NEUROLOGY AND NEUROSURGERY

COMPLEX NEUROIMAGING ASSESSMENT OF THE PROXIMAL SEGMENT AFTER RIGID FIXATION AND DYNAMIC STABILIZATION IN PATIENTS WITH DEGENERATIVE LUMBAR DISEASE

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ABSTRACT

Background. *The development of the adjacent level syndrome and, as a consequence, adjacent segment degenerative disease are currently the most common complications of decompression and stabilization surgery with the development of segmental instability.*

The aim of the study. *To conduct a comprehensive neuroimaging assessment of the proximal adjacent segment after rigid fixation and dynamic stabilization in degenerative lumbar disease.*

Materials and methods. *We conducted a prospective multicenter study of the results of surgical treatment of 274 patients with degenerative-dystrophic diseases of the lumbar spine, who underwent monosegmental decompression and stabilization surgery using the TLIF (transforaminal lumbar interbody fusion) technique and open transpedicular rigid fixation, as well as open hemilaminectomy with stabilization of the operated segments with nitinol rods. The study included radiography, diffusion-weighted magnetic resonance imaging and computed tomography (dual-energy mode) of intervertebral discs and isolated facet degeneration of the upper adjacent level.*

Results and discussion. *Combination of the initial proximal segment degeneration in the form of facet joints degeneration (density of cartilaginous plate – 163.5 ± 14.2 HU, density of external facet – 709.35 ± 13.6 HU, density of internal facet – 578.1 ± 12.1 HU), Pfirrmann III, IV grade degeneration of intervertebral disc and a measured diffusion coefficient of less than 1300 mm^2/s cause high risks of developing adjacent segment degenerative disease, which regulates the use of monosegmental dynamic fixation with nitinol rods, or preventive rigid fixation of the adjacent segment.*

Conclusion. *Using complex neuroimaging in the preoperative period makes it possible to predict the results of surgical treatment, take timely measures to prevent degenerative diseases of the adjacent segment, and to carry out dynamic monitoring of processes in the structures of the spinal motion segment.*

Key words: *degenerative diseases of the lumbar spine, rigid fixation, dynamic fixation, adjacent segment, intervertebral disc, facet joint*

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КОМПЛЕКСНАЯ НЕЙРОВИЗУАЛИЗАЦИОННАЯ ОЦЕНКА ПРОКСИМАЛЬНОГО СЕГМЕНТА ПОСЛЕ РИГИДНОЙ ФИКСАЦИИ И ДИНАМИЧЕСКОЙ СТАБИЛИЗАЦИИ У ПАЦИЕНТОВ С ДЕГЕНЕРАТИВНЫМ ЗАБОЛЕВАНИЕМ ПОЯСНИЧНОГО ОТДЕЛА

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РЕЗЮМЕ

Введение. *Развитие синдрома смежного уровня и, как следствие, дегенеративное заболевание смежного сегмента в настоящее время являются самыми частыми осложнениями декомпрессивно-стабилизирующих вмешательств с развитием сегментарной нестабильности.*

Цель исследования. *Провести комплексную нейровизуализационную оценку проксимального смежного сегмента после ригидной фиксации и динамической стабилизации при дегенеративной патологии поясничного отдела позвоночника.*

Материалы и методы. *Проведено проспективное мультицентровое исследование результатов хирургического лечения 274 пациентов с дегенеративно-дистрофическими заболеваниями поясничного отдела позвоночника, которым выполнено моносегментарное декомпрессивно-стабилизирующее вмешательство с применением методики TLIF (transforaminal lumbar interbody fusion) и открытой транспедикулярной ригидной фиксации, а также открытой гемиляминэктомии со стабилизацией оперированных сегментов стержнями из нитинола. Исследование включало рентгенографию, диффузионно-взвешенные магнитно-резонансную томографию и компьютерную томографию (в двухэнергетическом режиме) межпозвонковых дисков (МПД) и изолированной фасеточной дегенерации верхнего смежного уровня.*

Результаты и обсуждение. *При сочетании исходной дегенерации проксимального сегмента в виде дегенерации дугоотросчатых суставов с плотностью хрящевой пластинки 163,5 ± 14,2 HU, наружной фасетки 709,35 ± 13,6 HU, внутренней фасетки 578,1 ± 12,1 HU, денегерации МПД III, IV степени по C.W. Pfirrmann и измеряемого коэффициента диффузии менее 1300 мм*^{2}*/с имеются высокие риски развития дегенеративного заболевания смежного сегмента, что регламентирует использование моносегментарной динамической фиксации с использованием стержней из нитинола, или проведение превентивной ригидной фиксации смежного сегмента.*

Заключение. *Использование комплексной нейровизуализации в предоперационном периоде позволяет проводить прогнозирование результатов хирургического лечения, своевременно принимать профилактические меры по профилактике дегенеративных заболеваний смежного сегмента и осуществлять динамическое наблюдение за процессами в структурах позвоночно-двигательного сегмента.*

Ключевые слова: *дегенеративные заболевания поясничного отдела позвоночника, ригидная фиксация, динамическая фиксация, смежный сегмент, межпозвонковый диск, дугоотросчатый сустав*

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INTRODUCTION

Lumbar spinal stenosis is the most common indication for operation in spinal surgery. The main method of surgical treatment of such pathology is the use of decompressive-stabilizing interventions, which allow to control neurological symptoms [1, 2]. At the same time, surgical treatment does not stop the progression of the disease, but is only aimed at eliminating its clinical manifestations. A number of experts note that after surgery in the long term, there is a decrease in the quality of life of patients as a result of recurrence of degenerative pathology [3–5].

The development of adjacent level syndrome and, as a consequence, adjacent segment degenerative disease (ASDD) are currently the most frequent complications of decompressive-stabilizing interventions with the development of segmental instability [6]. According to the literature, the development of ASDD 10 years after posterior rigid stabilization occurs in 6.7–80.0 % of patients, 24 % of whom require revision surgery, with the vast majority of cases involving the upper (proximal) adjacent segment [7–10]. In order to level the progression of the degenerative cascade and preserve physiological parameters of adjacent segment biomechanics, dynamic stabilizing systems [11, 12] have been introduced into the clinical practice of spinal surgeons to prevent the development of ASDD.

Along with the improvement of implants for decompressive and stabilizing interventions on the spine, a detailed preoperative assessment of not only the affected but also adjacent segments is necessary to prevent adverse clinical outcomes and the risks of repeated surgical interventions [6]. Modern preoperative neuroimaging should include standard and functional radiography, magnetic resonance imaging (MRI), and Multislice Spiral CT Scan (MSCT) [13–15], which allow proper planning of the surgical strategy and assessment of the dynamics of pathological processes after surgical intervention [16].

One of the efficient ways to assess the microstructural state of the intervertebral disc (IVD) to determine the possible surgical treatment tactics is the use of diffusion-weighted (DW) MRI with calculation of the Apparent diffusion coefficient (ADC) values [17]. An adjacent segment MDC value of less than 1300 mm^2/s was found to be statistically significantly associated with the development of ASDD [18].

The second of the main parameters in the assessment of the adjacent functional spinal unit (FSU) is the assessment of the facet joints (FJ). A correlation between morphological and radiological changes in FJ according to dual-energy computed tomography (DECT) has been established [19, 20]. The obtained numerical indices of FJ element density [21] in combination with ADC indices for IVD allow a comprehensive assessment of the affected and adjacent segments when planning surgical treatment of patients with degenerative pathology of the lumbar spine, as well as for postoperative control.

This research study aims to analyse the dynamics of degenerative changes in the IVD and FJ of the proximal adjacent segment after decompressive-stabilising interventions using different fixation systems in the context of the risks of ASDD development.

THE AIM OF THE STUDY

To conduct a comprehensive neuroimaging assessment of the proximal adjacent segment after rigid fixation and dynamic stabilization in degenerative lumbar disease.

MATERIALS AND METHODS

In the period from January 2017 to January 2022, in three clinics: Department of Traumatology No. 2 (Vertebrology) of the Clinical Medical and Surgical Center of the Ministry of Health of the Omsk region (Omsk), Department of Spinal Pathology, National Medical Research Center for Traumatology and Orthopedics named after N.N. Priorov (Moscow), Center for Neurosurgery, Clinical Hospital "Russian Railways-Medicine" (Irkutsk) – a prospective multicentre study according to a single approved protocol was conducted. The study was carried out in accordance with the Declaration of Helsinki of the World Medical Association "Ethical Principles of Scientific Medical Research Involving Human Subjects" as amended in 2000 and "Rules of Clinical Practice in the Russian Federation" approved by the Order of the Ministry of Health of Russia No. 266 dated June 19, 2003. The study was approved by the Ethical Committee of the Omsk State Medical University (protocol No. 4 dated December 12, 2016).

Medical records of 274 patients who underwent decompression-stabilizing interventions using rigid and dynamic fixation between January 2017 and January 2018 were included in the study. Informed consent was obtained from each patient before the examination. Two main groups were selected: group I (n = 139) underwent monosegmental decompression-stabilizing intervention using open median access with bilateral skeletonisation of paraspinal musculature, facetectomy, decompression of neural structures, TLIF (transforaminal lumbar interbody fusion) methodology and open transpedicular rigid fixation; group II (n = 135) underwent monosegmental decompression-stabilizing intervention using open median access with bilateral skeletonization of the paraspinal musculature, hemilaminectomy and decompression of neural structures, with stabilization of the operated segments with nitinol rods.

The inclusion criteria were monosegmental lesion at the level of L_{IV}–L_V, L_V–S_I with clinical manifestations of compression radiculopathy, high level of segmental translation in the area of the affected segment, absence of clinical and radiological signs of proximal syndrome.

The exclusion criteria were as follows: bisegmental lesions with clinical manifestations of compression radiculopathy; previous surgical interventions on the lumbosacral spine; history of spinal trauma; confirmed tumour process; infectious lesions of the spinal column; spondylolysis spondylolisthesis and the presence of osteoporosis (T-test below –2.5 SD). The study design with exclusion reasons is summarised in Figure 1.

Clinical parameters were assessed using the visual analog scale (VAS) of pain for back and lower extremities, the Oswestry Disability Index (ODI) and the SF-36 questionnaire (Short Form 36).

Digital images were evaluated using the image archiving and transmission system and MultiVox DICOM Viewer software (Gammamed, Russia). Measurements were performed by three independent expert radiologists, from whom all information, including age, patients' name and imaging time, was completely concealed to prevent subjective interpretation error. The mean values of the measurements between the three observers were taken for analysis in order to ensure inter-observer consistency. Segmental translation was measured from lateral radiographs of the lumbar spine; for this measurement, a perpendicular line was drawn from the posterior edge of the lower endplate of the upper vertebra to the line of the upper endplate of the lower vertebra; the length between the two lines was defined as segmental translation, a criterion for segment instability. The study of adjacent segments (IVD) was performed using T2-mode MRI with C.W. Pfirrmann classifications and diffusion-weighted image analysis. The condition of isolated degeneration of the FJ proximal adjacent level was assessed using MSCT in DECT with determination of quantitative X-ray morphometric parameters of the FJ (optical density of the external and internal facets, cartilage plate area) according to Hounsfield unit (HU).

Clinical results and a set of instrumental parameters were evaluated before surgery and 6, 12, 36, 60 months after surgical treatment.

Statistical processing of the obtained data was performed by methods of variation statistics using standard packages Microsoft Excel 2016 (Microsoft Corp., USA), Statistica 12.0 (StatSoft Inc., USA), BioStat (AnalystSoft, USA). We also used a standard control in MS Excel to sample the values of the middle of the table to display on the chart in the infinity symbol style. The advantages and disadvantages of each method of fixation are revealed through a comparative chart. Microsoft Excel 2016 spreadsheet editor (Microsoft Corp., USA) was used to create the database. In case of non-normal distribution type, non-parametric criteria were used: intergroup analysis using Mann – Whitney test (p_{M-U}), intragroup analysis using Wilcoxon test (p_W). Statistical measurement of the relationship (strength and direction) between the signs was carried out by calculating the Spear-

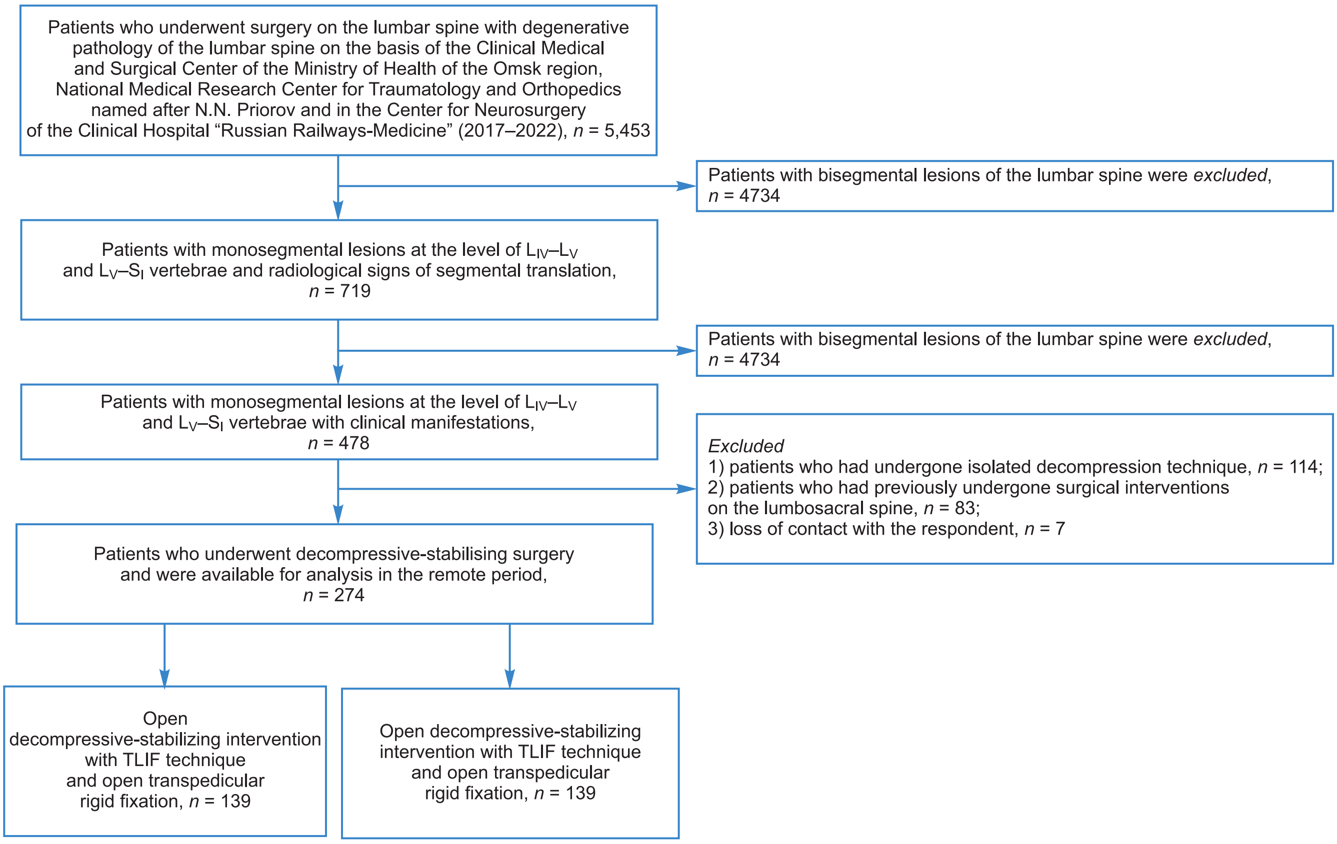

FIG. 1.
Flowchart of patients included in the study

man's rank correlation coefficient (r_s) followed by an assessment of diagnostic significance (binary logistic series, Z-test). The sample size was calculated using Lehr's formula for 80 % power and a two-sided level of statistical significance of $p < 0.05$.

RESULTS

Positive dynamics ($p_W < 0.05$) was observed in both groups of patients studied when examining changes in pain syndrome in the lumbar spine and lower extremities (Fig. 2).

Comparative assessment of functional status by ODI and SF-36 revealed a comparable level of preoperative parameters in the studied groups ($p_{M-U} > 0.05$). At the time of 6, 12, 36 and 60 months after surgical treatment, the best functional status was verified in group II ($p_{M-U} < 0.05$) compared with group I (Fig. 3, 4).

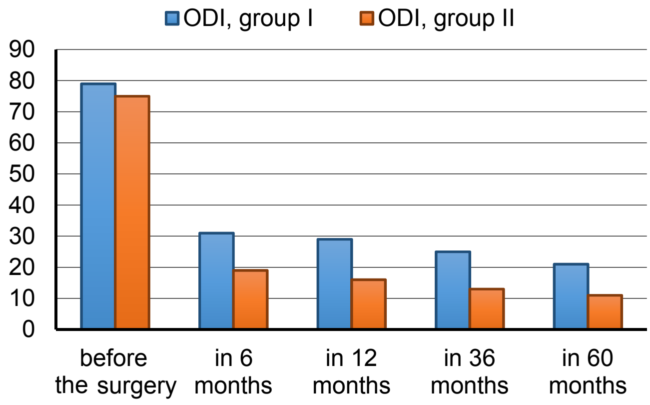

FIG. 3.
Dynamics of the functional state according to Oswestry Disability Index (0–100 %) in the studied groups of patients

An assessment of the degenerative changes severity of IVD of the proximal FSU is summarised in Table 1.

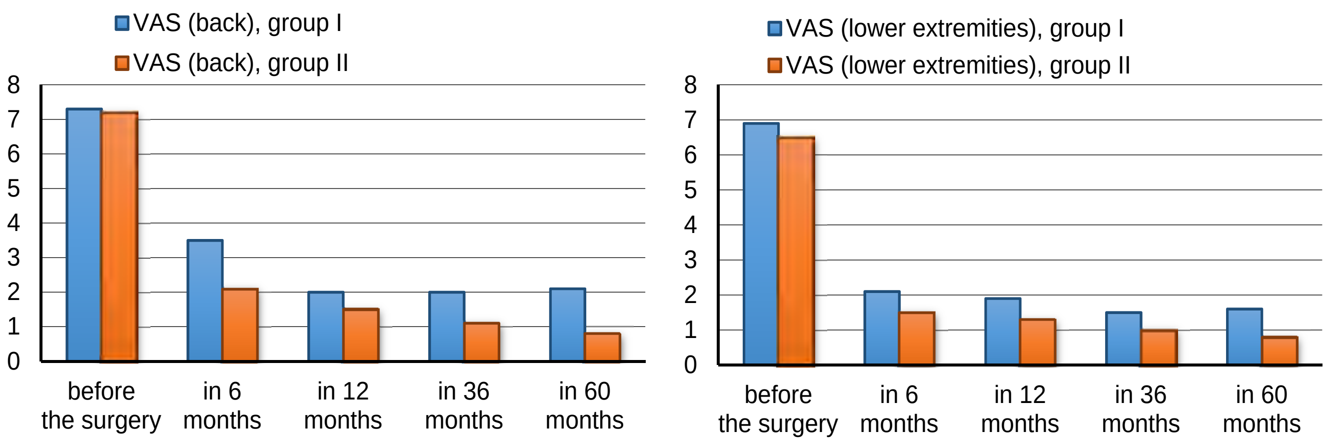

FIG. 2.
Dynamics of pain syndrome (according to visual analogue scale (0–10 cm)) in the lumbar spine and lower extremities in the studied groups of patients

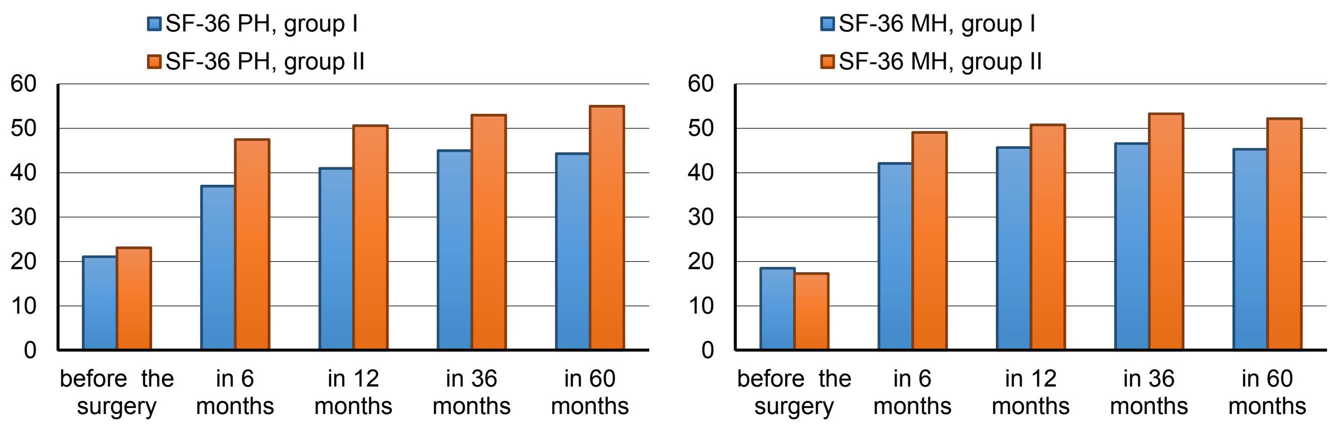

FIG. 4.
Dynamics of the functional state according to SF-36 questionnaire in the studied groups of patients: PH – Physical Health; MH – Mental Health

The analysis revealed a statistically significant change in the degree of degeneration in group I (p_W = 0.03), while in group II no significant degenerative changes were registered in the distant postoperative period (p_W = 0.47) (Table 1).

A statistically significant progression of IVD degeneration in group I (p_W = 0.01) was revealed when comparing the results of DW-MRI in the studied groups, while no significant degenerative changes of the proximal segment were observed in group II in the remote postoperative period (p_W = 0.73) (Table 2).

After surgical treatment in group I, progression of proximal IVD degeneration was detected in 24.1 % of cases. Between 12 and 60 months following surgery, 29 patients required revision interventions with prolongation of rigid fixation.

In group II, degeneration of the adjacent proximal IVD was noted in 5.8 % of cases (p_{M-U} = 0.01). Revision intervention with extension of dynamic stabilisation was performed in 2 patients at 36 and 60 months after the primary intervention. The incidence of ASDD in group I patients was 20.1 %, while in group II it was 2.0 % (p_{M-U} = 0.002).

When analyzing the severity of FJ degeneration according to the results of DECT before surgery, a comparable optical density of FJ between groups (p_{M-U} < 0.05) was noted.

After 60 months, the progression of degenerative processes in FJ was observed: in group I, the cartilage lamina density increased by 13.4 % compared to preoperative values, the density of the external facet – by 15.1 %, the density of the internal facet – by 15.6 %. In group II, cartilage lamina density increased by 3.7 % compared to preoperative values, external facet density by 4.1 %, and internal facet density by 2.2 % (p_{M-U} < 0.05) (Table 3).

In comparative analysis using a 5-point system with calculation of risk and positive outcome of the strategy according to the proposed models of surgical interventions, a heat map was used to visually detail the degree of degenerative processes in the FJ (Fig. 5, 6). Each risk is described by a number of criteria such as optical density of the external and internal facet, Hounsfield cartilage plate area. The value of each risk criterion was ranked by the probability of risk occurrence.

Therefore, when using the traditional method with monosegmental rigid fixation (group I), progression of degenerative processes in the FJ was observed, which may be a risk factor for ASDD development in 75 % of cases. In contrast, when dynamic stabilisation was used (group II), the degree of degenerative changes was 50 %

TABLE 1

DEGENERATIVE CHANGES OF PROXIMAL INTERVERTEBRAL DISC IN PATIENTS OF THE STUDIED GROUPS

Indicator		Group I (*n* = 139)		Group II (*n* = 135)	
		before the surgery	in 60 months	before the surgery	in 60 months
Degree of disc degeneration according to C.W. Pfirrmann, *n* (%)	I	–	–	–	–
	II	68 (47.3)	32 (22.1)	69 (50.1)	62 (45.3)
	III	71 (52.7)	96 (68.8)	66 (49.9)	73 (54.7)
	IV	–	11 (9.1)	–	–
	V	–	–	–	–

TABLE 2

RESULTS OF DIFFUSION-WEIGHTED MAGNETIC RESONANCE IMAGING OF PROXIMAL INTERVERTEBRAL DISC IN PATIENTS OF THE STUDIED GROUPS

Indicator	Group I (n = 139)		Group II (n = 135)	
	before the surgery	in 60 months	before the surgery	in 60 months
Apparent diffusion coefficient (mm^2/s), Me (25; 75)	1422 (1366; 1471)	1118 (1017; 1293)	1438 (1367; 1492)	1412 (1338; 1482)

TABLE 3

DENSITY INDICATORS OF THE ELEMENTS OF FACET JOINT OF THE UPPER ADJACENT LEVEL IN PATIENTS OF THE STUDIED GROUPS

Indicators	Group I (*n* = 139)		Group II (*n* = 135)	
	before the surgery	in 60 months	before the surgery	in 60 months
Cartilaginous plate density, HU	164.8 ± 14.2	221.2 ± 10.5	161.7 ± 15.8	171.2 ± 3.9
External facet density, HU	713.65 ± 13.6	1035.3 ± 21.6	702.43 ± 12.3	730.9 ± 4.8
Internal facet density, HU	582.1 ± 15.1	899.9 ± 9.2	575.5 ± 11.6	586.2 ± 4.1

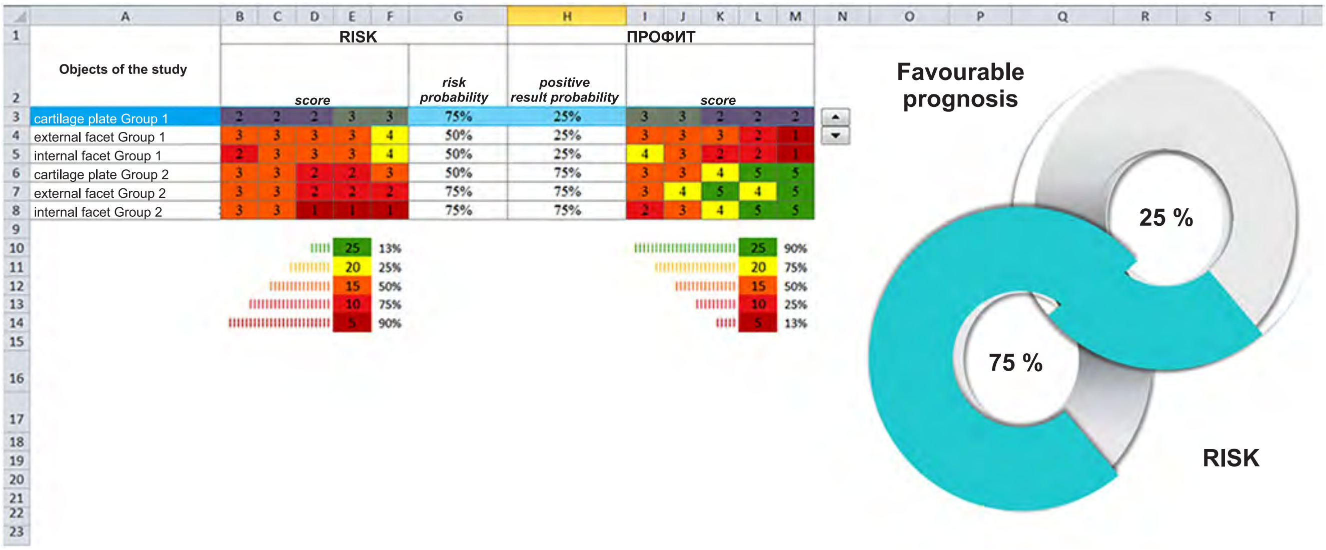

FIG. 5.

Comparative analysis of the state of facet joint with an assessment of the risks of degeneration progression and positive treatment results after rigid fixation (group I)

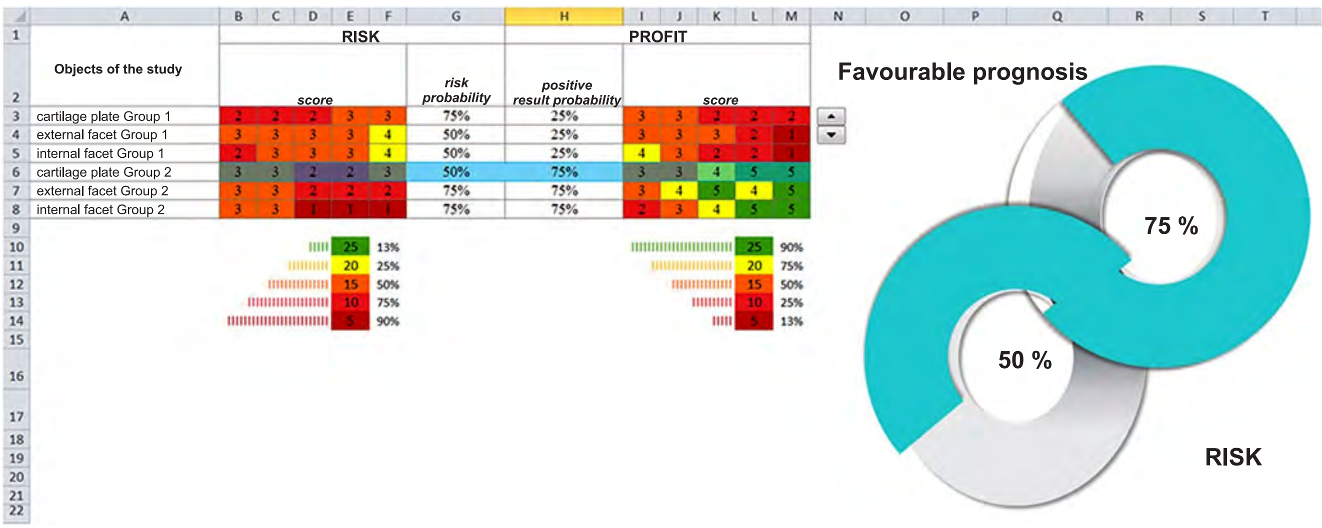

FIG. 6.

Comparative analysis of the state of facet joint with an assessment of the risks of degeneration progression and positive treatment results after dynamic stabilization (group II)

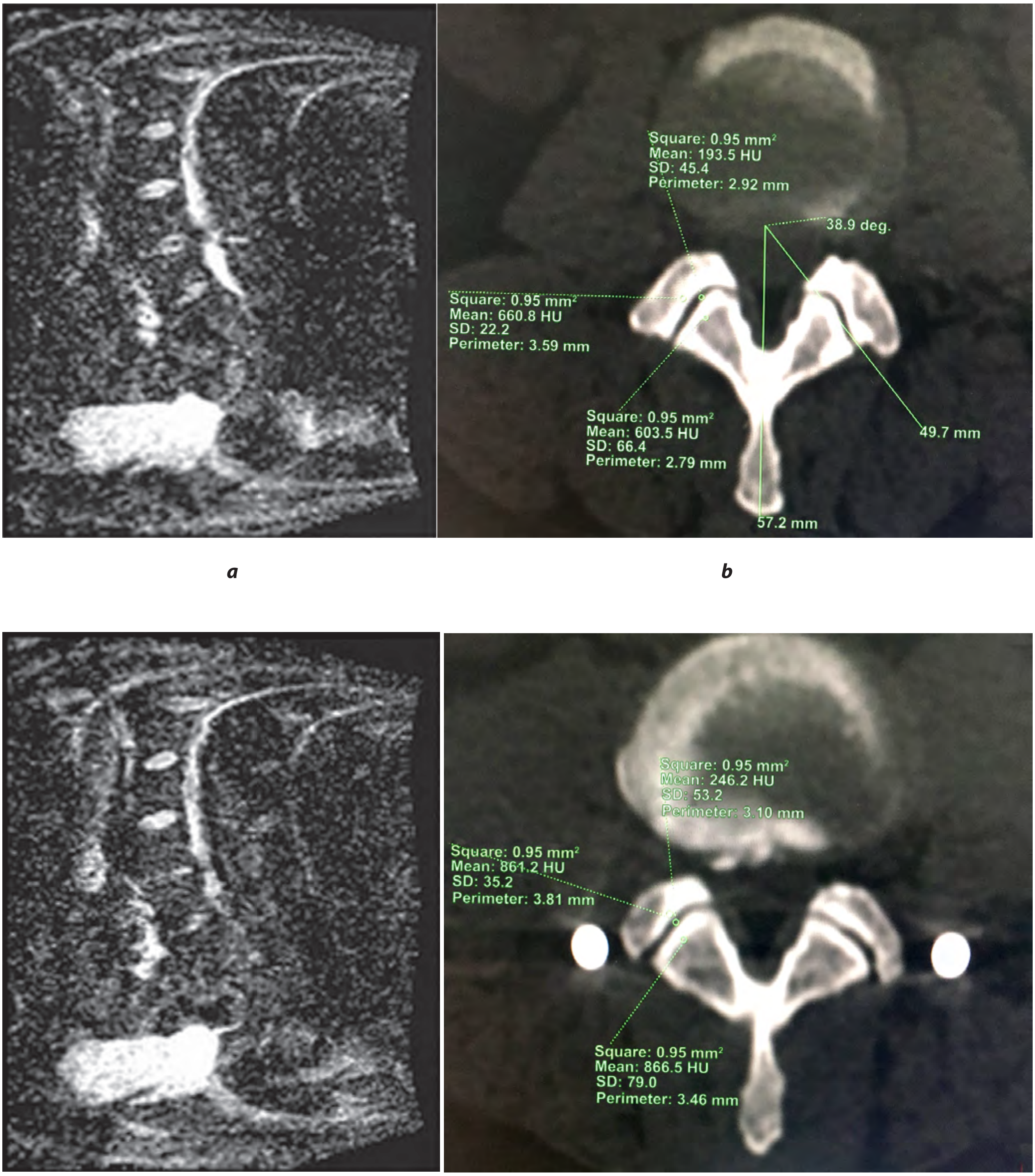

FIG. 7.

Patient S., 32 years old. Degenerative diseases of the lumbar spine in the L_V–S_I segment: ***a*** *– diffusion-weighted magnetic resonance imaging (apparent diffusion coefficient: L_V–S_I – 1102 mm^2/sec, L_{IV}–L_V – 1415 mm^2/sec);* ***b*** *– axial projection of computed tomography of facet joint (cartilaginous plate density – 193.5 HU, outer facet density – 660.8 HU, inner facet density – 603.3 HU);* ***c*** *– sagittal projection of diffusion-weighted magnetic resonance imaging after TLIF surgery and open transpedicular rigid fixation (apparent diffusion coefficient: L_{IV}–L_V – 1175 mm^2/sec, negative dynamics);* ***d*** *– axial projection of computed tomography of facet joint after surgical intervention using TLIF technique and open transpedicular rigid fixation (cartilaginous plate density – 246.2 HU, outer facet density – 861.2 HU, inner facet density – 886.6 HU; negative dynamics of an increase in the density of facet joint of L_{IV}–L_V segment)*

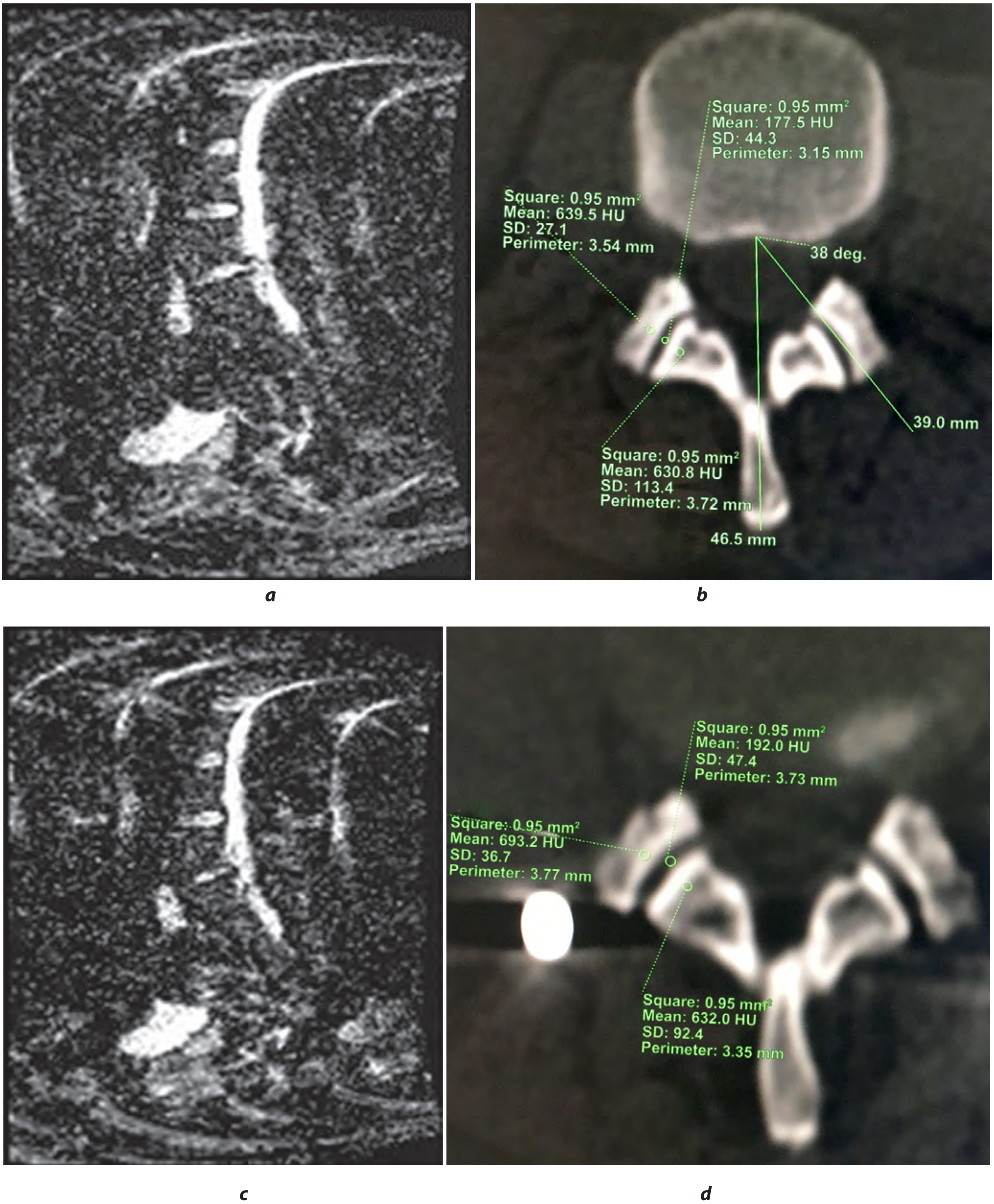

FIG. 8.

Patient N., 36 years old. Degenerative disease of the lumbar spine in the L_V–S_I segment: ***a*** *– diffusion-weighted magnetic resonance imaging (apparent diffusion coefficient: L_V–S_I – 1141 mm²/sec, L_{IV}–L_V – 1424 mm²/sec);* ***b*** *– axial projection of computed tomography of facet joint (cartilaginous plate density – 177.5 HU, outer facet density – 639.5 HU, inner facet density – 630.8 HU);* ***c*** *– sagittal projection of diffusion-weighted magnetic resonance imaging after decompression with stabilization of the operative segment with nitinol rods (apparent diffusion coefficient: L_{IV}–L_V – 1395 mm²/sec, no progression of adjacent level degeneration according to apparent diffusion coefficient);* ***d*** *– axial projection of computed tomography of facet joint after decompression with stabilization of the operative segment with nitinol rods (cartilaginous plate density – 192.0 HU, outer facet density – 693.2 HU, inner facet density – 632.0 HU; slight progression of degenerative processes in the facet joint elements of L_{IV}–L_V segment)*

(Fig. 6), indicating proper distribution of biomechanical stress on the upper adjacent segment.

Clinical examples (Fig. 7, 8) demonstrate the dynamics of degenerative processes in IVD and FJ of the proximal segment in patients of groups I and II according to DW-MRI and DECT data before surgery and 60 months after surgery.

DISCUSSION

Unsatisfactory outcomes following rigid decompressive-stabilizing interventions are mostly associated with disruption of the natural biomechanics of adjacent segment elements [22]. It stimulates both researchers and clinicians, on the one hand, to analyze possible risk factors for ASDD development, while, on the other hand, to use devices that preserve normal biomechanics parameters of the surgically operated and adjacent segments [23, 24]. ASDD affects FJs and IVDs, which are important structural elements of the FSU. Comprehensive preoperative neuroimaging of anatomical structures of vertebral segments allows predicting long-term clinical results and implementing timely prophylactic measures to prevent ASDD development [16, 25].

In their prospective study, J. Anandjiwala et al. [26] revealed a high frequency of signs of adjacent segment degeneration in respondents with initial degeneration of IVD adjacent segments of the III degree according to C.W. Pfirrmann's classification. Similar findings were obtained in a study by J. Liang et al. [27], which clearly emphasises the initial degeneration of IVD of the 3rd degree according to S.W. Pfirrmann, which is one of the most accurate indicators of ASDD development.

The initial FJ degeneration is also important in the stability of the adjacent FSU; for instance, in the work of A.M. Wu et al. [28] it has been found that the initial degeneration of FJ 3rd degree according to A. Fujiwara is also a predictor of the development of instability in the segment. Similar results were obtained in the work of S.V. Hadlow et al. [29] and A. Fujiwara et al. [30]. The authors report insufficient assessment by surgeons of the initial degeneration severity of the adjacent FSU and, in particular, its dynamic structures. This study fully confirms the results of earlier clinical and instrumental studies, and the use of sensitive neuroimaging methods, such as DW-MRI and DECT, allows assessment of degenerative processes at all stages of treatment.

This study clearly demonstrated that patients who underwent posterior trapedicular fixation using nitinol rods had better long-term clinical outcomes; these results correlate with earlier studies demonstrating the efficacy of rod and nitinol versus rigid fixation [31, 32]. For instance, in group II, the progression of degenerative processes in IVD was 5.8 %, and ASDD was registered in only 2 % of cases. In group I, progression of degenerative changes in FJ was registered in the form of an increase in the optical density of the cartilage plate by 13.4 %, in the density of the external facet by 15.1 %, and in the density of the internal facet by 15.6 %. In group II insignificant changes were revealed in the form of increase in optical density: cartilage plate – by 5.7 %, external facet – by 7.8 %, internal facet – by 4.2 %.

Therefore, the combination of initial proximal segment degeneration in the form of FJ degeneration with cartilage plate density of 163.5 ± 14.2 HU, external facet density of 709.35 ± 13.6 HU, internal facet density of 578.1 ± 12.1 HU, IVD degeneration of III, IV degree according to C.W. Pfirrmann, and ADC less than 1300 mm^2/s, there are high risks of ASDD development, which requires the use of monosegmental dynamic fixation with nitinol rods or preventive rigid fixation of the adjacent segment. This will reduce the number of early and late revision interventions, which is consistent with previous experimental studies [33].

Complex neuroimaging in the preoperative period during planning of decompressive-stabilizing interventions makes it possible to assess the state of the proximal IVD and FJ as the main predictors of ASDD development, as well as to predict the long-term clinical results and to initiate preventive measures in a timely manner.

Study limitations

It should be noted that the study conducted has certain limitations. Firstly, the study has a small homogeneous sample without randomization procedure, which may act as a cause of systematic error. Second, the observational study did not take into account the adjacent segment facet angle parameters, FJ tropism abnormality, postoperative fatty degeneration of paraspinal muscles, and vertebro-pelvic balance parameters that influence the risk of ASDD development after lumbar spinal surgery. Third, only one method of ASDD prophylaxis using nitinol rods has been examined in this study without comparison with other types of stabilization.

CONCLUSION

The study has revealed that the combination of initial proximal segment degeneration in the form of FJ degeneration with cartilage plate density of 163.5 ± 14.2 HU, external facet density of 709.35 ± 13.6 HU, internal facet density of 578.1 ± 12.1 HU and ADC of the proximal IVD less than 1300 mm^2/s increases the risk of ASDD development in patients using rigid fixation by 24 %, whereas in patients using dynamic fixation the risk of development is 1.2 %, as the biomechanical parameters of the stabilized segment are preserved and thus there is adequate distribution to adjacent segments.

Using the complex neuroimaging in the preoperative period provides an opportunity to predict the results of surgical treatment, take timely preventive measures to avoid ASDD and perform dynamic monitoring of the processes in the FSU structures.

Conflict of interest
The authors of this study declare no conflicts of interest.

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