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Analysis of preoperative risk factors of adjacent segment disease after transforaminal lumbar interbody fusion

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ABSTRACT

Currently, there is no information on the combined effect of body mass index (BMI), age, gender, main spinal-pelvic parameters and parameters of adjacent functional spinal unit (FSU) degeneration according to magnetic resonance imaging on development of adjacent segment degenerative disease (ASDd).

Objective. To evaluate the effect of preoperative biometric and instrumental parameters of adjacent FSU on the risk of ASDd after transforaminal lumbar interbody fusion and determine personalized neurosurgical approach.

Material and methods. We retrospectively studied patients after single-level transforaminal lumbar interbody fusion (group I, *n*=54), single-level transforaminal lumbar interbody fusion and interspinous stabilization of adjacent level (group II, *n*=55), preventive rigid fusion of adjacent segment (group III, *n*=56). Preoperative parameters and long-term clinical outcomes were assessed.

Results. Paired correlation analysis established the main predictors of ASDd. Regression analysis determined absolute values of these predictors for each type of surgical intervention.

Conclusion. Surgical intervention at the level of asymptomatic proximal adjacent segment is recommended as interspinous stabilization for moderate degenerative lesions, BMI <25 kg/m^2, difference between pelvic index and lumbar lordosis 10.5—15°, segmental lordosis 6.5—10.5°. In case of severe degenerative lesions, BMI 25.1—31.1 kg/m^2, significant deviations of spinal-pelvic parameters (segmental lordosis 5.5—10.5°, difference between pelvic index and lumbar lordosis 15.2—20°), preventive rigid stabilization is indicated.

Keywords: *lumbosacral spine, degenerative disease, posterior lumbar fixation, adjacent segment disease, prognosis, risk factors.*

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Abbreviations

VAS — visual analogue scale
DDSS — dorsal decompression-stabilization surgery
DSD — degenerative spine disease
ASD — adjacent segment disease
FJ — facet joint
ADC — apparent diffusion coefficient
IVD — intervertebral disc
ISS — interspinous stabilization
FSU — functional spinal unit
GLL — global lumbar lordosis
LL — lumbar lordosis
MCS — mental component score
ODI — Oswestry disability index
O-TLIF — open transforaminal lumbar interbody fusion
PCS — physical component score
PI — pelvic incidence
PI-LL — difference between pelvic incidence and lumbar lordosis

Introduction

Dorsal decompression-stabilization surgery is effective for degenerative spine disease accompanied by functional spinal unit instability and acquired deformities requiring correction of spinal-pelvic balance [1]. The pur-

pose of DDSS is neural decompression with interbody fusion [2]. Increased load on adjacent FSU followed by significant degeneration is a frequent complication of DDSS (adjacent segment disease) [3].

Interspinous stabilizers were developed to reduce the incidence of ASD after DDSS [1, 4, 5]. Despite their diversity, indications are still controversial [6—8]. The choice of surgical correction of adjacent "asymptomatic" level with signs of mild degeneration is ambiguous [7, 9].

Modern studies describe the results of simultaneous ISS and DDSS in patients with degenerative spine disease [8, 10, 11], as well as preventive rigid stabilization of adjacent segment [12, 13]. Unclear data on the effect of body mass index (BMI), age, gender, basic vertebral-pelvic parameters and indicators of adjacent FSU degeneration on the incidence of DDSS inspired this analysis.

The purpose of the study was to evaluate the effect of preoperative biometric and instrumental parameters of adjacent FSU on the risk of ASD after transforaminal lumbar interbody fusion and determine a personalized neurosurgical approach.

Material and methods

A retrospective study included medical records from own register of DSD patients who underwent interbody fusion and transpedicular fixation for the following indications: 1) drug-resistant long-term or recurrent pain syndrome, persistent neurological deterioration; 2) X-ray signs of instability at the level of symptomatic FSU: vertebral displacement > 15%, dynamic instability with vertebral displacement by more than 4.5 mm, FSU hypermobility with angular deformity more than 20° at the L_{IV}-L_V level and more than 25° at the L_V—S_I level according to functional spondylography data [14]. According to inclusion criteria, we analyzed 165 patients who underwent primary DDSS for L_{IV}—S_I disease. There were 3 groups: group I (n=54) — single-level DDSS, group II (n=55) — single-level DDSS with ISS of adjacent FSU, group III (n=56) — preventive rigid stabilization of adjacent FSU. The median follow-up was 36 (28; 42) months.

All interventions were performed through open median approach with transforaminal interbody fusion and transpedicular fixation (O-TLIF). U-shaped implants were used for ISS of adjacent FSU.

We excluded patients with infectious diseases, traumas, tumors, severe comorbidities, signs of distal ASD, pain syndrome recurrence not associated with proximal ASD (implant malposition, cicatricial adhesive epiduritis, neuropathic pain syndrome, etc.). Moreover, we excluded patients with interbody block due to severe degeneration of symptomatic FSU who required decompression without interbody fusion.

We assessed general data (gender, age, BMI, bone mineral density (BMD/T-criterion)), duration of disease between clinical debut and surgery (months) and X-ray data (GLL, PI, segmental angle of lumbar lordosis (LL) of adjacent proximal FSU). MR characteristics of adjacent FSU included IVD degeneration according to classification by Pfirrmann S. (MR-assessment of signal intensity on T2WI), differentiation of nucleus pulposus and annulus fibrosus, vertical size of IVD, its ADC, FJ degeneration according to classification of spondylarthrosis by Fujiwara A. (signal intensity on T1-T2-weighted images and presence/absence of hypertrophic enlargement of facet joint). We analyzed the following clinical outcomes: Oswestry Disability Index (ODI), SF-36 parameters (PCS, MCS), VAS score of pain syndrome in the lumbar spine and lower extremities. Incidence and forms of ASD were analyzed.

We estimated diagnostic data and clinical outcomes in preoperative long-term postoperative period, respectively. Statistical analysis was carried out using Microsoft Office Excel (Microsoft, Inc., USA) and Statistica-13.5 (StatSoft, Inc., USA) software.

Distribution normality was analyzed using the Shapiro—Wilk (pW), Kolmogorov—Smirnov (pD), Cramer von Mises (pW—sg) and Anderson—Darling (pA—Sq) tests. We analyzed contingency tables to establish the mutual influence of qualitative variables. Correlation between variables was tested using Spearman/Pearson correlation coefficients. To analyze the relationship between qualitative variables as dependent indicators and subset of quantitative parameters, we used logistic regression model with stepwise algorithms for including and excluding predictors. Ranking of predictors depending on their correlation with dependent variable was carried out by sorting of appropriate modules of standardized regression coefficients. To assess the quality of predictive model, we analyzed diagnostic sensitivity, specificity and efficiency using ROC analysis.

Results

All groups did not differ in sex, age, bone mineral density and duration of disease (p_W=0.2829) (p_D=0.1500) (p_{W-sg}=0.2500) (p_{A-Sq}=0.2500). BMI >30 kg/m^2 prevailed in group III (p_W, p_D, p_{W-sg}, p_{A-Sq}<0.001) **(Fig. 1 a—d)**.

According to χ2-test and Mantel-Haenszel χ2-test, adjacent IVD degeneration Pfirrmann grade I/II correlated with adjacent FJ degeneration Fujiwara grade I (p<0.001), Pfirrmann grade III with Fujwara grade II (p<0.001), Pfirrmann grade IV with Fujiwara grade III (p<0.001), Pfirrmann grade V with Fujiwara grade IV (p<0.001). Analyzing contingency, we found the relationship between adjacent IVD degeneration Pfirrmann grade I/II and single-level DDSS (group I) (p<0.001), Pfirrmann grade III with simultaneous DDSS and ISS (group II) (p<0.001), Pfirrmann grade IV/V with two-level DDSS (group III) (p<0.001).

DSD rate in this study was 9% (n=14). The main form of DSD was spinal stenosis following herniation, spondylarthrosis and pseudospondylolisthesis.

Analyzing quantitative and qualitative variables in all patients, we found significant correlation between clinical and biometric parameters, as well as risk of ASD with preoperative characteristics of adjacent level **(Table 1, 2)**.

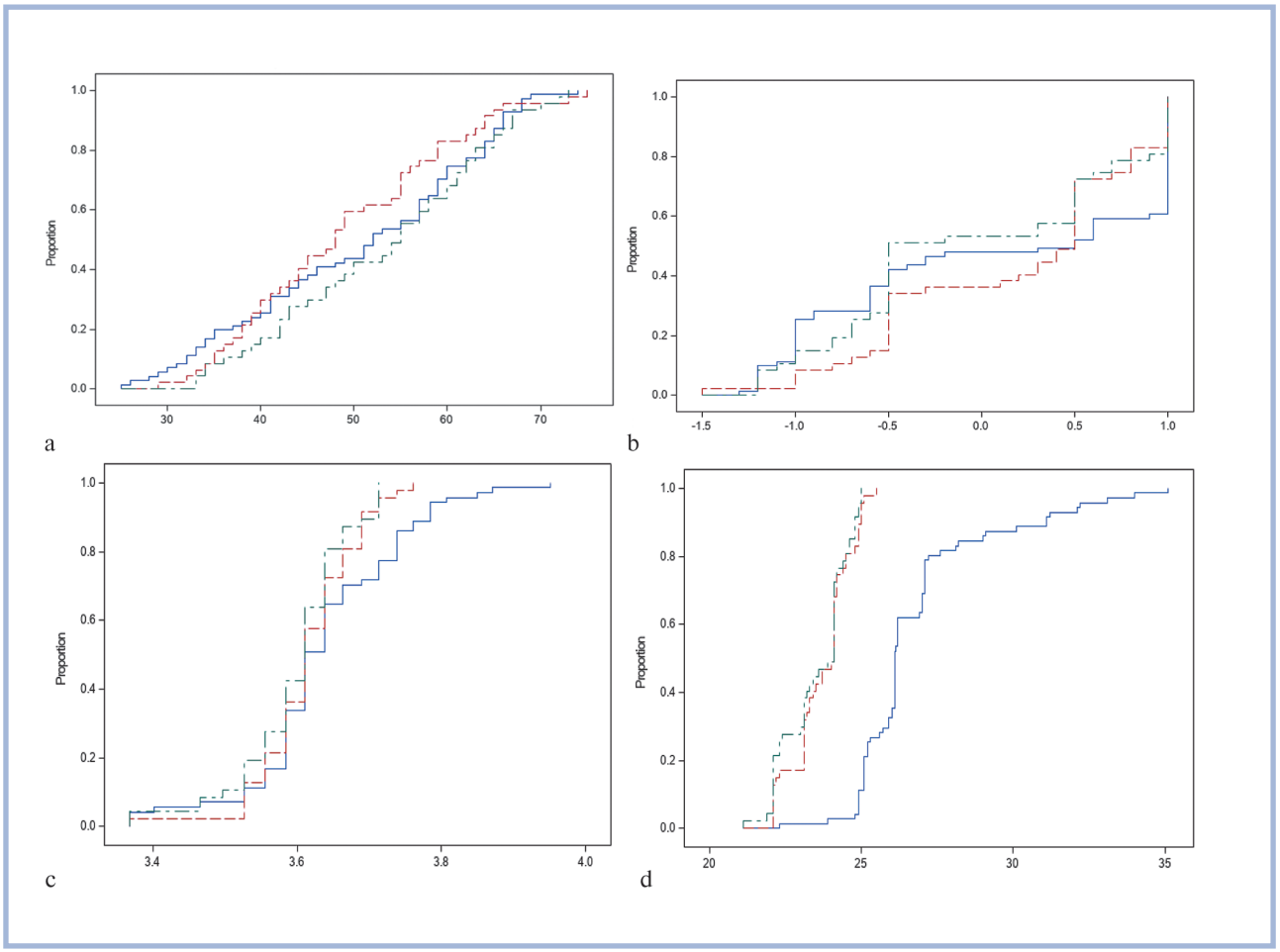

Fig. 1. **Distribution of variables.**
a — age; b — bone mineral density; c — duration of disease; d — body mass index. I group; II group; III group.

Table 1. **Correlation of preoperative parameters with ODI**

Variable	I group (*n*=54)		II group (*n*=55)		III group (*n*=56)	
	r	*p*	r	*p*	r	*p*
VAS — lumbar spine/36months	0.97246	0.0001	0.89256	0.0001	0.91347	0.0001
VAS — lower extremities/36months	0.97809	0.0001	0.79806	0.0001	0.81706	0.0001
SF —36MCS	–0.77438	0.0001	–0.67518	0.0001	–0.75518	0.0001
SF —36PCS	–0.78276	0.0001	–0.78276	0.0001	–0.69321	0.0001
GLL (LI—SI)	–0.11312	0.3372	–0.22115	0.2341	–0.19815	0.1121
Segmental LL of adjacent FSU	–0.39463	0.0061	–0.49153	0.0052	–0.38243	0.0032
PI	0.36093	0.0127	0.38021	0.0121	0.40032	0.0251
PI/LL	0.31438	0.0314	0.40348	0.0421	0.41128	0.0312
FJ of adjacent segment (Fujiwara grading system)	0.91983	0.0001	0.87683	0.0001	0.81623	0.0001
IVD of adjacent segment (Pfirrmann grading system)	0.99932	0.0001	0.93641	0.0001	0.91541	0.0001
ADC of adjacent IVD	–0.91134	0.0001	–0.91134	0.0001	–0.89113	0.0001
BMI (kg/m^2)	0.32745	0.0247	0.41646	0.0321	0.52546	0.0231
BMD/(T-test)	–0.04711	0.7532	–0.08530	0.1648	–0.20597	0.4629
Age	0.14312	0.3372	0.04318	0.7732	0.16345	0.2723
Sex	0.16345	0.2723	0.10730	0.4728	0.06870	0.6463

Note: here and in Table 2, 3, 4VAS — visual analogue scale; SF — social functioning; MCS — mental component score; GLL — global lumbar lordosis; PI/LL — difference between pelvic incidence and lumbar lordosis; FJ — facet joint; FSU — functional spinal unit; IVD — intervertebral disc; ADC — apparent diffusion coefficient; BMD — bone mineral density.

Table 2. **Correlation of adjacent segment disease with preoperative characteristics of adjacent level**

Variable	*n*=165	
	r	*p*
GLL (L_I—S_I)	–0.18105	0.3411
Segmental LL of adjacent FSU	–0.48551	0.0061
PI	0.56400	0.0215
PI/LL	0.51645	0.0421
FJ of adjacent segment (Fujiwara grading system)	0.91983	0.0001
IVD of adjacent segment (Pfirrmann grading system)	1.00000	0.0001
ADC of adjacent IVD	–0.91134	0.0001
BMI (kg/m^2)	0.35852	0.0135
BMD/(T-test)	–0.04711	0.7532
Age	0.25095	0.3372
Sex	0.16345	0.2723

Table 3. **Predictors and coefficients of logit regression equation for predicting clinical outcome after DDSS**

Variable	Regression coefficient	Wald test	*p*	Standardized regression coefficient
VAS — lumbar spine/36 months	0.1126	65.734	0.0001	0.467831
VAS — lower extremities/36 months	0.5300	56.432	0.0001	0.345532
SF —36 MCS	–0.6438	9.658	0.0003	–0.155183
SF —36 PCS	–0.5826	7.878	0.0001	–0.193212
Segmental LL of adjacent FSU	–0.5943	24.953	0.0042	–0.428343
PI	0.4783	8.801	0.1321	0.410032
PI/LL	0.1438	24.448	0.0121	0.421128
FJ of adjacent segment (Fujiwara grading system)	0.1983	22.883	0.0001	0.821223
IVD of adjacent segment (Pfirrmann grading system)	1.5932	18.941	0.0001	0.291541
ADC of adjacent IVD	–0.0134	10.134	0.0001	–0.179213
BMI (kg/m^2)	0.3245	23.646	0.0021	0.551446

Note: regression coefficient — weighted value for each predictor in the model; standard error — error of weighted values; Wald test is based on data for comparison with $\chi 2$ distribution with one degree of freedom.

Differential choice of surgical approach depended on qualitative and quantitative binary variables. Data characterizing clinical outcomes were presented in two gradations (satisfactory and unsatisfactory) after 36 postoperative months. The first ones included clinical outcomes without signs of ASD, VAS score of lumbar pain < 15 mm, leg pain < 10 mm, ODI < 20%, PCS > 40 points, MCS > 40 points. Unsatisfactory outcomes included ASD, VAS score of lumbar pain > 15 mm, leg pain > 10 mm, ODI > 20%, PCS < 40 points, MCS < 40 points. Preoperative quantitative and qualitative parameters with the highest correlation coefficient and the lowest p value were selected as predictors.

We analyzed binary logistic regression equations. Among 100 logit regression equations, we chose one formula with the highest agreement rate (concordance 92.7; Somers' D coefficient 0.87; Hosmer-Lemeshow test $\chi 2$=2.08; *p*=0.0001). Predictors included in equation, coefficients and regression results are presented in **Table 3, 4**.

Regression analysis established the main predictors of ASD with their absolute values. Clinical significance of predictors for long-term clinical outcomes after DDSS was confirmed by ROC analysis **(Table 3, 4, Fig. 2)**.

When studying spinal-pelvic relations, we established the influence of only PI-LL on long-term clinical outcomes.

The following statements were established.

1. Single-level DDSS provided favorable results in patients with the following parameters: PI-LL 4.8—10°, segmental LL of adjacent FSU 10.5—15°, lesion of adjacent IVD Pfirrmann grade I—II and its ADC 1250—1450 mm^2/s , FJ degeneration Fujiwara grade I, BMI <25 kg/m^2.

2. Simultaneous DDSS and ISS provided favorable results in patients with following parameters: PI-LL 10.5—15°, segmental LL of adjacent FSU 6.5—10.5°, lesion of adjacent IVD Pfirrmann grade II—III and its ADC 1050—1220 mm^2/sec, FJ degeneration Fujiwara grade I—II, BMI <25 kg/m^2.

3. Preventive rigid stabilization of adjacent FSU provided favorable results in patients with the following parameters: lesion of adjacent IVD Pfirrmann grade IV-V and its ADC 850—1050 mm2/sec, FJ degeneration Fujiwara grade III-IV, segmental LL of adjacent FSU 5.5—10.5°, PI-LL 15.2—20°, BMI 25.1—31.1 kg/m^2.

Table 4. **Results of stepwise regression in selection of variables**

Variable	Wald test	Percentage of correct prediction (%)	*p*
VAS — lumbar spine/36 months	75.7242	75.8	0.0001
VAS — lower extremities/36 months	64.4424	81.4	0.0001
SF —36 MCS	14.5685	82.3	0.0003
SF —36 PCS	17.6584	90.1	0.0001
Segmental LL of adjacent FSU	14.9534	91.1	0.0042
PI	8.7013	92.1	0.0621
PI/LL	14.4568	90.2	0.0121
FJ of adjacent segment (Fujiwara grading system)	12.8683	89.1	0.0001
IVD of adjacent segment (Pfirrmann grading system)	21.9441	88.1	0.0001
ADC of adjacent IVD	12.1354	87.1	0.0001
BMI (kg/m^2)	24.5676	86.2	0.0021

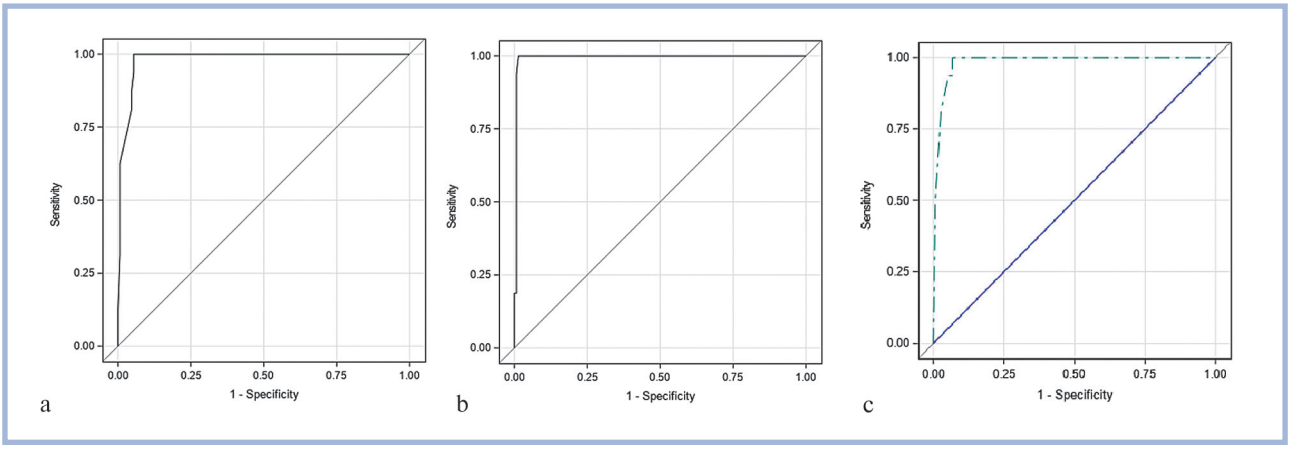

Fig. 2. **ROC curves of effectiveness of the model for predicting long-term clinical outcomes.**
a — MR signs: Pfirrmann grade of adjacent intervertebral disc degeneration; b — X-ray signs: PI-LL; c — biometric parameters: body mass index.

Discussion

ASD makes up 5.2—18.5% [1, 4, 12]. It is the main factor of poor outcomes and redo surgeries in long-term period [13, 15]. The main risk factors and causes of ASD are overweight, disorders of vertebral-pelvic relations and baseline asymptomatic degeneration of adjacent FSU [9, 11].

High BMI is a significant risk factor of ASD after DDSS. For example, Symmons D.P. et al. [4] emphasized overweight as a significant predictor of IVD degeneration. Wang H. et al. [15] and Imagama S. et al. [6] obtained similar data.

Analysis of spinal-pelvic relations (PI-LL) is the main method for assessing compensatory resources of the spine [16]. Senteler M. et al. [17] found that increased PI-LL causes FJ overload at the LIII—SI level. PI-LL >12 is a sign of latent spinal deformity and cause of instability of adjacent FSU after DDSS [1].

Various surgical approaches are proposed depending on preoperative parameters of adjacent segment [11—13]. Wang H. et al. [15] found no risk of ASD in patients with degeneration of adjacent IVD Pfirrmann grade <II (mean follow-up 48 months). Konev V.P. et al. [18] found enough cartilage tissue cells in IVD with signs of degeneration Pfirrmann grade < II that indicated intact functionality of FSU and low risk of DDSS. Analyzing moderate baseline degeneration of adjacent segment, Bredow J. et al. [19] found that ISS for prevention of ASD could significantly improve long-term postoperative outcomes. Korovessis P. et al. [10] confirmed these data. Indeed, ISS of adjacent segment with Wallis implant (Abbott Spine, France) reduces the risk of ASD in patients with FJ degeneration Fujiwara grade ⩽ III.

There are few reports devoted to surgical approach for adjacent segment with baseline severe degeneration. Anandjiwala J. et al. [12] found that degeneration Pfirrmann grade IV-V is a direct risk factor of ASD. They proposed primary preventive rigid stabilization of adjacent segment. Zhang X. et al. [11] noted that ISS is ineffective for prevention of ASD in patients with IVD degeneration Pfirrmann grade III-IV and spinal stenosis. In their opinion, spinal fusion is more advisable.

ASD is a multifactorial disease [1, 12, 16, 19]. These studies on prediction of ASD are based on analysis of one of the risk factors. We studied preoperative biometric and instrumental parameters, as well as their influence on development of ASD.

High incidence of ASD (9%) was due to baseline selection bias since inclusion criteria were based on subjective assessment of preoperative parameters. Thus, assessing baseline degeneration and choosing surgical tactics through a comprehensive analysis of instrumental parameters is an effective method for predicting long-term clinical outcomes.

Study limitations: no preoperative percutaneous diagnostic methods for adjacent IVD and FJ verifying silent symptoms and morphological changes [20], retrospective design, no randomization and analysis of outcomes in mid-term follow-up period.

Conclusion

Comprehensive analysis of preoperative parameters of asymptomatic adjacent segment is valuable to determine surgical strategy ensuring the best long-term clinical outcomes.

1) No surgery is required for mild degeneration and no changes in spinal-pelvic parameters.

2) ISS is advisable for moderate degeneration, BMI <25 kg/m^2, PI-LL 10.5—15°, segmental lordosis 6.5—10.5°.

3) Preventive rigid stabilization of adjacent proximal segment is required for severe degeneration, BMI 25.1—31.1 kg/m^2, significant deviations of vertebral and pelvic parameters (segmental lordosis 5.5—10.5°, PI-LL 15.2—20°).

To objectify these data, we need for further prospective studies with analysis of long-term clinical outcomes among patients with homogeneous preoperative clinical and biometric parameters.

Author contribution:
Concept and design of the study — Byvaltsev V.A., Spiridonov A.V.
Collection and analysis of data — Byvaltsev V.A., Kalinin A.A., Pestryakov Yu.Ya., Spiridonov A.V.
Writing the text — Byvaltsev V.A., Kalinin A.A., Pestryakov Yu.Ya., Spiridonov A.V.
Editing — Byvaltsev V.A., Kalinin A.A.

No conflict of interests to declare.

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COMMENT

These data complement our information about preoperative risk factors of ASD. Of course, surgery does not affect the causes of disease proceeding as usual after surgery. It is especially true if the patient does not slow down disease with exercises, strengthening the back muscles, reducing adverse loads on the spinal column. Probably, adjacent segments have significant percentage of degenerative lesion prior to surgery, and establishing the indications for correction is a matter of time and diligence of the patient.

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