Joint Diseases and Related Surgery

Jt Dis Relat Surg
2022;33(1):162-171

ORIGINAL ARTICLE

Correlations of proximal junctional kyphosis with radiographic measurements, spinopelvic parameters, and health-related quality of life in Lenke type V adolescent idiopathic scoliosis

Cem Albay, Mehmet Akif Kaygusuz, Deniz Kargın, Ali Öner

Department of Orthopedics and Traumatology, Metin Sabancı Baltalimanı Bone Diseases Training and Research Hospital, Istanbul, Turkey

ABSTRACT

Objectives: This study aims to investigate the effects of radiographic measurements, spinopelvic parameters, and Scoliosis Research Society-22r (SRS-22r) subscales on proximal junctional kyphosis (PJK) in patients with Lenke type V adolescent idiopathic scoliosis operated with only a posterior all-pedicle-screw instrumentation technique.

Patients and methods: Between January 2011 and March 2019, data of 115 patients (17 males, 98 females; mean age: 14.6±2.9 years; range, 10 to 18 years) with Lenke type V AIS who were operated with posterior fusion were retrospectively analyzed. Proximal junctional angle (PJA) was measured as a Cobb angle (CA) between the inferior endplate of the upper instrumented vertebra and the superior endplate of the second suprajacent vertebra. A ≥10° PJA and being ≥10° greater than its preoperative value was defined as PJK. Radiographic measurements, SRS-22r scores, and correlations with the PJA were evaluated for PJK and non-PJK groups.

Results: The prevalence of PJK was 35.6%. There were statistically significant differences between the groups in terms of preoperative CA (p=0.002), preoperative thoracic kyphosis angle (TKA) (p<0.001), postoperative TKA (p=0.001), PJA (p<0.001), postoperative pelvic tilt (p=0.038), preoperative pain (p=0.005), preoperative self-image (SI) (p=0.045), preoperative subtotal score (p=0.006), preoperative total score (p=0.007), and sex distribution (p=0.002). No statistically significant differences were detected for other parameters (p>0.050). Positive correlations were found between PJA and preoperative TKA (p=0.042), postoperative TKA (p=0.002), preoperative sagittal balance (SB) (p=0.015), preoperative SI (p=0.012), postoperative SI (p=0.032), postoperative mental health (p=0.011), postoperative subtotal score (p=0.018), postoperative total score (p=0.014), and postoperative sacral slope (SS) (p=0.015). A negative correlation was found between PJA and preoperative satisfaction (p=0.044).

Conclusion: The occurrence of PJK is multifactorial, including clinical, surgical, and radiographic factors. Male patients with higher pre and postoperative TKA, preoperative SB, and postoperative SS and patients with lower satisfaction have a higher risk of PJK development.

Keywords: Health-related quality of life, proximal junctional kyphosis, scoliosis, spinopelvic parameters.

The ability to correct spinal deformities has increased and the need for anterior surgery has decreased with the development of pedicle screws (Figure 1). However, the all-pedicle-screw instrumentation technique has increased the prevalence of proximal junctional kyphosis (PJK).[1-4] Proximal junctional kyphosis is a broad-spectrum disorder that can present with different clinical signs and symptoms, particularly in adult patients. Several studies have reported the prevalence of PJK to range from 9.2 to 61.7%.[5,6]

Proximal junctional kyphosis is mostly diagnosed within two years of surgery.[7] Numerous definitions for PJK have been suggested. Glattes et al.[8] defined it as a ≥10° proximal junctional angle (PJA) and ≥10° increase compared to the

Received: November 23, 2021
Accepted: February 02, 2022
Published online: March 28, 2022

Correspondence: Cem Albay, MD. Metin Sabancı Baltalimanı Kemik Hastalıkları Eğitim ve Araştırma Hastanesi, Ortopedi ve Travmatoloji Kliniği, 34470 Sarıyer, İstanbul, Türkiye.

E-mail: cemalbay@hotmail.com

Doi: 10.52312/jdrs.2022.497

Citation: Albay C, Kaygusuz MA, Kargın D, Öner A. Correlations of proximal junctional kyphosis with radiographic measurements, spinopelvic parameters, and health-related quality of life in Lenke type V adolescent idiopathic scoliosis. Jt Dis Relat Surg 2022;33(1):162-171.

©2022 All right reserved by the Turkish Joint Diseases Foundation

This is an open access article under the terms of the Creative Commons Attribution-NonCommercial License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited and is not used for commercial purposes (http://creativecommons.org/licenses/by-nc/4.0/).

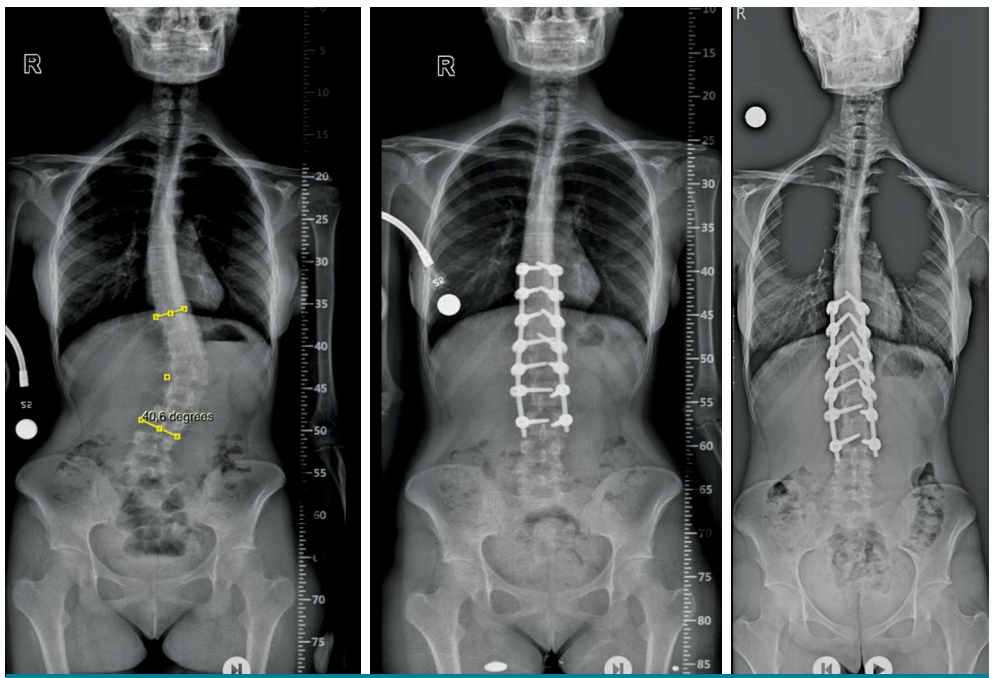

FIGURE 1. Preoperative, immediate postoperative and last follow-up anterior-posterior orthoroentgenograms of the same patient.

preoperative measurement (Figure 2).[8] A PJA of >10° is considered as the most acceptable and most commonly used critical angle to define PJK.[8,9] The PJA is the sagittal Cobb angle (CA) between the inferior end plate of the upper instrumented vertebra (UIV) and the superior end plate of the second suprajacent vertebra.[8] A preoperative PJA of more than 5° is reported as a risk factor for PJK.[10]

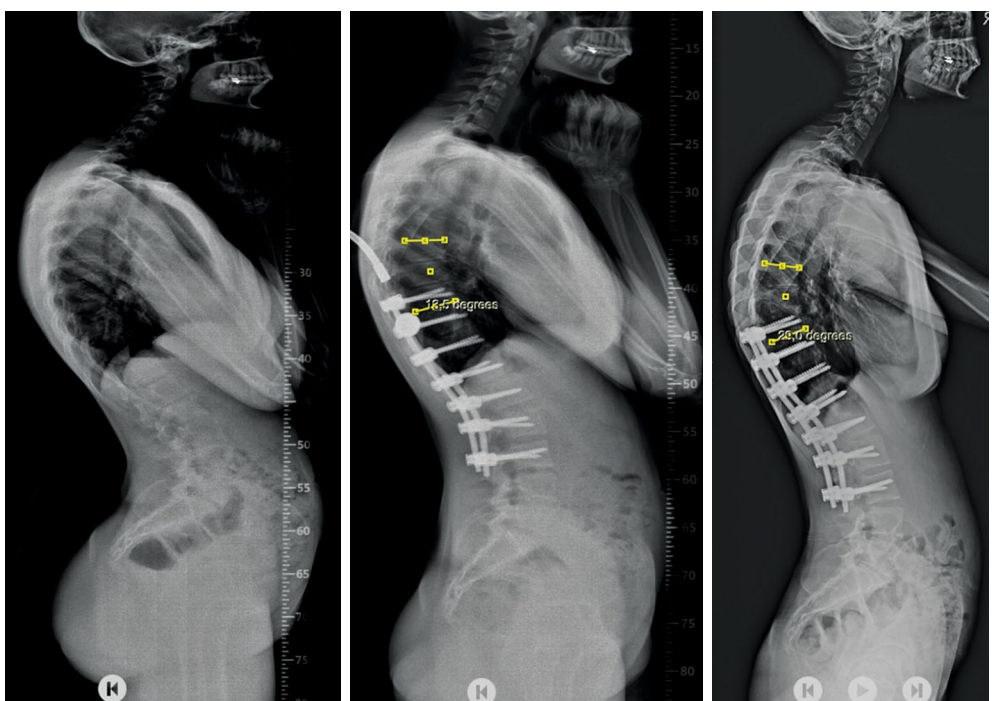

FIGURE 2. Preoperative, immediate postoperative and last follow-up lateral orthoroentgenograms of the same patient and measurement of proximal junctional kyphosis.

Proximal junctional kyphosis may occur acutely due to deterioration of the interspinous ligament and facet joint structures at a level suprajacent to the UIV, or due to a fracture at the UIV level in chronic processes.[11] Accordingly, it is clear that bone quality disorders such as osteoporosis may be effective in the development of PJK.[12] Increased age may also be counted as an important factor in this situation.[12] The presence of comorbidities is another risk factor for the development of PJK.[13]

Several studies have shown that the risk of PJK increases among patients with pelvic screws and patients with anterior fusion to the L5-S1 level.[14] Overcorrection of coronal balance (CB) and sagittal balance (SB) has been reported to increase the likelihood of PJK.[1] This is thought to be related to the increased load at the UIV level due to the rigid construction.

Similar to the selection of the lowest instrumented vertebra (LIV), the selection of the UIV contributes to the risk of PJK.[8,15] For instance, the risk of PJK increases, when the UIV is in the thoracolumbar (TL) junction.[13] Increased thoracic kyphosis angle (TKA) and male sex are also related to PJK.[3]

The factors listed above have led to the development of various strategies to prevent PJK in adult patients. However, studies evaluating health-related quality of life (HRQoL) in patients with adolescent idiopathic scoliosis (AIS) and PJK are very limited.

The spine transfers the load to the lower extremities through the pelvis. Therefore, it is obvious that spinopelvic parameters would be effective on the development of PJK. In the literature, studies examining PJK in cases of lumbar scoliosis are limited. In addition, studies examining the effect of PJK together with spinopelvic parameters and HRQoL with Scoliosis Research Society-22r (SRS-22r) scores are even more limited. No such study conducted for the Turkish population has been found to date. In the current study, we aimed to investigate the effects of radiographic variables, spinopelvic parameters, and SRS-22r subscales on PJK in patients with Lenke type V AIS operated with only a posterior all-pedicle-screw instrumentation technique.

PATIENTS AND METHODS

This single-center, retrospective study was conducted at Metin Sabancı Baltalimanı Bone Diseases Training and Research Hospital, Department of Orthopedics and Traumatology between January 2011 and March 2019. Data of 115 patients (17 males, 98 females; mean age: 14.6±2.9 years; range, 10 to 18 years) with Lenke type V AIS who were operated with posterior fusion were reviewed. Inclusion criteria were as follows: age between 10 and 18 years; having Lenke type V AIS; only posterior fusion surgery; all-pedicle-screw instrumentation; a body mass index (BMI) of <30 kg/m^2; having no history of spinal surgery; minimum two-year follow-up, good-quality preoperative, early postoperative, and postoperative second year scoliosis X-rays, and preoperative, early postoperative, and postoperative second year complete SRS-22r scores. Exclusion criteria were as follows: age below 10 or above 18 years; having other types of scoliosis; anterior surgery; hybrid instrumentation; a BMI of ≥30 kg/m^2; lack of X-rays; lack of SRS-22r scores; history of spinal trauma after surgery; comorbidities; and revision surgery. A written informed consent was obtained from the parents and/or legal guardians of the patients. The study protocol was approved by the Institutional Review Board of Metin Sabancı Baltalimanı Bone Diseases Training and Research Hospital (IRB No. (2018/30). The study was conducted in accordance with the principles of the Declaration of Helsinki.

The study was initiated with a total of 158 Lenke type V AIS patients. Five Lenke type V AIS patients with a BMI of >30 kg/m^2, 17 patients whose preoperative good-quality orthoroentgenograms were missing, and 21 patients whose preoperative and/or follow-up SRS-22r forms were missing were excluded from the study.

The surgical procedure was conducted according to the Lenke's suggestions for fusion levels.[16] In this study, we measured PJA according to the definition of Glattes et al.[8] Proximal junctional kyphosis of at least 10° and at least 10° greater than the preoperative value was evaluated as PJK.[8] This is the most common definition of PJK.

Non-PJK patients were evaluated as Group 1 (n=74), while patients with PJK were evaluated as Group 2 (n=41).

End vertebrae, instrumentation levels, blood transfusion amount (ESTx), operative times, preoperative and postoperative second-year CA, apical vertebral translation (AVT: distance between the central sacral vertical line [CSVL] and the center of the apical vertebrae of the TL/L curve), CB, truncal shift (TS: distance between the C7 plumb line and CSVL), T5-T12 TKAs, L1-S1 lumbar lordosis angles (LLAs), SB, pelvic obliquity (PO), pelvic tilt (PT), sacral slope (SS), and pelvic incidence (PI) were measured

from plain scoliosis anterior-posterior and lateral radiographs. The HRQoL was evaluated for each patient on the basis of SRS-22r scores. Preoperative and postoperative second-year values of the SRS-22r subscales, subtotals, and total score were calculated. All measurements were performed by two authors twice in a one-month period and the averages of the total of four values were used.

Statistical analysis

Statistical analysis was performed using the IBM SPSS version 22.0 software (IBM Corp., Armonk, NY, USA). Quantitative variables were presented in mean± standard deviation (SD) and median (min-max), whereas qualitative variables were presented in number and frequency. The Kolmogorov-Smirnov and Shapiro-Wilk tests were performed for the evaluation of normality. Independent-samples t-tests were used for comparisons of normally distributed variables. The Mann-Whitney U tests were used for comparisons of non-normally distributed variables. Within-group differences between pre- and postoperative values were evaluated by using paired t-tests for normally distributed variables and Wilcoxon tests were used for comparisons of non-normally distributed variables. A p value of <0.05 was considered statistically significant.

RESULTS

There was a statistically significant difference between the groups in terms of sex. A higher prevalence of PJK was detected among male patients (p=0.002).

Inter-group comparisons

The PJK prevalence was found to be 35.6% in this study. The mean PJA was 4.9±2.7, 17.2±4.5, and 7.7 (range, 0.4 to 30.9) degrees in Group 1, Group 2, and the overall patient population, respectively (p<0.001). The median Risser Stage was 4 (range, 3 to 5), 4 (range, 3 to 4), and 4 (range, 3 to 5) in Group 1, Group 2, and the overall patient population, respectively (p=0.190). The follow-up period was 55.8±27.8, 61.2±26.9, and 57.8±27.5 months in Group 1, Group 2, and the overall patient population (p=0.316). The instrumentation level was 9 (range, 5 to 15), 8 (range, 6 to 14), and 9 (range, 5 to 15) vertebrae in Group 1, Group 2, and the overall patient population, respectively (p=0.605). The median operative time was 205 (range, 110 to 420), 240 (range, 120 to 480), and 210 (range, 110 to 480) min in Group 1, Group 2, and the overall patient population, respectively (p=0.868). The median ESTx was 3 (range, 1 to 8), 3 (range, 1 to 5), and 3 (range, 1 to 8) unit in Group 1, Group 2, and the overall patient population, respectively (p=0.107).

Pre- and postoperative values of coronal and sagittal plane parameters are presented in Table I and spinopelvic parameters are presented in Table II. There were statistically significant

TABLE I
Coronal and sagittal plan parameters

	Group 1			Group 2			Total			
	Mean±SD	Median	Min-Max	Mean±SD	Median	Min-Max	Mean±SD	Median	Min-Max	*p*
Preoperative Cobb	51.7±10.3			45.6±9.4			49.5±10.4			0.002
Postoperative Cobb	12.7±7.2				10.6	0-19.9		10.5	0-19.9	0.061
CB preoperative	19.6±11.4				19.4	2.3-60.7		17.9	2.3-60.7	0.954
CB postoperative 2nd year	8.5±5.8				6.5	0-34		7.1	0-34	0.773
AVT preoperative	37.2±12.2			43.5±16.1			41.2±15.1			0.033
AVT postoperative 2nd year		9.4	0-26.7		7.5	0-29.3		8.6	0-29.3	0.106
TS preoperative		12	0-46.9		13.7	0-48.1		12.2	0-48.1	0.667
TS postoperative 2nd year		7.1	0-24.1		7.2	0-29.6		7.2	0-29.6	0.887
TKA preoperative	21.4±9.7			31.8±12.7			25.1±11.9			<0.001
TKA postoperative 2nd year	27.1±8.6			34.2±14				26.9	4.4-55.2	0.001
LLA preoperative	-51.7±14.5			-58.5±13.4			-54.2±15.9			0.072
LLA postoperative 2nd year	-44.4±15.7			-49.6±12			-46.2±14.6			0.068
SB preoperative	-6.9±32.7			-13.5±36.1			-9.2±33.9			0.315
SB postoperative 2nd year	2.1±21.3			-0.1±20.9			1.3±21.1			0.608

SD: Standard deviation; CB: Coronal balance; AVT: Apical vertebral translation; TS: Truncal shift; TKA: Thoracic kyphosis angle; LLA: Lumbar lordosis angle; SB: Sagittal balance.

TABLE II
Spinopelvic parameters

	Group 1			Group 2			Total			
	Mean±SD	Median	Min-Max	Mean±SD	Median	Min-Max	Mean±SD	Median	Min-Max	*p*
Preoperative PO		2.5	0.3-10.8		2.8	0.1-8		2.5	0.1-10.8	0.473
Postoperative 2nd year PO		1.9	0.1-11.9	2.2±1.2				2.1	0.1-11.9	0.352
Preoperative PT	11.5±6.4			11±7.4				10.7	1.3-30.7	0.753
Postoperative 2nd year PT		9.6	0.5-33.6		5.9	1.4-29.1	10.2±6.4			0.038
Preoperative SS	40.1±10.5			38.9±9.3			39.7±10.1			0.548
Postoperative 2nd year SS	40.1±10.9			38.8±9.2			39.6±10.3			0.542
Preoperative PI	51.5±12.7				45.9	30.4-73.5		47.9	28.8-85.7	0.496
Postoperative 2nd year PI	51.2±12.3			47.3±10.2			49.8±11.7			0.094

PO: Pelvic obliquity; PT: Pelvic tilt; SS: Sacral slope; PI: Pelvic incidence.

differences between the groups in terms of preoperative CA (p=0.002), preoperative AVT (p=0.033), preoperative TKA (p<0.001), postoperative TKA (p=0.001), and postoperative PT (p=0.038). No statistically significant differences were detected for other parameters (p>0.050).

The correction rate of the CA was found to be 76.7% in the PJK group and 75.4% in the non-PJK group. No statistically significant differences were detected. No correlation was found between PJA and deformity correction rate in our study group, and no statistically significant difference was found between the groups in terms of CB.

Pre- and postoperative second-year values of the SRS-22r subscales are presented in Table III. The last two questions of the SRS-22r questionnaire which investigate satisfaction are answered postoperatively and at follow-up visits. There were statistically significant differences between the groups in terms of preoperative pain (p=0.005), preoperative self-image (SI) (p=0.045), preoperative subtotal scores (p=0.006), and preoperative total scores (p=0.007). No statistically significant differences were detected in other parameters (p>0.050).

The comparison of pre- and postoperative radiological measurements and SRS-22r scores was

TABLE III
SRS-22r scores

	Group 1			Group 2			Total			
	Mean±SD	Median	Min-Max	Mean±SD	Median	Min-Max	Mean±SD	Median	Min-Max	*p*
Preoperative function		15	9-19		16	9-18		15	9-19	0.428
Postoperative 2nd year function		16	3-19		16	3-18		16	3-19	0.993
Preoperative pain		16.5	12-25	19.4±2.9				19	12-25	0.005
Postoperative pain		19	11-23		19	15-23		19	11-23	0.166
Preoperative self image		13	6-22		13	8-23		13	6-23	0.045
Postoperative self image		20	11-25	19.5±2.9				20	11-25	0.533
Preoperative mental health		15	14-17		15	14-17		15	14-17	0.338
Postoperative mental health		16	13-17		16	14-17		16	13-17	0.440
Early satisfaction		6.5	2-10		6	5-9		6	2-10	0.879
Postoperative 2nd year satisfaction		9	4-10		9	5-10		9	4-10	0.524
Preoperative subtotal	61.1±7.1			65.1±7.3			62.6±7.3			0.006
Postoperative subtotal	70.5±4.9			70.9±5			70.6±4.9			0.692
Preoperative total	67.9±7.2			71.7±7.3			69.2±7.4			0.007
Postoperative 2nd year total		81	64-93	79.8±6.4				81	64-93	0.575

SD: Standard deviation.

performed. The immediate postoperative satisfaction score was used as first value of satisfaction score for comparison.

Group 1: The values for CA, CB, AVT, TS, TKA, SI, Mental Health (MH), satisfaction, subtotal scores, total scores, PO (p<0.001), and function (p=0.005) were significantly different in Group 1. There were no statistically significant differences for LLA (p=0.110), SB (p=0.140), pain (p=0.063), PT (p=0.143), SS (p=0.836), or PI (p=0.530) values.

Group 2: The values of CA, CB, AVT, TS, LLA, SI, satisfaction, subtotal and total scores (p<0.001), MH (p=0.003), PO (p=0.001), PT (p=0.047), and PI (p=0.010) were significantly different in Group 2. No statistically significant differences were found for TKA (p=0.325), SB (p=0.160), function (p=0.200), pain (p=0.455), or SS (p=0.231) values.

Overall patient population: The values of CA, CB, AVT, TS, TKA, LLA, SI, MH, satisfaction, subtotal and total scores, PO (p<0.001), SB (p=0.005), function (p=0.002), PT (p=0.015), PI (p=0.048), and residual deformity (p=0.026) were significantly different in overall patient population. There was no statistically significant difference for pain (p=0.228) or SS (p=0.558) values.

PJA correlations

Group 1: Positive correlations were found between PJA and follow-up time (r=0.254, p=0.028), postoperative function (r=0.233, p=0.045), and preoperative SI (r=0.290, p=0.012). Negative correlations were found between PJA and preoperative SB (r=-0.382, p=0.001), postoperative SB (r=-0.371, p=0.001), and postoperative function (r=-0.233, p=0.045).

Group 2: Positive correlations were found between PJA and preoperative TKA (r=0.323, p=0.042), postoperative TKA (r=0.468, p=0.002), preoperative SB (r=0.382, p=0.015), preoperative SI (r=0.392, p=0.012), postoperative SI (r=0.339, p=0.032), postoperative MH (r=0.399, p=0.011), postoperative subtotal score (r=0.372, p=0.018), postoperative total score (r=0.387, p=0.014), and postoperative SS (r=0.383, p=0.015). A negative correlation was found between PJA and preoperative satisfaction (r=-0.320, p=0.044).

Overall patient population: Positive correlations were found between PJA and preoperative TKA (r=0.413, p<0.001), postoperative TKA (r=0.379, p<0.001), preoperative pain (p=0.237, p=0.011), postoperative pain (r=0.208, p=0.026), preoperative SI (r=0.372, p<0.001), preoperative MH (r=0.202, p=0.030), preoperative subtotal (r=0.37, p<0.001), and preoperative total score (r=0.362, p<0.001). Negative correlations were found between PJA and ESTx (r=-0.215, p=0.021), preoperative CA (r=-0.302, p=0.001), and preoperative LLA (r=-0.196, p=0.035) among the overall patient population.

DISCUSSION

Proximal junctional kyphosis is common after adult spinal deformity surgery.[13] However, the number of studies investigating the occurrence of PJK in cases of Lenke type V AIS remains small and the prevalence rates found in these studies are inconsistent. Yang and Chen[17] found the prevalence of PJK to be 43% among patients with Lenke type V AIS after posterior selective lumbar fusion, while Hollenbeck et al.[5] reported only one case of PJK among 13 patients with Lenke type V AIS.

In the current study, we presented the radiographic risk factors for PJK among patients with Lenke type V AIS and HRQoL as evaluated by SRS-22r scores to guide future research to help minimize the risk of this challenging complication.[18] We also presented the relationships between spinopelvic parameters and PJK.

The etiology of PJK seems to be multifactorial.[7] Surgical mistakes, radiographic variables, and patient-related risk factors may all cause PJK.[13] It is a broad-spectrum disorder seen in a range from asymptomatic cases to functional and neurological deficits including radiculopathy, myelopathy, and complete paralysis.[10,13] More severe cases of PJK are described as proximal junctional failure (PJF).[1] Deformity recurrence and pain may be reasons for hospital admission.[13] Recent studies have reported worse clinical outcomes and more pain in these cases.[19] Although it is a common complication, the need for revision after PJK is much lower.[19] It is clear that the SRS-22r scores of PJF patients would be affected. Therefore, the rare patients who underwent revision surgery for PJK were not included in our study.

Peng et al.[20] and Kim et al.[3] reported more male patients with PJK among their sample of individuals undergoing surgery for AIS. Kim et al.[3] retrospectively assessed 410 patients and demonstrated a higher prevalence among male patients. Our findings also revealed statistically significant differences for male patients between the PJK and non-PJK groups, although the underlying reasons for this are unclear.

Patient-specific factors such as obesity and the presence of other comorbidities are always important considerations before any spinal surgery.[13] Increased age, osteopenia or osteoporosis, sarcopenia, and tobacco use are reported to be associated with PJK.[7,8,12,19,21] The current study enrolled patients with AIS under the age of 18 years and there were no statistically significant differences between the PJK and non-PJK groups in terms of age or Risser stage. In our study, we included AIS patients with BMI of <30 kg/m^2 and no comorbidities with the aim of excluding the impact of patient-specific factors such as BMI, presence of concomitant disease, and osteoporosis. In this context, no statistically significant differences were found between the groups in terms of follow-up time, level of instrumentation, or operation time, similarly to the conclusions of Peng et al.,[20] who found no statistically significant differences for age at surgery, BMI, amount of correction, or UIV and LIV levels. Zhao et al.[15] also found no statistically significant differences for age, Risser sign, follow-up time, or LIV. The findings of the current study are in line with those previous results in terms of these demographic variables.

Construction rigidity may increase the load at the UIV.[3,7,22] Rigid three-column fixation by all-pedicle-screw instrumentation is one of the major causes of PJK due to overcorrection of kyphosis.[7] All-pedicle-screw constructions are shown to be more prone to PJK than all-hook constructions and hybrid constructions.[2,3,7,22] This is thought to be associated with the softer landing provided by lower mechanical stress at the UIV with hooks.[7] The widespread use of pedicle screws, which allows control of all three columns and correct rotation in spinal surgery, has reduced the need for anterior surgeries and posterior fusion has become a generally accepted approach. Therefore, patients treated with all-pedicle-screw instrumentation with only posterior approaches were included in our study.

Selection errors in identifying the UIV level,[8,15] disruption of posterior soft tissues, and deterioration of interspinous ligaments and facet joints cause increased range of motion with a risk of PJK.[3,8,12,15,23] A worse postoperative sagittal vertical axis, fewer fusion levels, and selection of the TL region as the UIV also increase the risk of PJK.[7,13,22] Kim et al.[12] reported that selecting the UIV at T1-T3 increased the risk of PJK by almost twice, but Ha et al.[24] reported no significant difference in PJK at a UIV of T2-T5 compared to T9-L1. Zhao et al.[15] found that PJK was seen more often with the UIV cut-off at lower thoracic levels.[15] Lonner et al.[21] reported that UIV at or cephalad to the upper end vertebrae was an independent risk factor for PJK in patients with Lenke type V AIS.

Fusion to the pelvis may also increase the risk of PJK.[14] However, in terms of cost/benefit analysis, pelvic screwing with L5-S1 anterior fusion is still considered in adult patients to prevent pseudoarthrosis. There was no case of fusion to the sacrum in our study. In the selection of UIV and LIV, the recommendations of Lenke et al.[16] were followed.

Three-fold higher levels of PJK after a combined anterior-posterior approach compared to a posterior approach were presented by Kim et al.[12] Similar to rigid all-pedicle-screw constructions, combined anterior-posterior fusion leads to greater force at the UIV with greater sagittal plane correction.[7,12] On the other hand, the risk of PJK after only posterior fusion was shown to be greater than that after only anterior fusion.[14] This is thought to be the result of extensive soft-tissue dissection and disruption of the posterior ligamentous and joint complex.[7] In our study, patients with only posterior surgery were included and patients who underwent anterior surgery or combined approaches were excluded to allow us to focus on the radiographic risk factors of the most commonly performed surgical technique in AIS surgeries.

Greater magnitude of deformity correction is also reported to increase the risk of PJK.[22,25] Overcorrection of deformity may increase the stress on the UIV, which can cause PJK.[1,13] Although we did not find a correlation between PJA and deformity correction rates in this study, we found higher preoperative AVT values in the PJK group. Furthermore, we found a statistically significant difference between groups in terms of preoperative CA, but not postoperative CA, suggesting that we could reconsider the groups according to similar radiographic angles obtained from postoperative radiographs as per Lenke's recommendations, but the loading on the UIV that triggers PJK was seen to be dependent on preoperative CA measurements.

High preoperative SB[15,22] and TKA[25] values are reported to be factors increasing the risk of PJK. We found a trend of higher preoperative SB values in the PJK group, in line with previous results. We also found higher preoperative TKA values, in line with the previous studies of Kim et al.,[4] Zhao et al.,[15] and Peng et al.,[20] which included 193, 87,

and 44 AIS patients, respectively. In another study of 410 cases, Kim et al.[3] proposed that a larger immediate postoperative TKA decrease was a risk factor for PJK among AIS patients. Zhao et al.[15] recommended carefully contouring the rod.

Gomez et al.[26] reported that 38% of early-onset scoliosis patients developed radiographic PJK and 18% developed PJF. They further reported that preoperative TKA of >50°, high postoperative CA, and greater preoperative to postoperative changes in PT and PI/LL were the most significant risk factors for PJF.[26] Our study also found a statistically significant difference between groups in terms of both pre- and postoperative TKA, in line with previous data.

Although there was no statistically significant difference between the groups in terms of LLA, the LLA values did not differ in the postoperative period in the non-PJK group compared to the preoperative period, while a statistically significant difference was found for the postoperative LLAs of the PJK group compared to the preoperative period. These data show us that the amount of correction made in sagittal plane angles can affect the UIV via a compensation mechanism, and rod countering should be performed meticulously for these patients to the necessary extent.

Zhao et al.[15] found no significant differences in pelvic parameters between their PJK and non-PJK groups; however, they also reported that they could not ignore the association between pelvic parameters and PJK in long-term follow-up. Our study included a larger number of patients with Lenke type V AIS and we found that postoperative PT values were lower among the PJK group. Only the PO values in Group 1 differed postoperatively. In Group 2, the values of PO, PT, and PI changed in comparison to the values of the preoperative period. In this context, we also found statistically significant differences in PO, PT, and PI for the overall study group. Lower preoperative SS, higher PI, and pelvic retroversion are reported as factors increasing the risk of PJK.[25] Lower PT angles in the PJK group in the current study are in line with the expected results of retroversion. Furthermore, a positive correlation was found between PJA and postoperative SS in the PJK group. The correlations obtained in the present study confirm the association between pelvic parameters and PJK.

Kim et al.,[4] Zhao et al.,[15] and Rhee et al.[27] reported no significant correlations between PJK and HRQOL. However, they recommended paying adequate attention to the long-term clinical outcomes of PJK in patients with AIS. We also found statistically significant differences between the PJK group and non-PJK group in terms of preoperative subtotal score, preoperative total score, preoperative pain, and preoperative SI. However, no statistically significant differences were found between the groups for postoperative SRS-22r subscales. We found that SI, MH, satisfaction, subtotal scores, total scores, and function were improved by surgery in Group 1, while in Group 2, SI, satisfaction, subtotal scores, total scores, and MH were improved. For the overall patient population, SI, MH, satisfaction, subtotal scores, total scores, and function were improved by the applied surgical procedures. These findings confirm that surgical procedures not only improve the radiographic findings of these cases, but also improve the SRS-22r subscale scores. We further found that patients with Lenke type V AIS paid more importance to lumbar pain and the spinal curve's impact on self-image than the effect of PJK within the considered period.

In the current study, we found that the risk of PJA was increased among male patients, patients with high pre- and postoperative TKA values, patients with high SB preoperatively, patients who had negative pre- and/or postoperative body image, patients who were unhappy in the postoperative period, and patients with high postoperative subtotal and total scores. On the other hand, the PJA values of the patient group with higher preoperative treatment satisfaction were lower.

The current study has included the highest number of cases to date among efforts to examine the relationship between radiographic measurements and PJK in patients with Lenke type V AIS with spinopelvic parameters and SRS-22r scores. This is also the first such study conducted in the Turkish population. In addition, we have added our findings on the correlations of PJA with the parameters to provide a contribution to the literature.

Considering the data obtained in the present study, certain recommendations should be followed to decrease the risk of PJK.[28] Cases of preoperative segmental kyphosis above 5° should be included in fusion treatments. Construction rigidity should be decreased with the usage of composite materials and fewer implants. Osteotomies should be more distal and care must be taken to avoid soft tissue destruction at the UIV. Spinal balance and postoperative alignment should be optimized.

The current study is limited by its nature as a retrospective single-center study that included only patients with Lenke type V AIS. Larger prospective

studies including all AIS types are now required. Further long-term multicentric follow-up studies would guide future practice.

The occurrence of PJK is multifactorial, driven by clinical, surgical, and radiographic factors. Proximal junctional kyphosis is encountered proportionally in the practice of spine surgery and its risk must not be underestimated. Although the rates of development of PJF after PJK and the need for revision surgery are low, it is clear that SRS-22r scores would be affected as the angles of these patients increase. Considering that AIS patients have a long life expectancy, it is necessary to continue monitoring the effects of PJK on their SRS-22r scores into the future. This would surely be the subject of new studies examining the long-term effects of PJK and its treatment.

As the spinal column is a continuous structure from its proximal to distal ends, the applications that we perform during the instrumentation and correction phases may have an effect on the final outcomes, which may be seen primarily in terms of selected UIV and LIV in cases requiring compensation.

In conclusion, the occurrence of PJK is multifactorial, including clinical, surgical, and radiographic factors. Male patients with higher pre- and postoperative TKA, preoperative SB, and postoperative SS and patients with lower satisfaction have a higher risk of PJK development. In these cases, optimal correction with respect to the soft tissue should be provided, patient expectations should be understood, and high-risk patients should be informed.

Declaration of conflicting interests

The authors declared no conflicts of interest with respect to the authorship and/or publication of this article.

Funding

The authors received no financial support for the research and/or authorship of this article.

REFERENCES

1. Mika AP, Mesfin A, Rubery PT, Molinari R, Kebaish KM, Menga EN. Proximal junctional kyphosis: A pediatric and adult spinal deformity surgery dilemma. JBJS Rev 2019;7:e4.
2. Helgeson MD, Shah SA, Newton PO, Clements DH 3rd, Betz RR, Marks MC, et al. Evaluation of proximal junctional kyphosis in adolescent idiopathic scoliosis following pedicle screw, hook, or hybrid instrumentation. Spine (Phila Pa 1976) 2010;35:177-81.
3. Kim YJ, Lenke LG, Bridwell KH, Kim J, Cho SK, Cheh G, et al. Proximal junctional kyphosis in adolescent idiopathic scoliosis after 3 different types of posterior segmental spinal instrumentation and fusions: Incidence and risk factor analysis of 410 cases. Spine (Phila Pa 1976) 2007;32:2731-8.
4. Kim YJ, Bridwell KH, Lenke LG, Kim J, Cho SK. Proximal junctional kyphosis in adolescent idiopathic scoliosis following segmental posterior spinal instrumentation and fusion: Minimum 5-year follow-up. Spine (Phila Pa 1976) 2005;30:2045-50.
5. Hollenbeck SM, Glattes RC, Asher MA, Lai SM, Burton DC. The prevalence of increased proximal junctional flexion following posterior instrumentation and arthrodesis for adolescent idiopathic scoliosis. Spine (Phila Pa 1976) 2008;33:1675-81.
6. Lee JH, Kim JU, Jang JS, Lee SH. Analysis of the incidence and risk factors for the progression of proximal junctional kyphosis following surgical treatment for lumbar degenerative kyphosis: Minimum 2-year follow-up. Br J Neurosurg 2014;28:252-8.
7. Thawrani DP, Glos DL, Coombs MT, Bylski-Austrow DI, Sturm PF. Transverse process hooks at upper instrumented vertebra provide more gradual motion transition than pedicle screws. Spine (Phila Pa 1976) 2014;39:E826-32.
8. Glattes RC, Bridwell KH, Lenke LG, Kim YJ, Rinella A, Edwards C 2nd. Proximal junctional kyphosis in adult spinal deformity following long instrumented posterior spinal fusion: Incidence, outcomes, and risk factor analysis. Spine (Phila Pa 1976) 2005;30:1643-9.
9. Smith MW, Annis P, Lawrence BD, Daubs MD, Brodke DS. Early proximal junctional failure in patients with preoperative sagittal imbalance. Evid Based Spine Care J 2013;4:163-4.
10. Hart R, McCarthy I, O'brien M, Bess S, Line B, Adjei OB, et al. Identification of decision criteria for revision surgery among patients with proximal junctional failure after surgical treatment of spinal deformity. Spine (Phila Pa 1976) 2013;38:E1223-7.
11. Denis F, Sun EC, Winter RB. Incidence and risk factors for proximal and distal junctional kyphosis following surgical treatment for Scheuermann kyphosis: Minimum five-year follow-up. Spine (Phila Pa 1976) 2009;34:E729-34.
12. Kim HJ, Yagi M, Nyugen J, Cunningham ME, Boachie-Adjei O. Combined anterior-posterior surgery is the most important risk factor for developing proximal junctional kyphosis in idiopathic scoliosis. Clin Orthop Relat Res 2012;470:1633-9.
13. Kim HJ, Iyer S. Proximal junctional kyphosis. J Am Acad Orthop Surg 2016;24:318-26.
14. Yagi M, Akilah KB, Boachie-Adjei O. Incidence, risk factors and classification of proximal junctional kyphosis: Surgical outcomes review of adult idiopathic scoliosis. Spine (Phila Pa 1976) 2011;36:E60-8.
15. Zhao J, Yang M, Yang Y, Chen Z, Li M. Proximal junctional kyphosis following correction surgery in the Lenke 5 adolescent idiopathic scoliosis patient. J Orthop Sci 2018;23:744-9.
16. Lenke LG, Betz RR, Haher TR, Lapp MA, Merola AA, Harms J, et al. Multisurgeon assessment of surgical decision-making in adolescent idiopathic scoliosis: Curve classification, operative approach, and fusion levels. Spine (Phila Pa 1976) 2001;26:2347-53.
17. Yang SH, Chen PQ. Proximal kyphosis after short posterior fusion for thoracolumbar scoliosis. Clin Orthop Relat Res 2003;(411):152-8.
18. Atik OŞ. What are the expectations of an editor from a scientific article? Jt Dis Relat Surg 2020;31:597-8.

19. Kim HJ, Bridwell KH, Lenke LG, Park MS, Ahmad A, Song KS, et al. Proximal junctional kyphosis results in inferior SRS pain subscores in adult deformity patients. Spine (Phila Pa 1976) 2013;38:896-901.
20. Peng L, Lan L, Xiu P, Zhang G, Hu B, Yang X, et al. Prediction of proximal junctional kyphosis after posterior scoliosis surgery with machine learning in the Lenke 5 adolescent idiopathic scoliosis patient. Front Bioeng Biotechnol 2020;8:559387.
21. Lonner BS, Ren Y, Newton PO, Shah SA, Samdani AF, Shufflebarger HL, et al. Risk factors of proximal junctional kyphosis in adolescent idiopathic scoliosis-the pelvis and other considerations. Spine Deform 2017;5:181-8.
22. Iyer S, Lenke LG, Nemani VM, Fu M, Shifflett GD, Albert TJ, et al. Variations in occipitocervical and cervicothoracic alignment parameters based on age: A prospective study of asymptomatic volunteers using full-body radiographs. Spine (Phila Pa 1976) 2016;41:1837-44.
23. Lange T, Schulte TL, Gosheger G, Schulze Boevingloh A, Mayr R, Schmoelz W. Effects of multilevel posterior ligament dissection after spinal instrumentation on adjacent segment biomechanics as a potential risk factor for proximal junctional kyphosis: A biomechanical study. BMC Musculoskelet Disord 2018;19:57.
24. Ha Y, Maruo K, Racine L, Schairer WW, Hu SS, Deviren V, et al. Proximal junctional kyphosis and clinical outcomes in adult spinal deformity surgery with fusion from the thoracic spine to the sacrum: A comparison of proximal and distal upper instrumented vertebrae. J Neurosurg Spine 2013;19:360-9.
25. Annis P, Lawrence BD, Spiker WR, Zhang Y, Chen W, Daubs MD, et al. Predictive factors for acute proximal junctional failure after adult deformity surgery with upper instrumented vertebrae in the thoracolumbar spine. Evid Based Spine Care J 2014;5:160-2.
26. Gomez JA, Kubat O, Tovar Castro MA, Hanstein R, Flynn T, Lafage V, et al. The effect of spinopelvic parameters on the development of proximal junctional kyphosis in early onset: Mean 4.5-year follow-up. J Pediatr Orthop 2020;40:261-6.
27. Rhee JM, Bridwell KH, Won DS, Lenke LG, Chotigavanichaya C, Hanson DS. Sagittal plane analysis of adolescent idiopathic scoliosis: The effect of anterior versus posterior instrumentation. Spine (Phila Pa 1976) 2002;27:2350-6.
28. Lau D, Clark AJ, Scheer JK, Daubs MD, Coe JD, Paonessa KJ, et al. Proximal junctional kyphosis and failure after spinal deformity surgery: A systematic review of the literature as a background to classification development. Spine (Phila Pa 1976) 2014;39:2093-102.