Al-Azhar University Journal
for Virus Research and Studies

Proximal Junctional Kyphosis Following Correction of Lenke Type 3 Adolescent Idiopathic Scoliosis Using Pedicle Screw Only Construct: A Retrospective Study

Mohamed Fouad Abuhani[1], Hany Abd-El-Gawwad Soliman[1] and Hesham El-Saady Farhoud[1]

[1]Department of Orthopedic Surgery, Faculty of Medicine for Girls, Al-Azhar University, Cairo, Egypt.

***E-mail: MohammedFouad.2353@azhar.edu.eg**

Abstract

The purpose of this study is to investigate the incidence and risk factors for developing proximal junctional kyphosis (PJK) in Lenke 3 adolescent idiopathic scoliosis patients following all-pedicle instrumentation and correction after a minimum of two years follow up. From June 2016 to June 2019, medical records of Lenke 3 AIS patients were reviewed, including posteroanterior and lateral whole spine X-ray films preoperatively, postoperatively (8-10 days after surgery), and after 2 years of follow-up. Demographic data, as well as radiologic parameters, were evaluated. Binary logistic Regression analysis was performed to detect the risk factors of PJK. The current study recruited 50 Lenke 3 AIS patients with a minimum follow-up of 2 years. Three (6%) of 50 cases had PJK, no patient required revision because of PJK. Binary logistic regression showed that Larger preoperative thoracic kyphosis > 43°, larger preoperative lumbar lordosis and larger postoperative lumbar lordosis > 45° were the main risk factors of PJK [Odds Ratio (OR) = 0.429,0.863 and 1.024 respectively]. The incidence of PJK was 6%, greater preoperative thoracic kyphosis > 43°, greater preoperative, and postoperative lumbar lordosis > 45° were the main risk factors for PJK. Careful long-term follow-up should be performed to identify risk factors and reduce the occurrence of PJK.

Keywords: Proximal Junctional Kyphosis, Lenke type 3, Adolescent Idiopathic Scoliosis, all-pedicle screws.

1. Introduction

Adolescent idiopathic scoliosis (AIS) is a complex three-dimensional spine deformity with an incidence of 2% to 4% [1]. Aside from the cosmetic element of the deformity, more severe curvatures are frequently associated with medical issues such as functional limitations, increased back pain, and cardiorespiratory dysfunction [2)].

The goals of surgical treatment for AIS patients are to obtain significant curve correction and to prevent progression or recurrence through the induction of spinal arthrodesis. The treatment of AIS has evolved in the past decade with the implementation of all-pedicle-screw constructs. The introduction of pedicle screws has allowed greater correction of

the three-dimensional scoliotic deformity. Advantages offered by posterior spinal fusion (PSF) with all pedicle screw constructs include a secure 3-column fixation, superior control of the upper and lower instrumented vertebrae, and the ability to manage larger scoliosis deformities with a posterior-only approach. [3,4].

However, strong correction using all-pedicle instrumentation also resulted in a series of issues, such as the decrease in thoracic kyphosis (TK). (5) Moreover, the phenomenon of PJK has drawn the attention of many spine surgeons, because PJK has been associated with a clinical outcome in elderly populations [6].

Junctional kyphosis (JK), a special type of Adjacent Segment Disease (ASD), is considered a complication of instrumented spinal fusion due to the increased rigidity of the fused segment. JK occurs at a noteworthy rate following all types of spinal disorders, necessitating revision surgery in roughly one-fifth of those who develop it. Many patients with JK are unaware of it and do not complain about it, but in symptomatic patients, emphasis should be paid to putting together a plan to treat it properly. Recently, it has come to the focus of attention with many studies on its incidence, risk factors, prevention, and treatment [7].

Proximal junctional kyphosis is a kyphotic deformity that occurs at the upper instrumented vertebra (UIV) and it is determined by measuring the Proximal Junctional Angle (PJA) which is the sagittal Cobb angle between the inferior endplate of the UIV and the superior endplate two vertebrae proximal to the fusion (UIV +2). Also, PJK should have two criteria: (1) PJA more than or equal to 10° and (2) It is 10° more than the preoperative measurement [8]. Despite several studies on the PJK phenomenon in AIS patients, there was a lack of data on the incidence of PJK in Lenke 3 AIS after corrective surgery. The purpose of this study is to investigate the incidence and risk factors that may predispose to PJK following PSF for Lenke 3 AIS using all-pedicle screw constructs.

2. Patients and Methods

Medical records of 50 Lenke 3 AIS patients surgically corrected using all pedicle screw constructs were recruited over 3 years from an outpatient clinic of a tertiary care hospital. Records included posteroanterior and lateral whole spine X-ray films preoperatively, postoperatively (8-10 days after surgery), and at 2 years follow-up. For participation in this study, each patient had to match the following criteria:

1) Lenke 3 AIS patients aged 11 to 20 years.
2) One-stage posterior pedicle screw instrumentation and corrective surgery.
3) Two years of minimal follow-up.

2.1 Data collection

Data were collected retrospectively. The following demographic data were recorded: Age (years), and gender (female/male). The standing posteroanterior and lateral X-ray films before surgery, postoperatively (8-10 days after surgery), and after 2 years follow-up were collected. On the posteroanterior X-ray film, the Main Thoracic Curve (MTC) and Thoracolumbar / Lumbar Curve (TL / LC) were measured. On the lateral film, the following parameters were measured: T5-T12 kyphosis (TK), lumbar lordosis (LL), and proximal junctional angle (PJA). PJA was measured using the Surgimap software and defined as the caudal endplate of the UIV to the cephalad endplate of the UIV+2 vertebrae [9]. PJK was evaluated using lateral whole spine upright radiographs preoperatively, postoperatively and at 2 years follow-up based on the following criteria as previously described: PJA $\geq 10°$ and PJA progression of $> 10°$ at the final follow-up (10). Moreover, the pelvic sagittal radiographic parameters, including

pelvic tilt (PT), pelvic incidence (PI), and sacral slope (SS), were measured.

2.2 Statistical Analysis

The statistical analyses were conducted by Statistical Package for Social Science (IBM SPSS) version 20. The data were presented as numbers and percentages for the qualitative data, mean, standard deviations, and ranges for the quantitative data with parametric distribution and median with interquartile range (IQR) for the quantitative data with the non-parametric distribution. The chi-square test was used in comparison with qualitative data and the Fisher exact test was used instead of the Chi-square test when the expected count in any cell was found to be less than 5. The Independent T-test was used in the comparison with quantitative data and parametric distribution and Mann-Whitney test was used in the comparison with quantitative data and non-parametric distribution. Paired t-test was used in the comparison with quantitative data before and after and parametric distribution and Wilxon Rank test was used in the comparison with quantitative data before and after and non-parametric distribution. The confidence interval was set to 95% and the margin of error accepted was set to 5%. A statistical significance was defined as a P value <.05. To reveal independent risk factors of PJK at the final follow-up, binary logistic regression models were constructed using variables that were of significance in univariate analysis.

3. Results

Initially, 95 Lenke 3 AIS patients were identified from the database. Following the inclusion and exclusion process, 50 Lenke 3 AIS patients (female/male: 44/6) were recruited for this study. The mean age at surgery was (15.62 ± 2.27 years; with a range 11-20 years old). Coronal, sagittal, and pelvic parameters are demonstrated in (Table 1). Table .1 shows (**P1)** preoperative compared with postoperative, and **(P2)** postoperative compared with follow-up.

Table (1): Comparison between radiological parameters pre-operative, post-operative, and after 2 years of follow-up.

	preoperative (N=50)	**postoperative (N=50)**	**Follow-up (N=50)**	**P1**	**P2**
	Mean ± SD	Mean ± SD	Mean ± SD		
MTC	62.11° ± 9.962	19.61° ± 8.228	20.34° ± 8.636	0.0001	0.076
TL/LC	52.70° ± 8.996	13. 54° ± 9.332	14.19° ± 8.446	0.0001	0.085
TK	37.04° ± 13.101	27.60° ± 10.042	29.34° ± 10.64	0.0211	0.138
LL	56.98° ± 11.089	48.60° ± 16.242	52.00° ± 12.23	0.0232	0.058
PJA	5.252° ± 1.602	7.989° ± 1.218	8.743° ± 0.682	0.0771	0.069
PT	20.74° ±13.39	22.70° ± 12.23	18.04° ± 10.16	0.0861	0.056
PI	53.48° ± 18.902	53.28° ± 19.462	48.38° ± 16.44	0.9741	0.078
SS	33.26° ± 9.1462	31.24° ± 13.442	30.63° ± 10.82	0.0533	0.12

3.1 Incidence of PJK

After 2 years of follow-up, there were 3 patients (6%) out of 50 Lenke 3 AIS patients who developed PJK at follow-up, while the rest of 47 patients demonstrated no significant PJK. No revision surgery was required for any patient during the follow-up period.

3.2 Risk factors for developing PJK

Binary logistic regression was conducted to investigate the main risk factors for developing PJK. Initially, univariate analysis was conducted to detect confounding variables, which showed risk factors as follows: preoperative TK, preoperative LL, and postoperative LL (Table 2).

Table (2): Univariate analysis for risk factors of PJK.

	B	S.E.	Wald	Df	Sig.	OR	95% C.I. for EXP(B)	
							Lower	Upper
Preoperative MTC	0.035	0.059	0.340	1	0.560	1.035	0.921	1.163
Postoperative MTC	-0.051	0.081	0.395	1	0.530	0.951	0.812	1.113
Preoperative TL/LC	-0.014	0.069	0.043	1	0.836	0.986	0.861	1.129
Postoperative TL/LC	-0.201	0.167	1.455	1	0.228	0.818	0.589	1.134
Preoperative TK	0.079	0.061	1.692	1	0.034	1.082	0.961	1.218
Postoperative TK	0.036	0.046	0.598	1	0.439	1.036	0.947	1.135
Preoperative LL	0.141	0.077	3.343	1	0.042	1.152	0.99	1.34
Postoperative LL	-0.027	0.065	0.171	1	0.026	0.974	0.858	1.105
Preoperative PJA	0.147	0.574	0.065	1	0.798	0.864	0.28	2.66
Postoperative PJA	0.372	0.570	0.426	1	0.514	1.450	0.475	4.430
Preoperative PT	0.025	0.043	0.329	1	0.566	1.025	0.942	1.115
Postoperative PT	-0.052	0.073	0.504	1	0.478	0.949	0.823	1.096
Preoperative PI	0.016	0.032	.0255	1	0.613	1.016	0.955	1.082
Postoperative PI	-0.004	0.037	.013	1	0.909	0.996	0.926	1.071
Preoperative SS	0.033	0.058	0.334	1	0.563	1.034	0.923	1.158
Postoperative SS	0.026	0.057	0.212	1	0.645	1.026	0.919	1.147

Then, binary logistic regression based on the aforementioned parameters showed that larger preoperative thoracic kyphosis > 43°, larger preoperative and postoperative lumbar lordosis > 45° were the main risk factors of PJK with ORs of 0.429,0.863 and 1.024 respectively (Table 3).

Table (2): Binary logistic regression analysis (Forward Wald method) for risk factors of PJK.

	B	S.E.	Wald	Df	Sig.	OR	95% C.I. for EXP(B)	
							Lower	Upper
preoperative TK	0.009	0.016	.077	1	0.012	0.429	-.024	.042
Preoperative LL	0.015	0.017	.139	1	0.034	0.863	-.019	.050
Postoperative LL	0.007	0.016	.070	1	0.024	1.024	-.025	.039
Constant	6.754	1.010	2.976	1	0.024	0.654		

4. Discussion

For AIS patients, PJK was a common phenomenon after corrective surgery. Previously, various studies reported an incidence rate that varies from 9.2% to 46% depending on different PJA cut-offs [11].

Despite several studies about the incidence of PJK in AIS patients, there was insufficient data on PJK in Lenke 3 AIS patients after all-pedicle instrumentation and correction. Our study included 50 Lenke 3 AIS patients following one-stage posterior all-pedicle instrumentation and correction. With the PJK cut-off of 10°, the study reported that the incidence of PJK was 6% after 2 years of follow-up.

This discrepancy in the incidence of PJK in literature could be attributed to the difference in PJA/PJK definition, which varied between studies. Some studies

measure the difference between pre-and postoperative radiographs, while others, similar to our study, measure the difference between the immediate postoperative and latest follow-up film Figure .1. Another possibility is the difference in instrumentation type.

Sebaaly et al [12, 13] considered that preoperative thoracic kyphosis more than 40° is a risk factor for developing PJK. Other authors [15, 16] reported no significant difference between the two groups (PJK and non-PJK). In this study, we found that larger preoperative thoracic kyphosis above 43° was a significant risk factor for developing PJK.

Lumbar spine is highly mobile. It acts as a compensatory mechanism to the increased thoracic kyphosis in a reciprocal way. Lumbar lordosis increases when thoracic kyphosis increases and vice versa, the aim is to keep the head aligned over the sacrum. Published literature found that high pre-operative lumbar lordosis is a risk factor of PJK [12, 13, 16]. In this study, we found that preoperative and postoperative lumbar lordosis above 45° was also a significant risk factor for developing PJK.

Pelvic parameters (PI, PT, and SS) have been reported to be correlated to junctional kyphosis [12, 13, 16]. In this study, the three pelvic parameters were not a significant risk factor for developing PJK. This was consistent with the finding of Kim et al [17] and Wang et al [18] who did not find a correlation between PI, PT, SS and PJK.

Although hook or hybrid constructs may minimize the incidence of PJK, no consensus has been established. According to several studies, the incidence of PJK was equivalent among all screws, all-hook, and hybrid constructs [19-20].

It's unclear why all-pedicle screw constructs increase PJK incidence. Two hypotheses, however, have been proposed. First, increased rigidity and decreased thoracic kyphosis following PSF using screws may be related to PJK. Pedicle screw constructs have greater correction ability than hook constructs but result in less thoracic kyphosis.

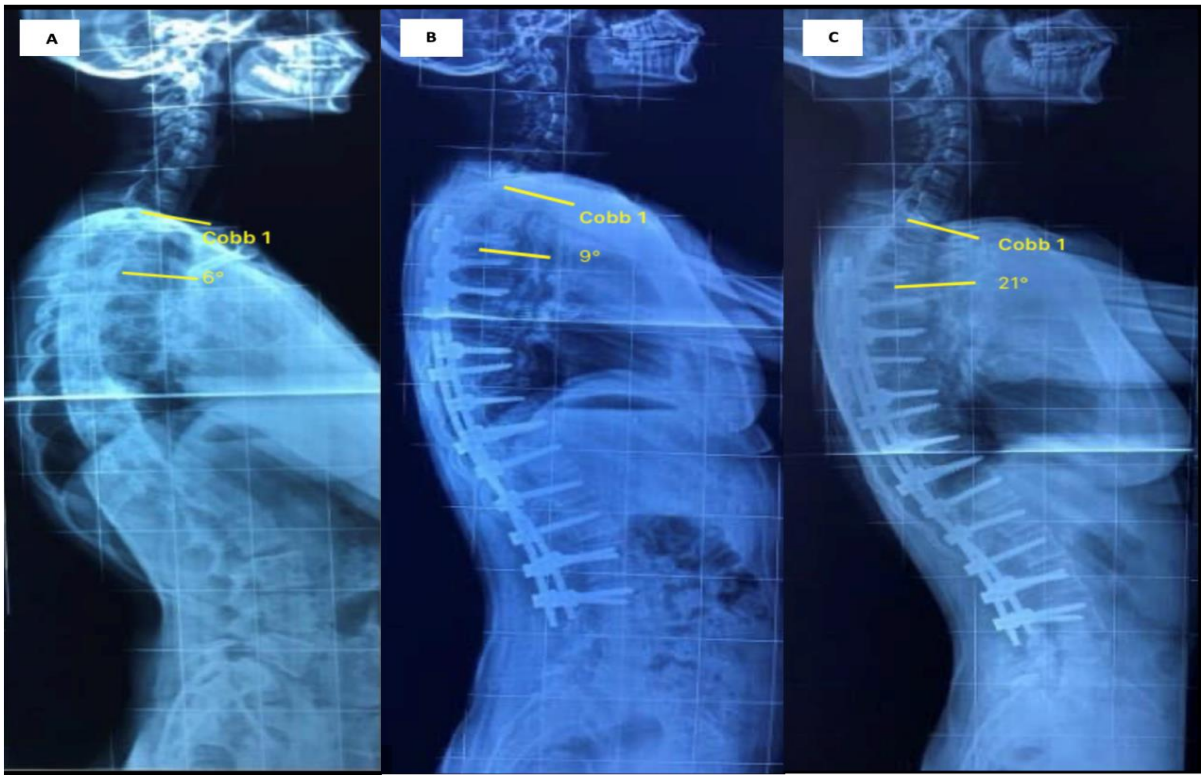

Figure (1): An example of proximal junctional kyphosis (PJK) following corrective surgery. Corrective surgery was performed at the age of 15. PJA was 21° at 17 years' follow-up.

Yoji Ogura et al. [20] reported that postoperative decrease in thoracic kyphosis was significantly greater in the PJK patients. PJK may be a compensation mechanism for the decreased thoracic kyphosis to restore global sagittal balance. These findings are consistent with the hypothesis that increased PJA is a compensation mechanism for decreased thoracic kyphosis and subsequent negative sagittal balance [20].

There is another study to support this hypothesis. Rhee et al. [21] studied the difference in sagittal plane radiographical parameters between anterior spinal fusion (ASF) and posterior spinal fusion (PSF); ASF was kyphogenic while PSF was lordogenic within the fusion area, which they attributed to anterior compression force in ASF. They also showed PSF was associated with greater increases in PJA than anterior surgery in AIS. These findings suggest that PJK is a compensatory mechanism; decreased kyphosis or increased lordosis within the fusion area results in the negative sagittal balance following PSF, resulting in proximal kyphosis to restore global sagittal balance.

The second hypothesis is soft tissue disruption. The supra-adjacent facet capsules are frequently violated when pedicle screws are placed at the UIV. The incidence of facet violation ranged from 8% to 47% when using pedicle screws. (22-23) Furthermore, a broad range of soft tissue dissection is necessary when inserting screws. Capsular disruption, as well as ligamentous and muscular disruption in PSF, could increase vulnerability to PJK.

Many attempts have recently been made to restore thoracic kyphosis using pedicle screws, modern correction techniques can better restore kyphosis and may change the incidence of PJK in patients with an all-screw construct [24].

PJK can include fracture of the upper instrumented vertebrae (UIV) or UIV+1, soft tissue failure, and implant pull-out. [25] The type of failure depends on the level of the UIV. Soft tissue failure is more common for upper thoracic UIV while fracture is more common for thoracolumbar UIV. Fracture or implant pull-out is less common in AIS as adolescent patients have better bone quality than patients with adult spinal deformity. [26] Pull-out or fracture was not reported in our study. All PJK patients in our study were classified as having a soft tissue failure type.

This study is limited by being retrospective and by small sample size but to the best of our knowledge, this is the first study to investigate the incidence and risk factors of PJK in a homogenous group of Lenk 3 AIS patients.

5. Conclusion

The incidence of PJK was 6%, greater preoperative thoracic kyphosis > 43°, greater preoperative and postoperative lumbar lordosis > 45° were the main risk factors for PJK. Careful long-term follow-up should be performed to identify risk factors and reduce the occurrence of PJK.

Funding Sources: There was no support for this study from any governmental, private, or non-profit organization**.**

Conflicts of interest: No competing interest

References

1- Brink RC, Colo, D, Schlösser, TPC et al: Upright, prone, and supine spinal morphology and alignment in adolescent idiopathic scoliosis. Scoliosis 12, 6 (2017).

2- Zhong J, Cao K, Wang B, et al: Incidence and risk factors for proximal junctional kyphosis in adolescent idiopathic scoliosis after correction surgery: a meta-analysis. World

Neurosurgery. 2019 May;125: e326-e335.

3- Kuklo TR, Lenke LG, O'Brien MF, et al: Accuracy and efficacy of thoracic pedicle screws in curves more than 90 degrees. Spine (Phila Pa 1976) 2005; 30(2):222-6.

4- Luhmann SJ, Lenke LG, Kim YJ, et al: Thoracic adolescent idiopathic scoliosis curves between 70 degrees and 100 degrees: is anterior release necessary? Spine (PhilaPa 1976) 2005;30(18):2061-7.

5- Ozkunt O, Karademir G, Sariyilmaz K, et al: Analysing the change of sagittal balance in patients with Lenke 5 idiopathic scoliosis. Acta Orthop Traumatol Turcica 2017 Oct; 51(5): 377- 80.

6- Raman T, Miller E, Martin CT, et al: The effect of prophylactic vertebroplasty on the incidence of proximal junctional kyphosis and proximal junctional failure following posterior spinal fusion in adult spinal deformity: a 5-year followup study. Spine J 2017 Oct;17(10):1489-98.

7- Agarwal N, Heary RF and Agarwal P: Adjacent-segment disease after thoracic pedicle screw fixation. J Neurosurg Spine. 2018;28(3):280-6.

8- Yan P, Bao H, Qiu Y, et al: Mismatch Between Proximal Rod Contouring and Proximal Junctional Angle. SPINE. 2017; 42(5), E280–E287.

9- Cobanoglu M, Yorgova, P, Neiss, G et al: Prevalence of junctional kyphosis in early-onset scoliosis: can it be corrected at final fusion?. Eur Spine J 2021;.

10- Ferrero E, Bocahut N, Lefevre Y, et al: Proximal junctional kyphosis in thoracic adolescent idiopathic scoliosis: risk factors and compensatory mechanisms in a multicenter national cohort. Eur Spine J. 2018;27:2241-2250.

11- Zhao J, Yang M, Yang Y, et al: Proximal junctional kyphosis following correction surgery in the Lenke 5 adolescent idiopathic scoliosis patient. Journal of Orthopaedic Science. 2018 Sep;23(5):744-749.

12. Sebaaly A, Sylvestre C, El Quehtani Y, et al: Incidence and Risk Factors for Proximal Junctional Kyphosis: Results of a Multicentric Study of Adult Scoliosis. Clin Spine Surg. 2018;31(3):E178E83.

13. Sebaaly A, Riouallon G, Obeid I, et al: Proximal junctional kyphosis in adult scoliosis: comparison of four radiological predictor models. Eur Spine J. 2018;27(3):613-21.

14. Yagi M, Akilah KB and Boachie-Adjei O: Incidence, risk factors and classification of proximal junctional kyphosis: surgical outcomes review of adult idiopathic scoliosis. Spine (Phila Pa 1976).36(1):E60-8.

15. Lee JH, Kim JU, Jang JS, et al: 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(2):252-8.

16. Pizones J, Moreno-Manzanaro L, Sanchez Perez-Grueso FJ, et al: Restoring the ideal Roussouly sagittal profile in adult scoliosis surgery decreases the risk of mechanical complications. Eur Spine J. 2020; 29(3):1-9.

17. Kim DK, Kim JY, Kim DY, et al: Risk Factors of Proximal Junctional Kyphosis after Multilevel Fusion Surgery: More Than 2 Years Follow-Up

Data. J Korean Neurosurg Soc.60(2):174-80.

18. Wang H, Ma L, Yang D, et al: Incidence and risk factors for the progression of proximal junctional kyphosis in degenerative lumbar scoliosis following long instrumented posterior spinal fusion. Medicine (Baltimore). 95(32):e4443.

19. Luo M, Li N, Shen M, et al: Pedicle screw versus hybrid instrumentation in adolescent idiopathic scoliosis: a systematic review and meta-analysis with emphasis on complications and reoperations.Medicine (Baltimore). 2017;96:e7337.

20. Ogura Y, Glassman SD, Sucato D, et al: Incidence of Proximal Junctional Kyphosis with Pedicle Screws at Upper Instrumented Vertebrae in Posterior Spinal Fusion for Adolescent Idiopathic Scoliosis. Global Spine Journal. 2021;11(7):1019-1024.

21. Rhee JM, Bridwell KH, Won DS, et al: Sagittal plane analysis of adolescent idiopathic scoliosis: the effect of anterior versus posterior instrumentation.Spine (Phila Pa 1976). 2002; 27:2350-2356.

22. Archavlis E, Amr N, Kantelhardt SR, et al: Rates of upper facet joint violation in minimally invasive percutaneous and open instrumentation: a comparative cohort study of different insertion techniques. J Neurol Surg A Cent Eur Neurosurg. 2018; 79:1-8.

23. Levin JM, Alentado VJ, Healy AT, et al: Superior segment facet joint violation during instrumented lumbar fusion is associated with higher reoperation rates and diminished improvement in quality of life. Clin Spine Surg. 2018; 31: E36-E41.

24. Ohrt-Nissen S, Dragsted C, Dahl B, et al: Improved restoration of thoracic kyphosis using a rod construct with differentiated rigidity in the surgical treatment of adolescent idiopathic scoliosis. Neurosurg Focus. 2017; 43:E6.

25. Lopez Poncelas M, La Barbera L, Rawlinson JJ, et al: Credibility assessment of patient-specific biomechanical models to investigate proximal junctional failure in clinical cases with adult spine deformity using ASME V&V40 standard, Computer Methods in Biomechanics and Biomedical Engineering, 2021;

26. Sardar ZM, Kim Y, Lafage V, et al: State of the art: proximal junctional kyphosis—diagnosis, management and prevention. Spine Deform. 2021; 9, 635–644.