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Therapeutic and diagnostic classification of degenerative spondylolisthesis: validation and multiple-center inter-observer agreement

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ABSTRACT

Object. To evaluate inter- and intra-observer agreement of the proposed diagnostic and treatment classification of degenerative spondylolisthesis.

Material and methods. The proposed diagnostic and treatment classification of degenerative spondylolisthesis was validated according to the GRRAS protocol. For this purpose, we retrospectively analyzed MRI, CT and spinal radiography data in 20 patients. Inter- and intra-observer agreement was carried out by 11 experts from 6 federal institutions of Russia. Fleiss and Cohen's kappas were calculated using the Statistical Package for the Social Sciences (SPSS), version 21.0 (SPSS Inc., Chicago, IL, USA).

Results. Validation was carried out in two stages. The first stage (3 experts from one clinical unit): inter-observer agreement k (Fleiss)=0.863 [0.786; 0.939]; intra-observer agreement — Cohen's kappa >0.81 (expert 1 — k=0.931, expert 2 — k=0.908, expert 3 — k=0.862). The second stage was multiple-center and included 11 experts. Inter-observer agreement k(Fleiss) was 0.792 [0.767; 0.817]. We compared agreement among surgeons with comparable experience depending on specialty: orthopedic — k=0.799 [0.774; 0.814]; neurosurgeons — k=0.791[0.769; 0.817] (p=0.687). Surgeon's experience did not affect significance of classification: <10-year experience — k=0.781 [0.767; 0.798], >10-year experience — k=0.808 [0.789; 0.817] (p=0.287).

Conclusion. The presented diagnostic and treatment classification of degenerative spondylolisthesis has significant inter- and intra-observer multiple-center and multidisciplinary agreement. Integration of classification into clinical practice will allow standardization of surgical tactics for degenerative spondylolisthesis.

Keywords: *degenerative spondylolisthesis, sagittal balance, lumbar spine, classification, validity, inter-observer consensus.*

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Introduction

Surgical treatment can significantly improve the quality of life in patients with degenerative spondylolisthesis [1, 2]. However, optimal surgical strategy is still discussable due to heterogeneity of morphological changes and clinical manifestations. It is difficult to systematize their results and propose approaches for unsatisfactory outcomes including repeated surgical interventions due to no evidence base for a certain unified approach to diagnosis and treatment. This necessitates optimization of surgical tactics using clinical and morphological criteria. The attempts to implement such approaches were made in some classifications [3—7]. However, each classification has own limitations, and one cannot use these classifications alone [8]. These limitations include the absence of one or more components: predominant clinical syndrome, local changes (stenosis or instability), spinal balance. Available classifications include parameters [sagittal vertical axis (SVA), pelvic tilt (PT), pelvic incidence — lumbar lordosis (PI-LL)], which were calculated regardless Roussouly type of lumbar lordosis [9] and patient's age. The last ones are significant for analysis of target indicators of harmonious balance. It seems important that modern classification contain data on predominant clinical syndrome, morphological changes, biomechanical state of the spine and appropriate surgical strategy. This will allow systematizing the data and reducing the incidence of unsatisfactory outcomes in patients with degenerative spondylolisthesis.

Competent community should approve the new classification regarding theoretical acceptability and test this system regarding reproduction before introduction into practical application. This objective is realized as an independent or a part of a large study. Available classifications of degenerative spondylolisthesis were approved by expert community and underwent intra- and inter-expert assessment [3—7]. Nevertheless, these classifications have certain significant limitations including small number of experts with different experience, monodisciplinary nature of expert community and small number of centers.

The purpose of the study was to evaluate inter- and intra-observer agreement of the proposed diagnostic and treatment classification of degenerative spondylolisthesis considering clinical and morphological characteristics of patients.

Material and methods

A retrospective study included patients with degenerative spondylolisthesis who underwent surgery between January 2022 and December 2023. Inclusion criteria: (1) degenerative spondylolisthesis L_{IV}, (2) age over 18 years, (3) available comprehensive preoperative diagnostic data (magnetic resonance imaging, computed tomography, postural X-ray of the spine in two projections). Exclusion criteria: (1) lumbar spine coronal deformity, Cobb angle >10°, (2) concomitant non-degenerative spine lesion, (3) previous spine surgery.

Classification

The developed classification was based on 3 blocks: biomechanical type (sagittal balance of the spine), clinical syndrome and surgical tactics **(Table 1)**. To assess sagittal balance of the spine, we used the following parameters: PI (pelvic incidence), SL (segmental lordosis), LL (lumbar lordosis), LDI [Lordosis distribution index=LL (L_{IV}—S_I)/LL (L_I—S_I)], IB (Barrey Index), PT and Roussouly type of lumbar lordosis. These parameters significantly correlate with postoperative quality of life, and one can estimate these values individually taking into account age [8, 10, 11]. Ideal values were established using the following equations:

$$SL\ (L_{IV}—L_V)=30–50\%\ LL\ (L_{IV}—S_I);$$

LDI for Roussouly type I, II — 80—90%, type III — 70—80%, type IV — 60—70%;

$$LL\ (L_I—S_I)=31.1–0.15\ age+0.58\ PI;$$
$$PT=0.44\ PI-11\ [10, 12, 13].$$

To determine the biomechanical type, we developed an algorithm in the form of calculator to simplify calculations (https://sites.google.com/view/baytactics) **(Fig. 1, 2)**.

Clinical syndrome included compression and instability. Compression syndrome is a radicular pain syndrome with or without neurological deficit and/or neurogenic intermittent claudication. Instability syndrome was defined as a mechanical vertebrogenic pain syndrome in the lumbar spine with VAS score of pain> 5. In case of combination of compression syndrome and instability, the last one determined treatment strategy.

Surgical treatment was based on biomechanical type and predominant clinical syndrome **(Table 1)**.

The classification did not include some factors that could affect surgical strategy. These include comorbid status and bone mineral density. The argument in favor of exclusion of these parameters was their non-standardized assessment. Thus, somatic status and bone mineral density disorders are assessed outside the proposed classification. If necessary stabilization and correction at certain level were impossible due to significant deviations of the above-mentioned factors, surgical intervention was limited by decompression of intracanal vessels and nerves.

The classification was validated according to the GRRAS protocol [14]. The study did not imply "blinding" of experts, but data analysis was carried out independently of each other. The chief investigator trained the experts in technical and methodological aspects of the study and discussed the appropriate issues. Sagittal balance parameters were calculated using the appropriate programs.

The study consisted of two stages. At the first stage, 3 specialists assessed intra- and inter-observer reliability. These were 2 traumatologists-orthope-

Table 1. **Classification of degenerative spondylolisthesis**

Type	X-ray criteria	Predominant clinical syndrome	Surgical strategy
Type I. Harmonious	SL≥SL (ideal) LL=LL (ideal)±10% Low LL (L_{IV}—S_I): — Roussouly I, II type — 80—90% LL (ideal) — Roussouly III type — 70—80% LL (ideal) — Roussouly IV type — 60—70% LL (ideal) PT⩽PT+10% (ideal) IB<1.0	Compression Compression and/or instability	Decompression Monosegmental fusion in situ with or without decompression
Type II. Segmental imbalance	SL<SL (ideal) LL=LL (ideal)±10% Low LL (L_{IV}—S_I): — Roussouly I, II type — 80—90% LL (ideal) — Roussouly III type — 70—80% LL (ideal) — Roussouly IV type — 60—70% LL (ideal) PT⩽PT+10% (ideal) IB<1.0	Compression Compression and/or instability	Decompression Monosegmental fusion with or without decompression
Type III. Regional imbalance	LL⩽LL (ideal)±10% PT (ideal)⩽PT⩽PT (ideal) Low LL (L_{IV}—S_I): — Roussouly I, II type ⩽80—90% LL (ideal) — Roussouly III type ⩽70—80% LL (idea.) — Roussouly IV type ⩽60—70% LL (ideal) IB <1.0	Compression Compression and/or instability	Decompression as the main stage for functional imbalance or the 1st stage for structural imbalance Mono- or short-segment corrective spondylodesis with mandatory restoration of Low LL (L_{IV}—S_I) LL with or without decompression Note: decompression only if instrumentation is contraindicated and/or there is a high surgical risk
Type IV. Total imbalance	LL<LL (ideal) — 10% Low LL (L_{IV}—S_I): — Roussouly I, II type <80—90% LL (ideal) — Roussouly III type <70—80% LL (ideal) — Roussouly IV type <60—70% LL (ideal) PT>PT (ideal)+10% IB>1.0	Instability Compression and/or instability	Short- or polysegmental corrective spondylodesis with restoration of Low LL (L_{IV}—S_I) and LL Short- or polysegmental corrective spondylodesis with restoration of Low LL (L_{IV}—S_I) and LL with or without decompression Note: decompression only if instrumentation is contraindicated and/or there is a high surgical risk

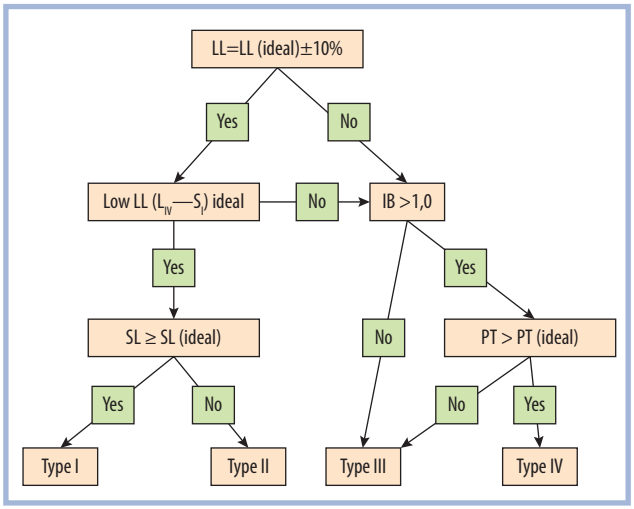

Fig. 1. **Algorithm of the treatment and diagnostic classification of degenerative spondylolisthesis.**

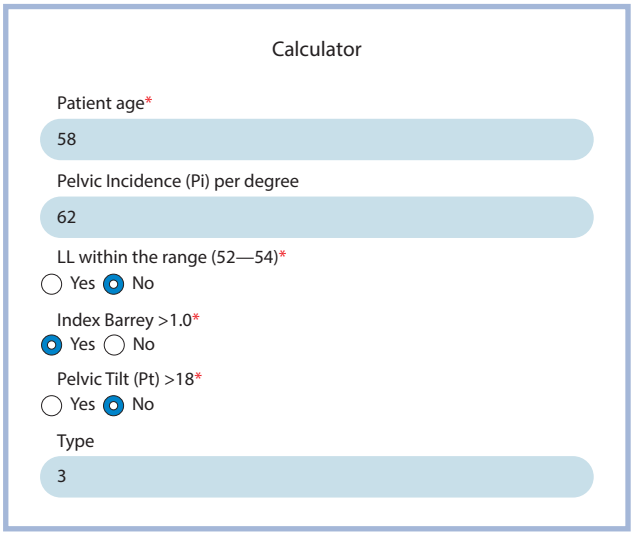

Fig. 2. **Calculator for analysis of biomechanical type.**

dists (experience <10 years) and 1 neurosurgeon (experience >10 years). The data were analyzed twice with 2-week interval. The second stage consisted of assessing the inter-observer reliability by specialists from 7 federal hospitals of Russia: Burdenko Neurosurgery Center (neurosurgeon, experience <10 years), Federal Center for Traumatology, Orthopedics and Endoprosthetics, Barnaul (neurosurgeon, experience >10 years), Federal Center for Traumatology, Orthopedics and Endoprosthetics, Cheboksary (traumatologist-orthopedist, experience >10 years), Ilizarov Research Institute of Traumatology and Orthopedics (neurosurgeon, experience >10 years), Priorov National

Table 2. **Inter-observer reliability of classification of degenerative spondylolisthesis (3 experts, Traumatology and Orthopedics Department *No.* 12 of the Priorov National Medical Research Center of Traumatology and Orthopedics)**

Variable	Biomechanical type	Clinical syndrome	Surgical strategy
Fleiss kappa	0.778 [0.651; 0.904]	0.958 [0.821; 1.000]	0.707 [0.624; 0.853]

Medical Research Center of Traumatology and Orthopedics (traumatologist-orthopedist, experience >10 years), Russian University of Medicine (neurosurgeon, experience >10 years), Semashko Scientific Educational Institute of Clinical Medicine (expert 1 (neurosurgeon) — experience >10 years, expert 2 (neurosurgeon) — experience <10 years).

Statistical analysis

Statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS), version 21.0 (SPSS Inc., USA). The following kappa was used for analysis: inter-observer reliability — Fleiss kappa, intra-observer reliability — Cohen kappa. Kappa score ranking: 0.00—0.20 — very low agreement, 0.21—0.40 — unsatisfactory, 0.41—0.60 — satisfactory, 0.61—0.80 — significant, 0.81—1.00 — excellent. Continuous variables were presented as median [first quartile; third quartile]; binary variables — numbers and percentages [95% confidence interval].

Results

Twenty patients were included. Mean age was 63.5 [53; 68.5] years. There were 18 women and 2 men. Taking into account the number of experts and multiplicity of analysis, MR scans were assessed 280 times, CT scans — 280 times, X-ray scans — 560 times.

Stage 1. Inter-observer reliability of classification was satisfactory (k=0.863 [0.786; 0.939]). Consensus regarding the classification blocks is presented in **Table 2.** Inter-observer reliability was excellent in the "clinical syndrome" block and significant in the "biomechanical type" and "surgical strategy".

Intra-observer reliability was excellent among all 3 raters (Cohen kappa >0.81): observer 1 — k=0.931, observer 2 — k=0.908, observer 3 — k=0.862.

The second multiple-center stage included 11 observers. Reliability of classification was significant (k=0.792 [0.767; 0.817]). There were only random variations in re-interpretation without systematic bias or confusion between different biomechanical types, clinical syndrome and surgical strategy as indicated by mean error matrix **(Table 3)**. The highest between-expert agreement was achieved in the "clinical syndrome" block (k=0.850 [0.791; 0.909]). Consensus in the "biomechanical type" and "surgical strategy" blocks corresponded to significant reliability (k=0.717 [0.675; 0.758] and 0.685 [0.652; 0.701], respectively).

To determine significance of expert's experience and specialty in classification reproducibility, we compared data between physicians with less and more than 10-year experience, as well as between neurosurgeons and traumatologists with more than 10-year experience. The data of the chief investigator were used as a "gold standard". Reproducibility of classification by surgeons with <10-year experience was lower (k=0.781 [0.767; 0.798]) compared to more experienced colleagues (k=0.808 [0.789; 0.817]). However, these data were not significant (p=0.287). Similar data were obtained when analyzing the role of specialty: orthopedic traumatologists — k=0.799 [0.774; 0.814], neurosurgeons — k=0.791 [0.769; 0.817] (p=0.687).

Discussion

Surgical approaches are currently contradictory due to clinical and morphological heterogeneity of degenerative spondylolisthesis [15]. To address this issue, several classifications have been created over the past decade for improvement of inter-expert agreement regarding diagnosis and surgical tactics [3—7]. Gille O. et al. proposed the first classification based on assessment of sagittal profile of the spine using modifiers of adult spinal deformities, such as SVA, LL, SL, PI, and PT [4, 16]. This system involves 3 types of sagittal balance changes determining surgical tactics. However, the reference values of these modifiers were determined regardless of age and Roussouly type. The last ones are important in restoring a harmonious sagittal profile affecting treatment outcomes [10, 17]. The PI-LL, SVA and PT parameters differ in patients with different PI. Thus, the template use of their reference values can result incorrect surgical tactics with higher incidence of mechanical complications [10, 12]. From this position, a critical look at the classification by H. Kobayashi et al. [5] is also justified. This classification is based on SVA assessment. These systems do not consider age-dependent sagittal profile changes when planning surgical correction [17]. The other two classifications focus only on segmental changes in spondylolisthesis zone regardless of regional and global disorders [3, 7]. The DSIC system [7] offers a surgical strategy based exclusively on assessing the spinal motion segment stability regardless of other structural and clinical data affecting postoperative outcomes. The CARDS classification [3] does not imply surgical tactics at all. We considered these facts in our system. The last one is based on personalized calculation of target

Table 3. **Mean error matrix of reliability for classification of degenerative spondylolisthesis (11 experts)**

Patient	Biomechanical type				Clinical syndrome		Surgical strategy				
	I	II	III	IV	Compression	Instability	Decompression	Monosegmental fusion in situ with or without decompression	Monosegmental corrective fusion with or without decompression	Single- or short-segmental corrective fusion with mandatory restoration of Low LL (L_{IV}—S_I) with or without decompression	Short- or polysegmental corrective spondylodesis with restoration of Low LL (L_{IV}—S_I) and LL with or without decompression
1	0	0	1	10	10	1	1	0	0	1	9
2	1	0	10	0	2	9	1	0	1	9	0
3	0	0	10	1	1	10	0	0	2	9	0
4	0	1	8	2	11	0	9	0	1	0	0
5	0	0	11	0	2	9	1	1	1	8	0
6	0	0	10	1	1	10	1	0	2	8	0
7	0	7	4	0	2	9	1	1	4	5	0
8	0	0	10	1	0	11	0	1	2	8	0
9	0	0	1	10	0	10	0	0	1	2	7
10	4	0	3	5	11	0	11	0	0	0	0
11	0	0	11	1	11	0	10	0	0	0	0
12	0	0	9	2	9	1	9	1	0	0	0
13	0	0	10	0	0	10	0	0	0	11	0
14	2	0	9	0	10	1	10	0	0	1	0
15	0	0	11	0	0	11	1	1	0	9	0
16	0	0	0	11	0	11	2	1	1	2	5
17	0	0	8	3	0	11	1	0	2	5	3
18	0	1	9	1	10	1	9	0	1	1	0
19	2	0	7	2	11	0	11	0	0	0	0
20	0	0	0	11	11	0	10	0	0	0	1

indicators of sagittal balance according to PI values, Roussouly type and age. These data are valuable to calculate the ideal values of LL, LowLL (L_{IV}-S_I), SL, PT. We distinguished 4 types of biomechanical disorders depending on discrepancy between actual and apparent values of parameters. These disorders determine necessary stabilization and correction for harmonious restoration of sagittal profile.

Surgical intervention in patients with degenerative spondylolisthesis is aimed at relief of predominant clinical syndrome. However, this important component is either not represented in the above-described classifications or has a minimal value. In our system, predominant clinical syndrome, along with X-ray data, is of decisive importance in choosing the surgical tactics.

The classification by Kulkarni A.G. et al. [6] is the most detailed one. This grading system considers certain morphological and clinical data. It is based on scoring of each factor (pain, age, motor activity, segmental kyphosis, dynamic translation, disc height, synovitis, orientation of facet joints in sagittal plane). Spondylodesis is recommended for scores > 5.5. However, this classification does not indicate restoration of sagittal profile. It has a "rigid" structure not considering various combinations of factors with the same total score and significance of each factor in their combination.

The implemented classification should be easy to understand and easily reproducible. This is verified via intra- and inter-observer reliability. We used the GRRAS protocol for validation [14]. Specialists from different centers with sufficient professional experience were involved in the study. The system by Gille O. [4] was the most studied among all previously described classifications. Assessment of intra- and inter-observer reliability was based on 99 patients, and almost ideal consensus was found (Cohen's kappa >0.89, Fleiss kappa — 0.82). However, these data can rightfully be considered overestimated as evidenced in analysis involving only three experts with at least 4-year experience. In our study, three experts from the same hospital assessed intra- and inter-observer reliability at the first stage and revealed significant consensus (Fleiss kappa — 0.863 [0.786; 0.939], Cohen kappa — 0.862—0.931). We should emphasize potential clinically unacceptable disagreements despite high reliability or agreement coefficient. Values 0.60—0.80 are often used as minimum standards for reliability coefficients [14]. To increase the value of the study, we performed a multiple-center analysis involving different specialists from 7 federal

hospitals. As expected, inter-observer reliability decreased. However, this change was insignificant, and reliability was significant (k=0.792 [0.767; 0.817]). In addition, we estimated the influence of experience and specialty on reliability. Surgeons with extensive experience had higher data comparability compared to less experienced colleagues (k=0.808 [0.789; 0.817] and k=0.781 [0.767; 0.798], respectively), but this was not significant (p=0.287). Data did not differ significantly between traumatologists-orthopedists and neurosurgeons (p=0.687) that indicated easy reproducibility of system.

Thus, the proposed classification includes three blocks: two diagnostic ("clinical" and "radiological") and one therapeutic ("surgical strategy") one. This allows us to consider this classification a full-fledged clinical tool. When developing the classification, we relied on scientifically based data. Relief of predominant clinical syndrome is the main component in the treatment of patients with degenerative pathology. Therefore, the classification defines two main syndromes (compression and instability). The first method involves only decompression of intracanal vessels and nerves. The second method requires stabilization in functionally advantageous position. To achieve this goal, the classification integrates sagittal balance parameters significantly affecting postoperative outcomes. These parameters may be calculated individually. Stabilization can be performed in situ or with correction depending on severity of spinal-pelvic relationship disorders. All this allows us to conclude that this classification may be introduced into practical healthcare after analysis of its clinical significance. This will provide scientific standardized approach to treating patients with degenerative spondylolisthesis.

Study limitations. The classification does not integrate such morphological changes as spinal canal stenosis, its length, severity and role in functional imbalance, as well as characteristics of spinal motion segment instability. Currently, there is no single criterion-defined concept of "instability". Its neuroimaging- and radiography-based characteristics are not standardized and have various reference values that introduces significant confusion in diagnosis of this condition. Length and degree of stenosis have no significant effect on preoperative clinical status and postoperative outcomes [18]. The role of stenosis in functional sagittal imbalance is confirmed only indirectly due to recovery of regional and global spine changes after decompression alone [19]. This was an argument in favor of exclusion of these morphological changes.

Conclusion

The presented diagnostic and treatment classification of degenerative spondylolisthesis has significant inter- and intra-observer multiple-center and multidisciplinary agreement. Integration of classification into clinical practice will allow standardization of surgical tactics for degenerative spondylolisthesis and reduce the number of unsatisfactory results including redo surgeries.

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No conflict of interests to declare.

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COMMENT

Vertebral displacement with or without neurological symptoms is one of the most common causes of disabling lumbar pain in adults. Biomechanically, progression of displacement in spondylolisthesis depends on shear component of gravitational force acting on lumbar vertebra and inability of supporting elements of lumbosacral segment to withstand these forces due to their degeneration. Risk of progression and severity of spondylolisthesis are proportional to severity of degeneration and shear loads. The last ones depend on spinal-pelvic balance. According to some authors, pelvic incidence is a constant value characterizing anatomy of the pelvis. Sacral slope (SS) and pelvic tilt (PT) are variables. Global lumbar lordosis (GLL) and thoracic kyphosis (TK) are used as the values characterizing spine centering. GLL increases with greater pelvic tilt. PI, SS, GLL and PT are significantly higher in patients with lumbar spondylolisthesis. This suggests that pelvic anatomy influences progression of spondylolisthesis including degenerative spondylolisthesis. The authors analyzed sagittal balance and pelvic tilt in spondylolisthesis and proposed a new classification of degenerative spondylolisthesis based on 3 blocks (sagittal balance, predominant clinical syndrome and surgical treatment). Surgical strategy should be aimed at recovery of physiological spinal-pelvic balance. This last one is determined not only by correction of instability, but also PT decrease as the best indicator of pelvic stability. Thus, the studies devoted to correction of lumbar instability and spinal-pelvic balance in the aspect of coxovertebral complex are very important in vertebrology and orthopedics. The proposed classification and algorithm for surgical treatment with validity and the reproducibility approved by some expert clinics is a subject for publication and discussion by specialists.

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