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Prognostic modeling of long-term outcomes after minimally invasive lumbar fusion based on complex clinical, radiological and neuroimaging analysis in employees of JSC «Russian Railways»

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ABSTRACT
The incidence of unsatisfactory postoperative outcomes after treatment of degenerative lumbosacral spine diseases depends on surgical method. Their prediction is difficult due to heterogeneity of clinical and instrumental characteristics of patient groups. Development of predictive models of clinical outcomes may be useful for decision making and favorable postoperative outcomes.
Objective. To develop and validate the effectiveness of multivariate predictive model for assessing the risks and benefits of minimally invasive lumbar fusion in railway workers with degenerative lumbar spine diseases.
Material and methods. We retrospectively analyzed prospective database consisting of 457 patients. They underwent minimally invasive lumbar fusion between 2020 and 2023. Comprehensive clinical, radiological and neuroimaging assessments were performed before surgery and 24 months later. Regression analysis was used to create prognostic models of long-term clinical outcomes (y_0 — ODI; y_1 — SF-36 PCS (physical component score); y_2 — SF-36 MCS (mental component score); y_3 — Macnab scale).
Results. All clinical parameters (ODI, VAS, SF-36) significantly improved after surgery compared to preoperative values ($p<0.01$). Within 90 days after surgery, redo surgery rate was 5.7%, and the number of readmissions throughout the entire follow-up period — 8.3%. About 87.3% of railway workers returned to previous work. Clinical deterioration was observed in 51 (11.2%) patients. Preoperative variables predict long-term clinical outcomes. Their role and dominance depend on prognostic model.
Conclusion. Predictive models may be valuable to improve long-term outcomes when planning minimally invasive lumbar spine fusion.

Keywords: *lumbar spine, degenerative diseases, railway workers, interbody fusion, minimally invasive interventions, long-term results, predictive modeling.*

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Abbreviations

VAS — visual analogue scale
ADC — apparent diffusion coefficient
BMI — body mass index
CT — computed tomography
ALIF — anterior lumbar interbody fusion
ASA — American Society of Anesthesiologists
DLIF — direct lumbar interbody fusion
MCS — mental component score
ODI — Oswestry disability index
PCS — physical component score
TLIF — transforaminal lumbar interbody fusion

Introduction

Degenerative spine lesions are associated with concomitant influence of genetic, anthropometric and traumatic factors, as well as natural involution [1]. Vari-

ous methods of percutaneous, decompression, decompression-dynamic and decompression-fusion surgeries are selected at different stages of pathomorphological degenerative cascade [2]. The choice of surgical method, surgical approach and the need for implant placement largely depends on clinical experience and manual skills of surgeons [3].

Lumbar interbody fusion is standard surgical treatment for most degenerative lumbar spine diseases [4]. Despite widespread nature of this technique, there is a high percentage of unsatisfactory outcomes [5]. This is often associated with adjacent segment degeneration, pseudoarthrosis or structural instability and requires redo surgery [6].

Long-term optimal functional status, high quality of life, preservation and return to previous work within the shortest possible time are criteria of proper surgical approach in patients with degenerative lumbar spine disease [7]. Diverse morphological forms of disease, clinical manifestations and examination data complicate unification of treatment and diagnostic approach for similar clinical groups of patients [8].

Methodology aimed at optimizing postoperative outcomes in patients with degenerative lumbar spine disease is based on identification of similar patient groups according to biometric and clinical characteristics. This will allow for objective assessment of indications for surgical technologies and minimizing the risk of potential perioperative complications in certain group of patients [9—11]. At the same time, preoperative clinical and instrumental criteria influencing favorable postoperative outcomes are still unclear.

No data on prognostic modeling of outcomes after minimally invasive lumbar interbody fusion inspired this study.

The purpose of the study was to develop and validate a multivariate prognostic model for assessing the risks and benefits of minimally invasive interbody fusion in railway workers with degenerative lumbar spine diseases.

Material and methods

The study included 457 patients with degenerative lumbar spine disease (employees of JSC Russian Railways) who were prospectively followed for 3 postoperative years. Study design involved preoperative data including assessment of physical and mental status, quality of life, general health, psychological and social-occupational factors, as well as results of instrumental examinations. This allowed us to compile preoperative patient profiles.

Inclusion criteria:
— single-level LIII-SI degenerative disease;
— back pain radiating to the lower extremities resistant to therapy for 8—12 weeks;
— X-ray signs of segmental instability [12];
— no previous lumbar spine surgery.

Exclusion criteria:
— multiple-level degenerative disease;
— osteoporosis (T-score ⩽ -2.5 SD according to dual-energy X-ray absorptiometry);
— traumatic, inflammatory, and neoplastic lumbar spine lesions.

Methodology

All patients who underwent elective minimally invasive interbody fusion between 2020 and 2023 were consecutively included in prospective single-center registry. We collected data prior to surgery and 24 months after surgery. We reviewed electronic medical records to collect patient information (gender, age, height, weight), as well as clinical data, including duration of symptoms, employment status, and neurological symptoms. Survey included back and lower extremity pain (VAS), functional status (ODI), SF-36 scores (physical and mental health component scores), and patient satisfaction with surgery (Macnab scale). Instrumental data included (1) radiographic parameters (lumbar lordosis (°), sagittal angle (°), linear displacement (mm)); (2) CT parameters (interbody space height (mm)); MR parameters (disc degeneration according to C. Pfirrmann, facet joint degeneration according to A. Fujiwara, facet angle (°), presence of facet joint tropism, ADC (mm^2/s)).

Model development

We used regression models to characterize patients who underwent minimally invasive lumbar interbody fusion. Linear regression model was considered:

$$y_k=\alpha_0+\Sigma_{i=1}^{m}\alpha_i x_{ki}+\varepsilon_k,\ \ k=\overline{1,n},$$

where y — dependent (output) variable, $\bar{x}_i$ — ith independent (input) variable, x_i — ith parameter to be estimated, ε_k — approximation error, k — case number, n — sample size.

We used predictive model of 3 categorical clinical outcome variables (ODI, SF-36, Macnab) based on regression mathematical modeling:

y_0 — postoperative outcome according to ODI;
y_1 — postoperative outcome according to SF-36 PCS;
y_2 — postoperative outcome according to SF-36 MCS;
y_3 — postoperative outcome according to Macnab scale.

Among multiple preoperative patient factors, independent variables included parameters significant in predicting the outcome of minimally invasive lumbar fusion according to regression models:

x_1 — age, year;
x_2 — body mass index, kg/m^2;
x_3 — duration of symptoms, months;

x_4 — presence of motor deficit;
x_5 — preoperative back pain, mm;
x_6 — preoperative lower extremity pain, mm;
x_7 — preoperative PCS;
x_8 — preoperative MCS;
x_9 — preoperative ODI;
x_{10} — postoperative back pain, mm;
x_{11} — postoperative lower extremity pain, mm;
x_{12} — preoperative interbody space height, mm;
x_{13} — preoperative sagittal angle, °;
x_{14} — preoperative lumbar lordosis, °;
x_{15} — preoperative linear translation, mm;
x_{16} — preoperative Pfirrmann grade of disc degeneration;
x_{17} — preoperative Fujiwara grade of unilateral facet joint degeneration;
x_{18} — preoperative disc ADC, mm²/s;
x_{19} — preoperative facet joint angle, °;
x_{20} — facet joint tropism before surgery.

We estimated influence of each independent variable on the output indicator considering factor contributions in analyzed models.

For the models, these contributionsa_i — $\delta(x_i)$ were calculated using the formula:

$$\delta(x_i)=\frac{|\alpha_i+\bar{x}_i|}{H},$$

where a_i — value of parameter, $\bar{x}_i$ — mean value of the variable in sample x_i, i.e.

$$\bar{x}_i=\frac{\Sigma_{k=1}^{457}x_{ki}}{457},\ H=\Sigma_{i=1}^{m}|\alpha_i+\bar{x}_i|.$$

Model validation

The least absolute deviation method, based on solving a linear programming problem, was used for mathematical models.

$$J_1(\alpha)=\sum_{k=1}^{n}|\varepsilon_k|.$$

Approximation error (E) was used to assess model accuracy. Assessment of adequate model implies error <20% that is standard practice in predictive modeling. Statistical analysis implied significance at $p<0.05$.

For internal validation, the entire group (n=457) was divided into two subgroups: larger (training) group

Table 1. **Patient characteristics.**

Variable	Value (n=457)
Age, years	41 (35;53)
BMI, kg/m²	24 (22;26)
Gender	
Male, *n* (%)	358 (78.3)
Female, *n* (%)	99 (21.7)
Smoking, *n* (%)	98 (21.4)
ASA	
1, *n* (%)	99 (21.7)
2, *n* (%)	228 (49.9)
3, *n* (%)	107 (23.4)
4, *n* (%)	23 (5)
Duration of symptoms	
<3 months, *n* (%)	39 (8.5)
3—12 months, *n* (%)	171 (37.4)
>12 months, *n* (%)	247 (54.1)
Comorbidities	
Type II diabetes mellitus, *n* (%)	32 (7)
Arterial hypertension, *n* (%)	41 (8.9)
Chronic obstructive pulmonary disease, *n* (%)	23 (5)
Coronary artery disease, *n* (%)	16 (3.5)
Level of surgery	
LIII—LIV, *n* (%)	69 (15.1)
LIV—LV, *n* (%)	191 (41.8)
LV—SI, *n* (%)	197 (43.1)
Surgical technique	
ALIF, *n* (%)	41 (8.9)
DLIF, *n* (%)	57 (12.5)
TLIF, *n* (%)	359 (78.6)
Preoperative VAS score of pain	
Lumbar spine	81 (72; 90)
Lower limbs	92 (78; 96)
Preoperative ODI	68 (58; 80)
Preoperative QoL	
PCS	25 (19.74; 32)
MCS	28.14 (22; 39.92)
Postoperative VAS score of pain	
Lumbar spine	8 (5; 13)
Lower limbs	4 (0; 8)
Postoperative ODI	10 (6; 14)
Postoperative QoL	
PCS	46 (39; 49.16)
MCS	47 (42; 51.44)
Redo surgeries within 90 postoperative days	
No	431 (94.3)
Yes	26 (5.7)
Readmissions within 90 postoperative days	
No	419 (91.7)
Yes	38 (8.3)
Return to work	
No	58 (12.7)
Yes	399 (87.3)

(with case numbers 1, 2, ..., τ) and smaller (control) group (with case numbers τ+1, τ+2, ..., *n*). A methodology based on prediction of dependent variable and its relative error was used to control subgroups. Length of control sample was calculated using the generally accepted method as 5—10% of the entire sample size. Thus, control subgroup size was 35/457 cases (7.7%).

Results

Baseline characteristics of study cohort and clinical outcomes after 24 postoperative months are summarized in **Table 1**. All clinical parameters improved ($p<0.05$): ODI from 68% to 10%, back pain from 81 to 8 mm, lower extremity pain from 92 to 4 mm, PCS from 25 to 46, MCS from 28.14 to 47. About 87.3% of railway workers returned to previous work. Redo surgery rate within 90 days after surgery was 5.7%, readmission rate — 8.3%.

Model development

Factor contributions for each model are presented in **Table 2**.

We identified the highest and lowest values of output variable in each model and sorted these data in descending order of their influence based on strict dominance relationship (>). Thus, the most significant variables for each model are on the left, and those with less influence are on the right:

1) for model y_0 (ODI): $x_{10}>x_{14}>x_{20}>x_8$;
2) for model y1 (SF-36 PCS): $x_{19}>x_{18}>x_2>x_{12}>x_{16}>x_{15}>x_{17}>x_{20}>x_{13}>x_{11}>x_1>x_3$;
3) for model y_2 (SF-36 MCS): $x_{18}>x_2>x_{19}>x_{16}>x_{12}>x_8>x_{20}>x_{11}>x_3>x_6>x_4$;
4) for model y_3 (Macnab): $x_{19}>x_2>x_{18}>x_{20}>x_6>x_1>x_{11}>x_{12}>x_9>x_{16}>x_{13}>x_7>x_5>x_3>x_8>x_4$.

Model validation

We obtained the following models according to approximation error:

(1) for $y_0=3.44+0.0029x_8+0.6854x_{10}+0.0341x_{14}-0.7986x_{20}$. E=39.2%;

(2) for $y_1=39.08-0.021x_1-0.280x_2-0.060x_3-0.557x_{11}+0.575x_{12}+0.242x_{13}+0.456x_{15}+1.520x_{16}+1.492x_{17}-0.008x_{18}+0.139x_{19}-2.452x_{20}$. E=13.9%;

(3) for $y_2=49.16-0.2742x_2-0.0680x_3-0.0357x_4-0.0007x_6+0.1156x_8-0.4297x_{11}+0.4340x_{12}+1.3613x_{16}-0.0078x_{18}+0.0743x_{19}-1.5833x_{20}$. E=15%;

(4) for $y_3=3.40-0.0048x_1-0.0256x_2-0.0066x_3-0.0867x_4-0.0004x_5-0.0036x_6+0.0040x_7+0.0003x_8-0.0021x_9-0.0721x_{11}+0.0216x_{12}+0.0132x_{13}+0.0429x_{16}-0.0002x_{18}+0.0109x_{19}-0.2730x_{20}$. E=17.3%.

Table 2. **Contributions of factors**

Independent variables	y_0 model (ODI), contributions of factors, %	y_1 model (SF-36 PCS), contributions of factors, %	y_2 model (SF-36 MCS), contributions of factors, %	y_3 model (Macnab), contributions of factors, %
x_1 — age, years	—	1.97	—	6.43
x_2 — BMI, kg/m^2	—	12.34	17.40	16.33
x_3 — duration of symptoms, months	—	0.36	0.59	0.58
x_4 — motor disorders	—	—	0.01	0.01
x_5 — preoperative back pain, mm	—	—	—	0.98
x_6 — preoperative lower limb pain, mm	—	—	0.17	7.87
x_7 — preoperative PCS	—	—	—	2.93
x_8 — preoperative MCS	0.74	—	9.78	0.32
x_9 — preoperative ODI	—	—	—	4.42
x_{10} — postoperative back pain, mm	81.94	—	—	—
x_{11} — postoperative lower limb pain, mm	—	3.34	3.72	6.26
x_{12} — preoperative interbody space height, mm	—	9.19	10.01	5.00
x_{13} — preoperative sagittal angle, °	—	4.36	—	3.46
x_{14} — preoperative lumbar lordosis, °	10.5	—	—	—
x_{15} — preoperative linear translation, mm	—	8.20	—	—
x_{16} — preoperative disc degeneration (C. Pfirrmann)	—	9.11	11.77	3.72
x_{17} — preoperative unilateral facet joint degeneration (A. Fujiwara)	—	5.96	—	—
x_{18} — preoperative disc ADC, mm^2/s	—	18.54	25.28	9.09
x_{19} — preoperative unilateral facet joint angle, °	—	21.73	16.70	24.71
x_{20} — preoperative facet joint tropism	6.82	4.9	4.57	7.89

Table 3. **Clinical and instrumental data of subgroups.**

Variable	Subgroup with improvement (*n*=406)	Subgroup with deterioration (*n*=51)	*p*
Age, years	41 (35; 53)	45 (37; 55)	0.13
BMI, kg/m^2	23 (22; 25)	26 (23; 31)	0.000007
Motor disorders, *n* (%)	172 (42.4)	35 (68.6)	0.0003
Preoperative VAS score of pain			
Lumbar spine	82 (72; 90)	76 (66; 89)	0.13
Lower extremities	92 (78; 96)	90 (73; 95)	0.33
Preoperative ODI	68 (58; 80)	60 (58; 80)	0.28
Preoperative QoL			
PCS	22.17 (20.00; 32.08)	24.00 (17.93; 29.00)	0.10
MCS	28.00 (22.00; 39.26)	32.00 (26.00; 49.00)	0.02
Postoperative VAS score of pain			
Lumbar spine	8 (4; 10)	24 (18; 29)	<0.001
Lower extremities	4 (0; 7)	14 (9; 19)	<0.001
Postoperative ODI	8 (6; 12)	30 (26; 34)	<0.001
Postoperative QoL			
PCS	47.00 (41.52; 49.76)	18.11 (16.00; 23.00)	<0.001
MCS	48.00 (43.00; 51.44)	21.28 (16.20; 53.00)	<0.001
Preoperative lumbar lordosis, °	40 (34; 44)	37 (32; 51)	0.84
Preoperative linear translation, mm	6 (5; 7)	12 (9; 16)	<0.001
Preoperative sagittal angle, °	14 (11; 16)	13 (11; 17)	0.52
Preoperative interbody space height, mm	7 (6; 8)	7 (6; 9)	0.52
Preoperative disc degeneration (C. Pfirrmann)	III (III; IV)	IV (III; IV)	0.17
Preoperative unilateral facet joint degeneration (A. Fujiwara)	III (II; III)	IV (III; IV)	0.19
Preoperative unilateral facet joint angle, °	67.5 (64; 73)	42 (33; 51)	<0.001
Preoperative facet joint tropism, *n* (%)	307 (75.6)	45 (88.2)	0.02
Preoperative disc ADC, mm^2/s,	1123 (997; 1255)	1358 (1295; 1451)	<0.001

Acceptable errors in approximation of regression models for y_1 (SF-36 PCS), y_2 (SF-36 MCS), and y_3 (Macnab) confirm their clinical potential. The y0 (ODI) model has significantly lower predictive power, but it can be effectively used as an additional tool for identifying factors influencing the output variable and quantifying the extent of this influence.

After internal validation, mean relative errors were found to be 37.96% for the y0 model, 13.24% for the y1 model, 15.52% for the y2 model, and 16.97% for the y3 model. Thus, mean relative errors for all four models are comparable to mean approximation errors. This also demonstrates high quality of these models.

To assess the relationship between pre-/postoperative clinical and instrumental parameters and postoperative outcomes, we divided patients into two subgroups: subgroup with improvement (*n*=406, 88.8%) and subgroup with deterioration (*n*=51, 11.2%) **(Table 3)**. Unsatisfactory outcome was defined by the following factors: VAS score of back and/or lower extremity pain >20 mm and ODI >20, redo surgery or readmission.

Thus, preoperative clinical and instrumental criteria associated with favorable clinical outcomes will predict successful minimally invasive LIII—SI fusion.

Discussion

Currently, there are many researches devoted to mathematical predictive models for postoperative outcomes. These models are aimed at improving the quality of medical care, its effectiveness, reducing the incidence of adverse events and economic costs [10, 11]. However, there was no analysis of impact of preoperative examination on long-term postoperative outcomes based on regression models, including railway workers.

There are several studies devoted to predicting the outcomes after spine surgery. It was found that regression models allowed for preoperative prediction of pain and disability after microsurgical resection of herniated disc [13]. Mathematical modeling technologies can predict ODI, leg and back pain in 12 months after surgery, redo surgery rate and duration of inpatient treatment with-

in 60—78% [14]. Multivariate logistic regression confirmed the importance of restoring the global spinal balance to its ideal range and preventing its overcorrection for postoperative proximal hyperkyphosis among patients with degenerative scoliosis [15]. The model developed by McGirt M.J. et al. [16] showed sufficient ability to predict complications, readmission, inpatient rehabilitation and return to work within 72—84%. However, prediction of 12-month outcome according to ODI was low (only 52%). Certain factors, such as heterogeneity of degenerative lumbar spine lesions, specifics of surgical approaches, specificity of surgical techniques and number of damaged segments, call into question some existing prognostic models [10, 11].

Significant shortcomings of prognostic models include difficult mathematical calculations, ethical issues regarding liability of physician and development team for perioperative complications, as well as likelihood of systemic software errors, clinical and biometric characteristics of patients potentially influencing outcomes. In our opinion, prognostic modeling technologies require a balance between validity of mathematical models and own clinical experience.

In our opinion, our prognostic modeling can improve patient and surgeon satisfaction with surgical intervention. Low approximation errors of regression models for SF-36 and Macnab scales confirm their clinical feasibility. Internal validation revealed mean relative errors for these models comparable to their mean approximation errors. This also indicates high quality of these models.

Study limitations

Study limitations include:

1) no control group receiving conservative treatment;
2) analysis of single-segment symptomatic degenerative lumbar spine disease with strict inclusion criteria;
3) analysis of a unified cohort of patients (employees of JSC Russian Railways undergoing surgery in a single neurosurgical hospital, the same surgical team);
4) incomplete inclusion of all possible factors influencing postoperative outcome, such as changes in adjacent lumbar segments, mental status, opioid use, etc.;
5) not all variables overlap each other in presented models;
6) some subjectivity in interpretation of questionnaires for predictive modeling;
7) statistical validation approach serves only for internal evaluation, it is not a separate data set and does not increase confidence that the proposed models can be applied to general population.

Conclusion

Original regression models based on preoperative anthropometric (age, body mass index), clinical (motor function), and instrumental (dynamic displacement, disc height and degeneration grade, facet joint degeneration, facet joint tropism, and ADC) parameters provides convenient and simple method for predicting the outcome of minimally invasive lumbar fusion.

We confirmed acceptable approximation errors of regression models for y1 (PCS), y2 (MCS), and y3 (Macnab scale) — 13.9%, 15%, and 17.3%, respectively. This confirms their clinical utility. Internal validation demonstrated high quality of these models. The y0 model (ODI) has significantly lower predictive power (39.2%), but it can be effectively used as an additional tool for identifying factors influencing the output variable and quantifying the extent of this influence. The overall success rate (postoperative VAS score of back pain and lower extremity pain <20 mm, ODI <20 scores and no redo surgery or readmission) was 88.8%.

These experimental models, subject to further validation as a clinical prognostic tool, may be useful in preoperative management and selection of candidate for minimally invasive lumbar fusion. Further prospective studies with larger samples, including external validation of models, are needed to clarify this relationship.

Author contribution:
Concept and design of the study — Byvaltsev V.A., Noskov S.N.
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REFERENCES

1. Fine N, Lively S, Séguin CA, Perruccio AV, Kapoor M, Rampersaud R. Intervertebral disc degeneration and osteoarthritis: a common molecular disease spectrum. *Nature Reviews Rheumatology.* 2023;19(3):136-152. https://doi.org/10.1038/s41584-022-00888-z
2. Byvaltsev VA, Kalinin AA, Aliyev MA, Pestryakov YY, Riew KD. Long-term results and surgical strategy development for degenerative disease treatment in athletes: a retrospective single-center study. *European Spine Journal.* 2024;33(9):3359-3368. https://doi.org/10.1007/s00586-024-08283-w
3. Bcharah G, Gupta N, Panico N, Winspear S, Bagley A, Turnow M, D'Amico R, Ukachukwu AK. Innovations in Spine Surgery: A Narrative Review of Current Integrative Technologies. *World Neurosurgery.* 2024;184:127-136. https://doi.org/10.1016/j.wneu.2023.12.124
4. Xu C, Huang C, Cai P, Fang Z, Wei Z, Liu F, Li J, Liu Y. Biomechanical Effects of Pedicle Screw Positioning on the Surgical Segment in Models After Oblique Lumbar Interbody Fusion: An in-silico Study. *International Journal of General Medicine.* 2022;15:1047-1056. https://doi.org/10.2147/IJGM.S352304

5. Hu X, Yan L, Jin X, Liu H, Chai J, Zhao B. Endoscopic Lumbar Interbody Fusion, Minimally Invasive Transforaminal Lumbar Interbody Fusion, and Open Transforaminal Lumbar Interbody Fusion for the Treatment of Lumbar Degenerative Diseases: A Systematic Review and Network Meta-Analysis. *Global Spine Journal.* 2024;14(1):295-305. https://doi.org/10.1177/21925682231168577
6. Ren BW, Zhao HM, Wu JH, An BC, Han ZC, Liu YH, Mao KY, Liu JH. Comparison of Fusion Rate and Clinical Outcomes in Minimally Invasive and Conventional Posterior Fusion for Lumbar Degenerative Disease: A Network Meta-Analysis. *World Neurosurgery.* 2024;189:357-372.e8. https://doi.org/10.1016/j.wneu.2024.06.031
7. Endo T, Kanemura N, Ito T, Sato K, Miura T, Onitsuka K, Miyazawa T, Kubota K, Iwabuchi M, Shirado O. Effect of Residual Pain After Posterior Fusion Surgery for Lumbar Degenerative Disorders on Health-Related Quality of Life: A Two-Year Follow-Up Using Patient-Reported Outcome Measures. *Cureus.* 2024;16(6):e61611. https://doi.org/10.7759/cureus.61611
8. Asghar J, Patel AI, Osorio JA, Smith JS, Small J, Mullin JP, Desai A, Temple-Wong M, Nicolau RJ. Mismatch Between Pelvic Incidence and Lumbar Lordosis After Personalized Interbody Fusion: The Importance of Preoperative Planning and Alignment in Degenerative Spine Diseases. *International Journal of Spine Surgery.* 2024;18(S1):S24-S31. https://doi.org/10.14444/8638
9. Byvaltsev VA, Kalinin AA. Assessment of Clinical Decision Support System Efficiency in Spinal Neurosurgery for Personalized Minimally Invasive Technologies Used on Lumbar Spine. *Sovremennye tehnologii v medicine.* 2021;13(5):13-21. (In Russ.). https://doi.org/10.17691/stm2021.13.5.02
10. Cui P, Wang S, Zhang H, Wang P, Chen X, Kong C, Lu S. Development and validation of a nomogram to predict the unfavorable outcomes in elderly patients undergoing lumbar fusion surgery for degenerative disease. *BMC Surgery.* 2024;24(1):401. https://doi.org/10.1186/s12893-024-02720-9
11. Wang Z, Zhao X, Li Y, Zhang H, Qin D, Qi X, Chen Y, Zhang X. Development and validation of a multimodal feature fusion prognostic model for lumbar degenerative disease based on machine learning: a study protocol. *BMJ Open.* 2023;13(9):e072139. https://doi.org/10.1136/bmjopen-2023-072139
12. Saremi A, Goyal KK, Benzel EC, Orr RD. Evolution of lumbar degenerative spondylolisthesis with key radiographic features. *The Spine Journal.* 2024;24(6):989-1000. https://doi.org/10.1016/j.spinee.2024.01.001
13. Staartjes VE, de Wispelaere MP, Vandertop WP, Schröder ML. Deep learning-based preoperative predictive analytics for patient-reported outcomes following lumbar discectomy: feasibility of center-specific modeling. *The Spine Journal.* 2019;19(5):853-861. https://doi.org/10.1016/j.spinee.2018.11.009
14. Siccoli A, de Wispelaere MP, Schröder ML, Staartjes VE. Machine learning-based preoperative predictive analytics for lumbar spinal stenosis. *Neurosurgical Focus.* 2019;46(5):E5. https://doi.org/10.3171/2019.2.FOCUS18723
15. Li J, Xiao H, Jiang S, Yang Z, Chen Z, Liu X, Liu Z, Wei F, Jiang L, Sun C, Wu F, Guo Z, Li J, Li W, Yu M. Risk Factors and Three Radiological Predictor Models for the Progression of Proximal Junctional Kyphosis in Adult Degenerative Scoliosis Following Posterior Corrective Surgery: 113 Cases With 2-years Minimum Follow-Up. *Global Spine Journal.* 2023;13(8):2285-2295. https://doi.org/10.1177/21925682221079791
16. McGirt MJ, Sivaganesan A, Asher AL, Devin CJ. Prediction model for outcome after low-back surgery: individualized likelihood of complication, hospital readmission, return to work, and 12-month improvement in functional disability. *Neurosurgical Focus.* 2015;39(6):E13. https://doi.org/10.3171/2015.8.FOCUS15338
17. Byvaltsev VA, Kalinin AA, Noskov SI, Pestryakov YY, Yuldashev RM, Riew KD. Prognostic model for outcome after L4-5 minimally invasive transforaminal lumbar interbody fusion based on a comprehensive clinical and radiological analysis. J Neurosurg Spine. 2026;44(3):411-419. https://doi.org/10.3171/2025.8.SPINE24618

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COMMENT

Complexity and multiplicity of surgical methods for degenerative lumbosacral spine disease, individual course of disease and the need to analyze many patient-specific factors require mathematical methods and computer tools to support decision-making when choosing optimal surgical option for a particular patient. Modern vertebrology should be based on large-scale, preferably national, outcome-registration initiatives. Therefore, this study is highly representative. This trial is based on mathematical modeling of effectiveness of spinal fusion and includes nearly 500 patients with degenerative spine disease who underwent minimally invasive fusion. Prediction using precedent-based recognition methods can be used to support decision-making when choosing optimal surgical treatment for patients with degenerative lumbosacral spine disease. This methodology enables implementation of a key paradigm of modern clinical practice (patient-centered approach).

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