RISK FACTORS OF PROXIMAL JUNCTIONAL KYPHOSIS AFTER SURGICAL CORRECTION OF SPINAL DEFORMITIES CAUSED BY SCHEUERMANN'S DISEASE

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Objective. To identify risk factors for the development of Proximal Junctional Kyphosis (PJK) in patients with Scheuermann's kyphosis operated on using segmental instrumentation.

Material and Methods. The study group consisted of 43 patients (13 females, 30 males), mean age was 17 years, and mean postoperative follow-up was 6 years. Spondylograms with a patient in a standing position performed before surgery, a week after surgery, and at the end of the follow-up period were analyzed. Radiological parameters were studied: cervical lordosis, absolute rotation angle, thoracic inlet angle, T1 vertebral body tilt, neck tilt, cranial tilt, thoracic kyphosis, thoracolumbar kyphosis, lumbar lordosis, vertebral and pelvic parameters (Pelvic Incidence, Pelvic Tilt, Sacral Slope), sagittal vertical axis, proximal junctional angle (PJA), and length of the posterior spinal fusion.

Results. The mean PJA before surgery was 7° [3°; 8°], immediately after surgery – 10° [8°; 13°], by the end of the follow-up period – 25°[19°; 32°]. The incidence of PJK by the end of the follow-up period was 79.1 % (in 34 out of 43 patients). The initial value of thoracic kyphosis was 77° [72°; 86°], after surgery – 41° [31°; 46°], at the last examination – 43° [35°; 53°]. The inclination of the T1 vertebral body in the sagittal plane before surgery was 39° [30°; 45°], at the stages of follow-up – 33° [22°; 37°] and 39° [27°; 45°]. Some significant predictors were identified. An increase in the inclination of the T1 vertebral body ($p = 0.005$) by k° is associated with an increase in the risk of PJK by 1.19k [1.08k; 1.37k] times, and an increase of thoracic kyphosis by k° ($p = 0.023$) – by 1.12k (1.03k; 1.27k) times. The formula for preoperative predicting the likelihood of this complication is: $P(PJK) = 1 - 1/(1 + \exp(-23.14 + 0.26 \times T1 + 0.21 \times TK))$, where P(PJK) is the probability of proximal junctional kyphosis; exp(z) is the exponential function to the power of z; T1 (T1 vertebral body tilt) and TK (thoracic kyphosis) are preoperative values of variables. Using ROC analysis, the threshold value for predicting PJK was determined to be 74.2 %, that is, the development of PJK was predicted in patients with a PJK probability greater than the threshold value calculated by the model formula. The predictive ability of the multivariate model was tested on the basis of the available initial data with a known final result. The prediction was correct in 41 cases out of 43.

Conclusion. Using the multivariate logistic regression method, two mutually independent multiplicative indicators were determined for predicting PJK with high accuracy (sensitivity 94.1 %, specificity 100.0 %) – inclination of the T1 vertebral body and thoracic kyphosis.

Key Words: Scheuermann's disease, proximal junctional kyphosis, surgical treatment, risk factors, PJK.

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The outcome of corrective surgery for spinal deformity in Scheuermann's disease is estimated not only by the reduced degree of thoracic kyphosis but also by changing the parameters of the anterior and sagittal balance of the trunk, by evaluating the condition of the segments of the spine not included in the instrumented spinal fusion zone, by patient satisfaction with the effect achieved (Health-Related Quality of Life) and by a number of other factors. One of the actual challenges to be identified at the postoperative follow-up is the so-called Proximal Junctional Kyphosis (PJK). The formation of PJK is described as an increased kyphosis angle between the lower endplate of the upper instrumented vertebra (UIV) and the upper endplate of the vertebra located two segments cranial to the upper instrumented vertebra, by more than 10° compared to the preoperative angle at the same level [1]. One of the factors of its development is the incorrect choice of the boundaries of the zone of spine instrumentation. In this regard, the issue of choosing the boundaries of the posterior spinal fusion is still actual since it allows for optimal correction of spinal deformity while preserving, as much as possible, the maximum number of non-fixed segments so that the patient's quality of life would not be downgraded. Other risk factors are also considered to be factors for the development of PJK. According to the literature [2, 3] these include a significant initial magnitude of thoracic kyphosis, hypercorrection or, conversely, insufficient correction of kyphosis, injured ligamentous apparatus of the posterior support column above the upper instru-

mented vertebra, decreased bone density, placement of pedicle screws at the level of the upper instrumented vertebra, etc. However, the literature sources do not contain data concerning such possible risk factors for the development of PJK as the patient's gender, indicators of the sagittal contour of the cervical spine, the inclination of the T1 vertebral body, and a number of others. All this complicates preoperative planning and may considerably reduce the curative effect, especially in the long-term postoperative period (the development of Proximal Junctional Failure (PJF) that usually requires the extension of the zone of instrumented spinal fusion to the lower cervical spine).

The objective is to identify risk factors for the development of proximal junctional kyphosis (PJK) in patients with Scheuermann's kyphosis operated on using segmental instrumentation.

Design: a single-center retrospective cohort study.

Material and Methods

Patients

The radiographs of 43 patients with Scheuermann's disease who underwent posterior segmental instrumentation surgery between 1997 and 2017 were analyzed. There were 13 female and 30 male patients. The mean age of patients at the time of surgery was 17 [15.0; 25.5] years, and the mean postoperative follow-up period was 6 [5.4; 20.0] years. Inclusion criteria: individuals diagnosed with Scheuermann's disease, a complete set of high-quality radiographs to reliably evaluate the frontal and sagittal parameters of the spine, a follow-up period of more than five years from the moment of surgery, and the absence of neurological and suppurative complications. Spondylograms with a patient in a standing position were analyzed in two projections from C2 to the pelvis with the capture of the femoral heads before surgery, a week after surgery and at the end of the follow-up period.

Techniques

Based on the literature sources [4] the following parameters were chosen as possible risk factors: cervical lordosis (CL), absolute rotation angle (ARA), thoracic inlet angle (TIA), the inclination of the T1 vertebral body in the sagittal plane (T1 tilt), neck tilt (NT), cranial tilt (CrT), thoracic kyphosis (TK), thoracolumbar kyphosis (TLK), lumbar lordosis (LL), pelvic incidence (PI), pelvic tilt (PT), sacral slope (SS), sagittal vertical axis (SVA) and proximal junctional angle (PJA).

The age of a patient at the time of surgery, gender, the extension of the posterior spinal fusion, the level of the upper instrumented vertebra (UIV), and the level of the apex of thoracic kyphosis were also evaluated. Spinal deformity correction was performed using a standardized technique with the help of posterior segmental instrumentation and multilevel transpedicular fixation. All patients answered the SRS-24 questionnaire at study stages.

Statistical analysis

A statistical study of the data obtained was performed at a significance level of 0.05; that is, the numerical relationship was considered significant at $p < 0.05$. The quality of the models was assessed by ROC analysis. All statistical calculations were performed using the RStudio software (version 1.3.959-2009-2020) in R programming language.

Results

The mean magnitude of kyphotic deformity correction after surgery was 49.3 %; by the end of the follow-up period some loss of the correction was noted, up to 42.8 % of the initial one (Table 1). Foremost, this is due to the peculiarity of measuring the parameters of thoracic kyphosis, since the upper end vertebra was most often chosen at the T3 level. Meanwhile, the upper limit of instrumented spinal fusion in 39.5 % of cases was T4, and with an augmentation of the proximal junctional angle, the overall indices of thoracic kyphosis typically increased. No significant loss of correction was detected when the parameters of thoracic kyphosis were measured precisely within the limits of instrumented spinal fusion. During the postoperative period, the mean decrease in the magnitude of lumbar lordosis was 32.9 %; during the follow-up period, the parameters of lordosis remained within the normal range. Junctional thoracolumbar kyphosis also reduced after surgery by 45.8 % and remained unchanged during the whole follow-up period. The lack of dynamics can be explained by the localization of junctional thoracolumbar kyphosis within the boundaries of instrumented spinal fusion. The decrease in the tilt of the T1 vertebral body after surgery was 16.6 %; by the time of the last control examination, it had returned to its initial values. Proximal junctional angle changed the most of all the considered sagittal parameters of the thoracic spine and lumbar spine. It increased by 57.4 % after surgery and by 264.2 % at the end of follow-up period in comparison with the initial angle. By the end of the follow-up period, PJK had formed in 79.1 % (34 out of 43) of patients.

The parameters of cervical lordosis and the thoracic inlet angle in the general cohort did not change significantly at the follow-up stages (Table 2). The absolute rotation angle and the cranial tilt decreased slightly immediately after surgery; at the end of the follow-up, they became larger than before the start of treatment. The increase in the neck tilt angle continued at all stages of postoperative follow-up.

As for the lumbopelvic parameters, pelvic incidence and sacral slope in the early postoperative period demonstrated a slight reduction in values that returned to the baseline levels at the end of the follow-up. Immediately after surgery, pelvic tilt increased almost twice, but at the end of the follow-up period, it also returned to the original values (Table 3).

To identify a statistically significant dependence of proximal junctional kyphosis on the parameters under consideration, a logistic regression model was built (Table 4).

By building univariate models for predicting the possibility of the development of proximal junctional kyphosis (logistic regressions), some significant predictors have been identified. Female gender ($p = 0.002$): the predictor is associated

with a reduced risk of PJK development by 0.06 [0.01; 0.32] times; male gender (p = 0.002): the predictor is associated with an increased risk of PJK development by 16.3 [3.10; 130.57] times. An increase in the tilt of the T1 vertebral body (p = 0.005) by k° is associated with an increased risk of PJK development by 1.19k [1.08k; 1.37k] times; increase in thoracic kyphosis by k° (p = 0.023) – by 1.12k (1.03k; 1.27k) times; increase in the thoracic inlet angle by k° (p = 0.008) – by 1.12 k [1.04 k; 1.23k] times; increase in the absolute rotation angle by k° (p = 0.027) – by 1.12k [1.03k; 1.26k] times; and increase in cervical lordosis by k° (p = 0.035) – by 1.28k [1.08k; 1.72k] times. By building a multivariate model for predicting the probability of the development of proximal junctional kyphosis (logistic regressions), the following dependencies have been identified: an increase in the preoperative T1 vertebral body tilt (p = 0.013) by k° is associated with an increased risk of PJK development by 1.3k (1.11k; 1.71k); an increased preoperative thoracic kyphosis (p = 0.033) by k° is associated with an increased risk of PJK development by 1.24k (1.07k; 1.61k).

The formula for the multivariate model of logistic regression of PJK to predict the probability of the development of this complication at the preoperative stage is as follow:

$P(PJK) = 1 - 1/(1 + \exp(-23.14 + 0.26 \times T1 + 0.21 \times TK))$,

where P(PJK) is the probability of developing proximal junctional kyphosis; exp(z) is the exponential function to the power of z; T1 (T1 body tilt) and TK (thoracic kyphosis) are the preoperative values of variables.

Using ROC analysis for assessing the best predictive accuracy of the model, the threshold value for predicting PJK was defined as 74.2 %. That means that the development of PJK was predicted in patients with a PJK probability computed by the model formula higher than the threshold. In the study group, the presented prediction method showed 94.1 % sensitivity and 100.0% specificity that was a high indicator of the quality as a prediction score (Fig. 1). The check of predictive ability of the obtained multivariate model was performed using the available initial data with a known result (Table 5). The prediction turned out to be correct in 41 cases out of 43.

Clinical case 1. Patient D., male, 14 years old suffering from Scheuermann's disease (grade III, painful form) and hyperkyphosis of the thoracic spine (77°) underwent surgery using hybrid segmental instrumentation.

The initial magnitude of thoracic kyphosis (as of February 8, 2016) was 77°; the tilt of the T1 vertebral body was 43°; and the magnitude of the proximal junctional angle was 6° (Fig. 2a). Eight days after surgery (on June 16, 2016) the thoracic kyphosis magnitude was 20°; the T1 tilt was 22°; and the proximal junctional angle was 9° (Fig. 2b). At the end of the follow-up period (July 10, 2021), the magnitude of thoracic kyphosis was 19° and the T1 body tilt was 39°; the formation of proximal junctional kyphosis of 56° was stated (Fig. 2c). The formula for the multivariate model of logistic regression of PJK was tested with the obtained data.

$P(PJK) = 1 - 1/(1 + \exp(-23.14 + 0.26 \times T1 + 0.21 \times TK))$;

$P = 1 - 1/(1 + \exp(-23.14 + 0.26 \times 43 + 0.21 \times 77)) = 0.98$;

$P = 0.98 \times 100 = 98$.

Table 1

Dynamics of sagittal parameters of the thoracic and lumbar spine

Parameters	Before surgery*	After surgery*	At the end of the follow-up period*	Differences (%)*	Wilcoxon signed-rank, p value
Thoracic kyphosis, degrees	77 [72.0; 86.0]	41 [31.0; 46.0]	43 [35.0; 53.0]	TK1-TK2: 38.0 [37.5; 38.0] (49.3) TK1-TK3: 33.0 [32.0; 33.0] (42.8) TK2-TK3: -3.5 [-4.0; -3.0] (7.3)	TK1-TK2: <0.001** TK1-TK3: <0.001** TK2-TK3: 0.004**
Lumbar lordosis, degrees	76 [67.0; 85.0]	50 [42.0; 6.5]	55 [47.5; 62.0]	LL1-LL2: 25.0 [25.0; 25.5] (32.9) LL1-LL3: 19.5 [19.0; 20.0] (25.6) LL2-LL3: -5.0 [-5.5;- 4.5] (10.0)	LL1-LL2: <0.001** LL1-LL3: <0.001** LL2-LL3: 0.001**
Junctional thoracolumbar kyphosis, degrees	12 [5.0; 20.0]	7 [4.0; 10.5]	7 [3.0; 12.5]	TLK1-TLK2: 5.5 [5.0; 6.0] (45.8) TLK1-TLK3: 5.5 [5.0; 6.0] (45.8) TLK2-TLK3: 0.0 [0.5; 0.0] (0.0)	TLK1-TLK2: 0.002** TLK1-TLK3: 0.012** TLK2-TLK3: 0.838
T1 tilt, degrees	39 [30.5; 45.0]	33 [22.5; 37.5]	39 [27.5; 45.0]	T1(1)-T1(2): 6.5 [6.0; 7.0] (16.6) T1(1)-T1(3): 0.0 [-0.5; 1.0] (0.0) T1(2)-T1(3): -6.0 [-6.5; -6.0] (18.1)	T1(1)-T1(2): 0.002** T1(1)-T1(3): 0.952 T1(2)-T1(3): <0.001**
Proximal junctional angle, degrees	7 [3.5; 8.0]	10 [8.0; 13.5]	25 [19.0; 32.0]	PJA1-PJA2: -4.5 [-5.0; -4.0] (57.4) PJA1-PJA3: -18.5 [-19.0; -18.0] (264.2) PJA2-PJA3: -13.5 [-14.0; -13.5] (135.0)	PJA1-PJA2: <0.001** PJA1-PJA3: <0.001** PJA2-PJA3: <0.001**

* Median — the mean value of non-normally distributed parameters;

** values are significant at p < 0.05.

The value of P (98) > 74.2 (threshold value), therefore in this case there was a high risk of PJK development.

Clinical case 2. Patient T., female, suffering from Scheuermann's disease (grade III, painful form) and hyperkyphosis of the thoracic spine (50°).

The patient underwent surgery using hybrid posterior instrumentation. The initial magnitude of thoracic kyphosis (as of January 28, 2016) was 50°; the T1 vertebra tilt in sagittal plane was 32°; and the magnitude of the proximal junctional angle was 4°. Seven days after surgery (February 5, 2016), the thoracic kyphosis magnitude was 18°; the T1 vertebra tilt was 13°; and the proximal junctional angle was 13°. At the end of the follow-up period (February 26, 2018), the magnitude of thoracic kyphosis was 34°; the T1 tilt was 24°; and the proximal junctional angle was 14°. A formula for the multivariate model of logistic regression of PJK was tested with the obtained data.

P(PJK) = 1 - 1/ (1 + exp (-23.14 + 0.26 × T1 + 0.21 × TK));

P = 1 - 1/(1 + exp (-23.14 + 0.26 × 32 + 0.21 × 50)) = 0.013;

P = 0.013 × 100 = 1.31.

The value of P (1.31) < 74.2 (threshold value), therefore in this case there was a low risk of PJK development.

The analysis of the results of the SRS-24 patient questionnaire revealed the following: the evaluation of surgical outcomes increases between the immediate and long-term postoperative periods in all parameters. However, statistically significant changes can be attributed to the evaluation of pain syndrome, postoperative function, general and professional activity (Table 6).

Discussion

The incidence of proximal junctional kyphosis after correction of spinal deformities due to Scheuermann's disease is variable [5, 6]. The causes of the development of this complication, despite numerous theories and proposals, remain unclear. In our opinion, the discussion of the current situation in this rather narrow sphere of spine surgery should be based on the results of studies with significant (more than five years) postoperative follow-up. The earliest of such published papers [7] contains information about 63 patients who were followed up for an average of 14 years (from 10 to 28) after correction by Harrington rods. The initial magnitude of thoracic kyphosis was 73°; at the end of the follow-up period it was 59° (loss of correction was 20°). Patients highly appreciate the achieved outcome; the authors do not provide data on the formation of PJK. In 2009, Denis et al. [8] showed the outcomes of Scheuermann's kyphosis correction in 67 patients with a minimum postoperative follow-up period of 5 years (mean 73 months). The deformity was largely corrected (from 78° to 45°), and the achieved effect was almost completely preserved with only 4° correction loss at the end of the follow-up period. PJK development was observed in 20 (30 %) patients. The authors considered the main reasons for the development of junctional deformity to be the non-inclusion of the proximal end vertebra of thoracic kyphosis in the fusion and injury to the yellow ligament by the proximal laminar hook or sublaminar wire. The initial magnitude of kyphosis and the degree of correction achieved do not matter. Graat et al. [9] reported the surgical outcomes of 29 patients who

Table 2

Dynamics of sagittal parameters of the cervical spine

Parameters	Before surgery*	After surgery*	At the end of the follow-up period*	Differences*	Wilcoxon signed-rank, p value
Cervical lordosis, degrees	11 [6.0; 28.5]	12 [3.0; 23.5]	13 [9.0; 29.5]	CL1-CL2: 3.0 [2.5; 3.5] CL1-CL3: -2.0 [-3.0; -1.5] CL2-CL3: -6.0 [-6.5; -5.5]	CL1-CL2: 0.224 CL1-CL3: 0.472 CL2-CL3: 0.011**
Absolute rotation angle, degrees	18 [7.0; 32.5]	15 [6.0; 24.5]	24 [11.0; 34.0]	ARA1-ARA2: 4.0 [3.5; 4.5] ARA1-ARA3: -4.5 [-5.0; -4.0] ARA2-ARA3: -9.0 [-10.0; -8.0]	ARA1-ARA2: 0.090 ARA1-ARA3: 0.093 ARA2-ARA3: 0.001**
Thoracic inlet angle, degrees	77 [74.0; 83.5]	79 [73.0; 86.0]	78 [71.0; 84.0]	TIA1-TIA2: -1.0 [-1.5; -1.0] TIA1-TIA3: 0.0 [0.0; 0.5] TIA2-TIA3: 0.5 [0.0; 1.0]	TIA1-TIA2: 0.374 TIA1-TIA3: 0.950 TIA2-TIA3: 0.751
Neck tilt, degrees	45 [39.0; 49.5]	49 [43.5; 57.5]	52 [43.0; 54.5]	NT1-NT2: -5.0 [-5.5; -4.5] NT1-NT3: -5.0 [-5.0; -4.5] NT2-NT3: 1.0 [0.5; 1.5]	NT1-NT2: 0.001** NT1-NT3: 0.001** NT2-NT3: 0.331
Cranial tilt, degrees	35 [29.0; 38.5]	33 [28.0; 38.5]	36 [31.0; 40.0]	CRT1-CRT2: 0.5 [0.5; 1.0] CRT1-CRT3: -2.5 [-2.5; -2.0] CRT2-CRT3: -3.0 [-3.5; -3.0]	CRT1-CRT2: 0.564 CRT1-CRT3: 0.075 CRT2-CRT3: 0.011**

* Median — the mean value of non-normally distributed parameters;

** values are significant at p < 0.05.

Table 3
Dynamics of sagittal parameters of the pelvis

Parameters	Before surgery*	After surgery*	At the end of the follow-up period*	Differences*	Wilcoxon signed-rank, p value
Pelvic Incidence, degrees	48 [40.5; 56.0]	46 [41.0; 58.5]	46 [43.0; 54.5]	PI1-PI2: -1.5 [-2.0; -1.0] PI1-PI3: 0.0 [-0.5; 0.5] PI2-PI3: 2.5 [2.0; 3.0]	PI1-PI2: 0.323 PI1-PI3: 0.995 PI2-PI3: 0.122
Pelvic Tilt, degrees	7 [3.5; 10.5]	12 [5.5; 17.5]	7 [4.0; 12.0]	PT1-PT2: -4.5 [-5.0; -4.5] PT1-PT3: -0.5 [-1.0; -0.5] PT2-PT3: 3.5 [3.5; 4.0]	PT1-PT2: <0.001** PT1-PT3: 0.429 PT2-PT3: 0.001**
Sacral Slope, degrees	40 [35.5; 46.0]	34 [29.5; 41.5]	40 [35.0; 48.5]	SS1-SS2: 5.0 [4.5; 5.0] SS1-SS3: 1.0 [0.5; 1.5] SS2-SS3: -4.5 [-4.5; -4.0]	SS1-SS2: <0.001** SS1-SS3: 0.541 SS2-SS3: 0.005**

* Median — the mean value of non-normally distributed parameters;
** values are significant at $p < 0.05$.

Table 4
Logistic regression models of proximal junctional kyphosis in all patients

Covariates	Univariate model		Multivariate model	
	OR [95 % CI]	p	OR [95 % CI]	p
Female	0.06 [0.01; 0.32]	0.002*	0.06 [0.01; 0.32]	0.002*
Male	16.33 [3.10; 130.57]	0.002*		
T1 1	1.19 [1.08; 1.37]	0.005*	1.30 [1.11; 1.71]	0.013*
TIA 1	1.12 [1.04; 1.23]	0.008*		
TK 1	1.12 [1.03; 1.27]	0.023*	1.24 [1.07; 1.61]	0.033*
ARA 1	1.12 [1.03; 1.26]	0.027*		
CL 1	1.28 [1.08; 1.72]	0.035*		
Instrumented spinal fusion T4—L2	0.13 [0.01; 0.90]	0.041*		
CRT 1	1.10 [1.01; 1.22]	0.050		
Instrumented spinal fusion T3—L2	4.95 [0.78; 97.40]	0.152		
SVA 1	0.97 [0.93; 1.01]	0.156		
PJA 1	1.18 [0.97; 1.53]	0.163		
Instrumented spinal fusion T4—L3	0.38 [0.08; 1.87]	0.222		
PI 1	1.04 [0.98; 1.12]	0.232		
PT 1	0.92 [0.79; 1.07]	0.268		
Age	0.95 [0.85; 1.06]	0.317		
LL 1	0.98 [0.92; 1.03]	0.436		
TLK 1	0.98 [0.91; 1.04]	0.460		
Instrumented spinal fusion T3—L3	2.07 [0.30; 41.77]	0.523		
SS 1	1.01 [0.94; 1.11]	0.751		
NT 1	1.00 [0.91; 1.10]	0.980		

* Values are significant at $p < 0.05$.

were followed up for an average of 18 years (14–21) after surgical treatment. The initial deformity magnitude was 82°; at the end of the follow-up period it was 69°; that is, the final corrective effect was minimal. The number of diagnosed PJK increased with the duration of postoperative follow-up: 9 (31 %) during the first year, 12 (43 %) for eight years, and 15 (53 %) at the end of the follow-up period. The authors did not prove the significance of the inclusion of the upper end vertebra in the block area. The results of the survey of patients showed that 72 % of them were satisfied with the treatment outcome and would be ready to undergo it again. The authors emphasize the connection between the

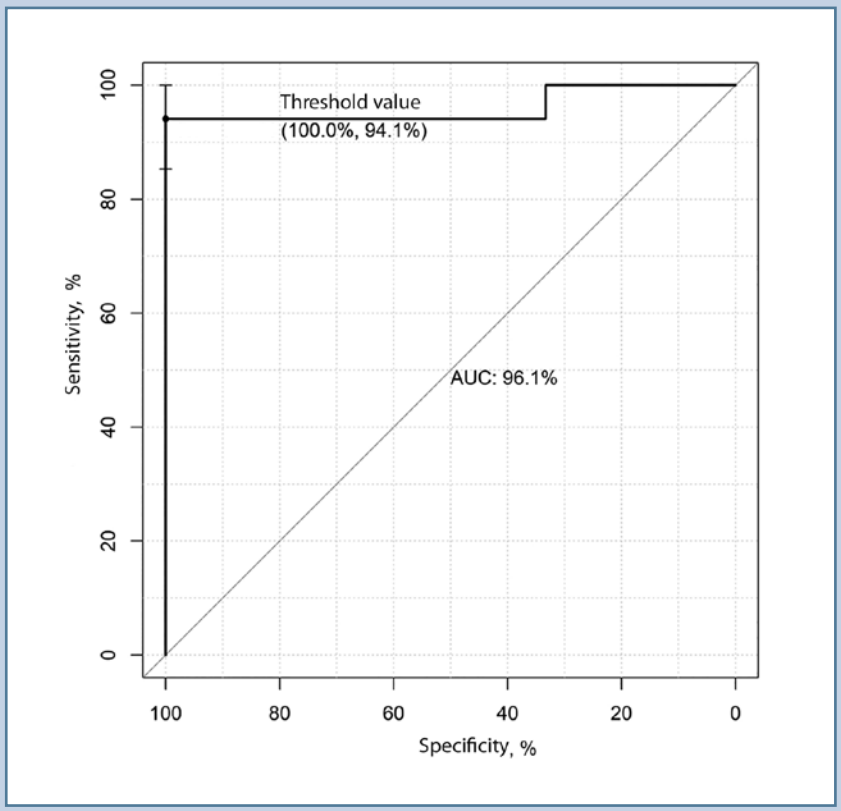

Fig. 1
ROC curve of the multivariate optimal model of proximal junctional kyphosis

Table 5
Conjugacy of the multivariate optimal model of proximal junctional kyphosis in all patients for a threshold value of 74.2 %

Parameters	PJK+ outcome	PJK- outcome	Total
Predicted PJK+	32	0	32
Predicted PJK-	2	9	11
Total	34	9	43

unsatisfactory radiographic findings after surgery and the data of clinical studies. The latter evidences the high vital activity of patients, despite the high incidence of pain syndrome. Hwang et al. [10] performed surgeries on 43 patients with kyphotic deformities, among which 15 suffered from Scheuermann's kyphosis. The mean follow-up period was 5.8 (5.0–9.7) years. The initial deformity magnitude was 91°; immediately after surgery it was 48.1°; the loss of correction was only 1.8°. Proximal junctional kyphosis was diagnosed in 2 out of 15 patients, and the survey data showed a significant improvement in the quality of life in all domains. In 2022, M.V. Mikhaylovskiy et al. [11] presented the deformity correction outcomes of 43 patients with the mean postoperative follow-up of 6.9 (5–20) years. The initial magnitude of thoracic kyphosis was 80.6°, immediately after surgery – 41.4°, and at the end of the follow-up period, it was 47.9°. Proximal junctional kyphosis was diagnosed in 21 (48.8 %) patients, and the inclusion of the upper end vertebra of kyphosis in the spine fusion area reduces the percentage of PJK development just from 60 to 45 %. The degree of kyphosis correction (more or less than 50 %) practically does not influence the incidence of PJK. According to the survey, the assessment of the surgical outcomes is growing in all domains between the immediate and long-term periods after the procedure, from 88.4 to 91.4 points. Meanwhile, the number of patients who would undergo surgery under the same conditions increased from 82 % to 86 %. In 2022, Debnath et al. [12] reported the surgical outcomes of 51 patients with Scheuermann's kyphosis. The mean follow-up period was 14 (10–16) years. Thoracic kyphosis was reduced from 84.4° to 44.0°, the loss of correction was 1.5°. The main question to which the authors attempted to find an answer is whether a two-stage (posteroanterior) procedure has an advantage over a one-stage one. No such advantage was found. Proximal junctional kyphosis was diagnosed in 7 (13.7 %) cases, and only in two cases it was not accompanied with pain. In the remaining five cases patients underwent repeated surgeries. The authors believe that anteroposterior surgeries, inclusion of T1–T3 vertebrae in the area of instrumented spinal fusion, disintegration of the posterior supporting structures of the spine, and excessive distraction of the paraspinal muscles during the cutting approach are risk factors for the development of PJK.

One of the world's leading vertebrologists, Dubousset, distinguishes two groups of factors for the development of PJK: mechanical and biological. Mechanical ones include destruction of posterior soft tissue structures, weakness of posterior instrumentation "for pulling out", reduction of resistance of bone tissue of vertebral bodies to compression loads due to osteoporosis, instability of UIV, smoothed thoracic kyphosis, and smoothd or increasd lumbar lordosis. Biological reasons include a grow-

Fig. 2
Radiographs of patient D., male, 14 years old, with Scheuermann's disease: **a** – before surgery; **b** – 8 days after surgery; **c** – at the end of the follow-up period

ing decrease in muscle strength with age, neurological disorders because of neuromuscular pathology, and bone metabolic pathology [13].

Disagreement on the factors for the development of PJK associated with a variety of more or less convincing assumptions may indicate in favor of the polyetiology of this condition. We made an attempt to approach the solution of the problem by examining the sagittal status of the vertebral column throughout its entire length with the inclusion of the head and pelvis, which Dubousset [13] determines as the cranial and pelvic vertebrae. We used 14 parameters characterizing the sagittal contour of the vertebral column from C-0 to S-1 and added this list (gender of the patient, the length of the area of instrumented spinal fusion, and the level of the deformity apex). According to the literature sources, this approach has not been used by anyone before in the study of the factors for the development of PJK.

In the group of patients with long-term postoperative follow-up, the incidence of proximal junctional kyphosis was 79.1 %. In most cases, the course was asymptomatic and did not require repeated surgeries. The initial magnitude of the proximal junctional angle showed no correlation with PJA after surgery, as well as with the value of the angle at the end of the follow-up. According to our data, such a predictor as female sex is associated with a 0.06-fold reduced risk of developing PJK. Meanwhile, in men, on the contrary, the risk of developing PJK are much higher – by 16.3 ($p = 0.002$) times. The extent of the posterior spinal fusion within the T4–L2 vertebrae had the weakest association with the development of PJK ($p = 0.041$). There was no statistically significant correlation between PJK and the length of posterior spinal fusion in the other variants considered, namely T3–L2, T4–L3 and T3–L3. The magnitude of preoperative kyphotic deformity in the thoracic spine ($p = 0.023$) is associated with the risk of PJK development: the greater the kyphosis in the thoracic spine before surgery, the higher the risk of PJK development by the end of follow-up. The correction degree of thoracic kyphosis after surgery was close to 50% of the initial one and was not a risk factor in the development of PJK. The magnitude of the inclination of the T1 vertebral body in the sagittal plane was also distinctly

Table 6
Results of studying the quality of life using the SRS-24 questionnaire, points

Domain	Early postoperative period	Late postoperative period	p value
Pain	3.71 ± 0.53	3.79 ± 0.49	0.009
General self-image	3.94 ± 0.56	4.10 ± 0.57	0.072
Postoperative self-image	4.40 ± 0.47	4.44 ± 0.41	0.062
Postoperative function	2.01 ± 1.15	2.34 ± 1.41	0.030
General activity	3.07 ± 0.73	3.24 ± 0.81	0.041
Professional activity	3.47 ± 0.73	3.52 ± 0.71	0.036
Satisfaction with the result of the surgery	4.43 ± 0.52	4.47 ± 0.54	0.057
Consent to surgical treatment under the same conditions	82 %	86 %	–
Total	88.3	91.2	0.058

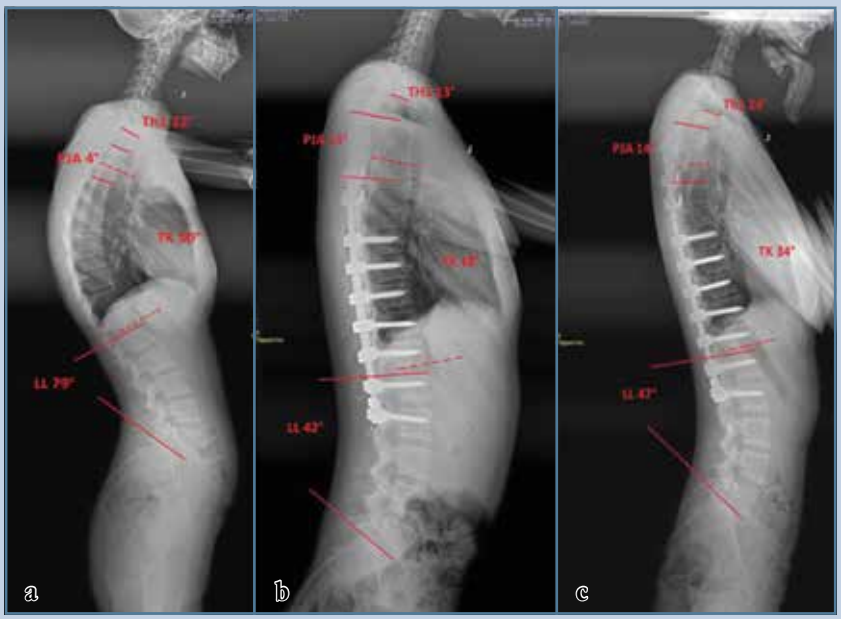

Fig. 3
Radiographs of patient T., female, with Scheuermann's disease: **a** – before surgery; **b** – 7 days after surgery; **c** – at the end of the follow-up period

correlated with the development of PJK ($p = 0.005$).

The thoracic inlet angle ($p = 0.008$), the absolute rotation angle ($p = 0.027$), and the magnitude of cervical lordosis ($p = 0.035$) were also associated with the development of PJK. The considered sagittal pelvic parameters, PI ($p = 0.232$), PT ($p = 0.268$) and SS ($p = 0.751$), were not associated with the development of PJK, as in many literature sources on this issue. According to the clinical examination findings (SRS-24 questionnaire), our patients showed improvement in all parameters; their consent to surgery under the same conditions increased from 82 % to 86 %. These data are consistent with the outcomes published by Graat et al. [8], who noted a clear disconformity between the degree of patient satisfaction with the treatment outcomes and the radiological findings in the long-term postoperative period (significant loss of correction, high percentage of PJK development). New studies should be conducted in order to clarify the multitopic issue under discussion.

Limitations of the study

The main limitation is the relatively small size of the group of examined patients. This is due to the requirement to include patients with the longest possible postoperative follow-up in the study. Since the hospital uses the protocol considering periodic follow-up medical care for three years, this situation is quite understandable. The use of the proposed formula of the multivariate model in other hospitals and the aggregate estimate of this study may prove its functionality and thereby significantly improve the quality of preoperative planning in patients with severe kyphosis associated with Scheuermann's disease.

Conclusion

Using the multivariate logistic regression method, two mutually independent multiplicative indicators were determined for predicting PJK with high accuracy (sensitivity 94.1 %, specificity 100.0 %) – inclination of the T1 vertebral body and initial magnitude of the thoracic kyphosis. The use of these variables in the multivariate model of logistic regression of PJK promotes the prediction of the probability of this complication development at the preoperative stage.

The study had no sponsors.
The authors declare that they have no conflict of interest.
The study was approved by the local ethics committee of the institution.
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