01$; OR, 3.77; 95% CI, 1.89 to 7.55), type 2 (1.6%; $p < 0.01$; OR, 3.29; 95% CI, 1.59 to 6.78), or type 6 (1.8%; $p = 0.04$; OR, 2.74; 95% CI, 1.06 to 7.10). Patients with type 3 also had a significantly higher instrumentation-related reoperation rate (3.8%) than those with type 1 (1.3%; $p = 0.01$; OR, 2.95; 95% CI, 1.34 to 6.52). There was no significant difference among Lenke types with respect to the rate of reoperation due to adding-on ($p = 0.73$) or due to a neurologic complication ($p = 0.67$).

Reoperation rates due to an instrumentation complication, stratified by the type of complication, are presented in Table IV for each Lenke type. The rates of reoperation due to implant prominence ($p = 0.04$), loss of fixation ($p = 0.01$), or a broken rod ($p = 0.03$) differed significantly by Lenke type. The rate of reoperation due to a prominent implant was significantly higher for patients with Lenke type-5 curves (0.9%) than for those with type 1 (0.1%; $p = 0.03$; OR, 11.70; 95% CI, 1.21 to 112.86). The rate of reoperation due to loss of fixation was significantly higher for patients with type 3 (2.6%) than for those with type 1 (0.7%; $p = 0.01$; OR, 4.37; 95% CI, 1.57 to 12.15) or type 2 (0.5%; $p = 0.01$; OR, 5.10; 95% CI, 1.48 to 17.59). Patients with type 5 also had a significantly higher rate of reoperation due to loss of fixation (2.4%) than those with type 1 (0.7%; $p = 0.01$; OR, 3.94; 95% CI, 1.47 to 10.57) or type 2 (0.5%; $p = 0.01$; OR, 4.61; 95% CI, 1.38 to 15.40). The rate of reoperation due to a broken rod was significantly higher for patients with type 5 (1.2%) than for those with type 1 (0.2%; $p = 0.02$; OR, 7.82; 95% CI, 1.43 to 42.87). The type of construct utilized (i.e., pedicle screw versus hybrid) did not significantly differ by Lenke type ($p = 0.11$).

TABLE I Patient Characteristics

		Lenke Type					
	Total	1	2	3	4	5	6
No. (%) of patients*	3,165	1,296 (41%)	757 (24%)	265 (8%)	178 (6%)	335 (11%)	334 (11%)
Female†	2,565 (81%)	1,082 (83%)	563 (74%)	217 (82%)	143 (80%)	286 (85%)	274 (82%)
Mean age at index surgery *(yr)*	14.6	14.6	14.5	14.4	14.0	15.2	14.5
Mean follow-up *(yr)*	4.4	4.4	4.3	4.5	4.1	4.6	4.2

*Percentages based on the cohort total. †Percentages based on the column total.

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TABLE II Reoperation Rates by Lenke Type

Lenke Type	No. of Patients	Total Reoperation Rate* (%)	Noninfectious Reoperation Rate† (%)
Type 1	1,296	3.0	1.9
Type 1A	758	2.5	1.9
Type 1B	273	4.4	2.2
Type 1C	265	3.0	2.3
Type 2	757	4.5	2.8
Type 3	265	4.9	4.5
Type 4	178	5.6	2.8
Type 5	335	7.2	6.0
Type 6	334	5.4	3.0

*Significantly different by Lenke type (p = 0.02). †Significantly different by Lenke type (p < 0.01).

Risk Factors for Reoperation

A preoperative major curve magnitude of ≥60° and a major curve correction of ≥40° were both independent risk factors for reoperation only for patients with Lenke type-5 curves. The reoperation rate was 31.3% for patients with type 5 with a major curve of ≥60° and was 4.6% for those with a major curve of <60° (p = 0.04; aOR, 4.18; 95% CI, 1.09 to 16.02). Patients with type 5 with a major curve correction of ≥40° had a reoperation rate of 26.1%, whereas those with a correction of <40° had a rate of 4.2% (p = 0.04; aOR, 3.6; 95% CI, 1.02 to 13.03). In patients with type-5 curves, no significant difference in reoperation rates was found among those with an LIV at L2, L3, or L4 (p = 0.35). In patients with type-1 curves, the rate of reoperation was higher for those with an LIV at or above L1 (3.8%) than for those with an LIV below L1 (1.8%; p = 0.02; aOR, 2.75; 95% CI, 1.19 to 6.36). Whether or not all structural curves were fused was not associated with a significant difference in reoperation rates for patients with type 2 (p = 0.47), type 3 (p = 0.59), or type 6 (p = 0.75). Age, sex, race, preoperative lumbar and thoracic lateral curve magnitudes, and the type of construct did not have a significant effect on the rates of reoperation for patients with each Lenke type. Univariate and multivariable regression models are presented in Appendices 2 and 3.

Discussion

The present study revealed that the rate of reoperation following PSF varied by Lenke type, with patients with type-5 curves having the highest rate of reoperation and patients with type-1 curves having the lowest. The rate of reoperation due to an instrumentation complication varied by Lenke type as well, with type-5 curves being associated with higher rates of reoperation due to implant prominence, loss of fixation, or a broken rod. Independent risk factors for reoperation were a major curve magnitude of ≥60° and a major curve correction of ≥40° for patients with type-5 curves, and an LIV at or above L1 for patients with type-1 curves.

Patients with Lenke type-5 curves were found to have the highest overall reoperation rate (7.2%), which was greater than the rate of 3.4% reported by Dong et al.[4]. In the present study, instrumentation-related complications were responsible for 80% of noninfectious reoperations in patients with type-5 curves; these patients had significantly higher rates of implant prominence (1.2%), loss of fixation (2.4%), and a broken rod (1.2%)

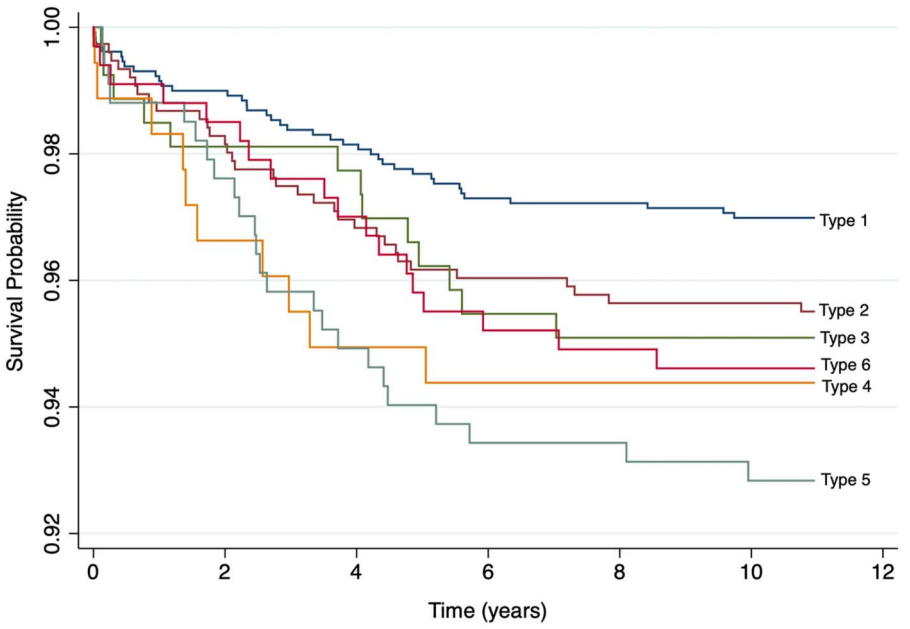

Fig. 1

Reoperation-free survival estimates by Lenke type.

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TABLE III Noninfectious Reoperation Rates for Patients with Each Lenke Type, by Reoperation Indication

Complication	Lenke Type *(no. [%] of patients)*						Total
	1	2	3	4	5	6	
Instrumentation complication*	17 (1.3%)	12 (1.6%)	10 (3.8%)†	4 (2.2%)	16 (4.8%)†	6 (1.8%)	65 (2.1%)
Adding-on	4 (0.3%)	5 (0.7%)	2 (0.8%)	0	2 (0.6%)	2 (0.6%)	15 (0.5%)
Neurologic complication	3 (0.2%)	4 (0.5%)	0	1 (0.6%)	2 (0.6%)	2 (0.6%)	12 (0.4%)

*The rate of reoperation due to an instrumentation complication significantly differed by Lenke type ($p < 0.01$). †The rate of reoperation due to an instrumentation complication was significantly higher for patients with Lenke type 5 ($p < 0.01$) or type 3 ($p = 0.01$) than for those with type 1.

compared with patients with type-1 curves. This finding may be attributable to corrective forces being distributed over a shorter, more mobile segment of the spine in thoracolumbar curves[12-14]. Interestingly, both a preoperative major curve magnitude of ≥60° and a major curve correction of ≥40° were identified as independent risk factors for reoperation for patients with type-5 curves, resulting in a fourfold increase in the rate of reoperation for these patients. There was no significant difference in reoperation rates when the LIV was at L2, L3, or L4; >95% of patients with Lenke type 5 had an LIV at L3 or L4, whereas only 3.5% had an LIV at L2.

Patients with Lenke type-1 curves treated with PSF had overall and noninfectious reoperation rates of 3.0% and 1.9%, respectively, which are lower than the rates reported after alternative surgical options. Dong et al.[4] reported a similar reoperation rate of 3.2% for patients with type-1 curves who underwent PSF, which was significantly lower than the reoperation rate of 13.3% in the group who underwent anterior or combined anterior-posterior approaches. Moreover, we found that the rate of reoperation was around 3 times greater for patients with Lenke type-1 curves with an LIV at or above L1 than for those with an LIV below L1. The majority (71%) of noninfectious reoperations in patients with type-1 curves were due to an instrumentation complication. Although selectively fusing thoracic curves has been shown to spontaneously correct the lumbar curve, patients may require subsequent extension of selective thoracic fusion to the lumbar spine in instances in which the lumbar curve is progressing[15,16]. In the present study, adding-on accounted for only 10% of overall reoperations among patients with type-1 curves.

This study has several limitations. First, reoperation rates may have been affected by reporting bias since the complications were self-reported by the participating sites. However, data were collected prospectively by individuals who did not take any part in the surgery, and standardized guidelines for reporting were utilized. In addition, all data underwent quality control checks at a central site. Patients were recruited for each follow-up milestone and data were recorded in real time, which reduces the risk of recall bias. Second, this was a multicenter study with patients treated by different surgeons at different institutions and at different time points, and therefore the surgical technique, approach, and decision to reoperate may have varied. Information on implant type and material was also lacking. Although the instrumentation strategy for the surgical treatment of AIS varies[17,18], the variation in our patient cohort also improves the generalizability of our findings. Third, patients <22 years of age were included, as AIS is defined as abnormal curvature beginning in adolescence. Finally, our data were collected over a long period, from 1995 to 2020, and AIS treatment strategies may have evolved over time, as indicated by research showing a decrease in major complication rates from the period of 1995 to 1999 to the period of 2010 to 2013[3]. Although we had

TABLE IV Reoperation Rates for Patients with Each Lenke Type, by Instrumentation-Related Complication

Complication	Lenke Type *(no. [%] of patients)*						Total
	1	2	3	4	5	6	
Implant prominence	1 (0.1%)	1 (0.1%)	2 (0.8%)	0	3 (0.9%)*	0	7 (0.2%)
Loss of fixation	9 (0.7%)	4 (0.5%)	7 (2.6%)†	3 (1.7%)	8 (2.4%)†	4 (1.2%)	35 (1.1%)
Broken rod	2 (0.2%)	3 (0.4%)	0	0	4 (1.2%)‡	0	9 (0.3%)
Broken screw	2 (0.2%)	1 (0.1%)	1 (0.4%)	0	0	2 (0.6%)	6 (0.2%)
Misplaced instrumentation	3 (0.2%)	3 (0.4%)	0	1 (0.6%)	1 (0.3%)	0	8 (0.3%)

*Significant difference in the rate of reoperation due to implant prominence between patients with type 5 and those with type 1 ($p = 0.03$). †Significant differences in the rate of reoperation due to loss of fixation between patients with type 3 and those with type 1 ($p = 0.01$) and between patients with type 5 and those with type 1 ($p = 0.01$). ‡Significant difference in the rate of reoperation due to a broken rod between patients with type 5 and those with type 1 ($p = 0.02$).

an mean follow-up of 4.4 years, complications requiring reoperation may take longer to occur for patients with certain curve types.

Conclusions

The reoperation rate following PSF varied by Lenke type. Patients with type-5 curves had the highest overall reoperation rate (7.2%), whereas patients with type-1 curves had the lowest (3.0%). Reoperations were most commonly due to instrumentation-related complications. Patients with type-5 curves had higher rates of reoperation due to implant prominence, loss of fixation, or a broken rod. A major curve magnitude of ≥60° and a major curve correction of ≥40° were found to be predictors of reoperation among patients with type-5 curves. With the availability of non-fusion options for treating AIS, a knowledge of reoperation rates following PSF may be important in guiding decision-making.

Appendix

eA Supporting material provided by the authors is posted with the online version of this article as a data supplement at jbjs.org (http://links.lww.com/JBJSOA/A703). ■

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