INTERRELATION OF TROPISM AND ANGULATION PARAMETERS OF FACET JOINTS AND RESULTS OF STABILIZATION SURGERIES FOR DEGENERATIVE DISEASES OF THE LUMBAR SPINE

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Objective. To clarify indications for dynamic and rigid stabilization based on the analysis of correlation between neuroimaging parameters of facet joints (FJ) and clinical outcomes of surgical treatment of patients with degenerative diseases of the lumbar spine.
Material and Methods. A total of 141 patients with degenerative diseases of the lumbar spine were surgically treated. Patients were divided into three groups: patients of Group I (n = 48) underwent surgical intervention with artificial intervertebral disc prosthesis; those of Group II (n = 42) – with interbody fusion and combined transpedicular and transfacetal stabilization; and those of Group III (n = 51) – with interbody fusion and bilateral transpedicular stabilization. The correlation between long-term clinical outcomes (pain syndrome according to VAS, functional state according to ODI, and satisfaction with surgical result according to MacNab scale) and preoperative neuroimaging parameters of FJ (degenerative changes according to Fujiwara, facet angle magnitudes, and the presence of tropism) was analyzed.
Results. A direct significant nonparametric correlation of neuroimaging parameters of facet angles and FJ tropism with long-term clinical outcomes of surgical treatment according to VAS and ODI was revealed. It was established that good clinical outcomes were achieved with the following preoperative parameters: in Group I, the facet angle was less than 60°, while the presence of tropism had no correlation dependence; in Group II, the facet angle – more than 60°, in the absence of FJ tropism; and in Group III, the facet angle – more than 60°, in the presence of FJ tropism.
Conclusion. Objective neuroimaging parameters of the facet angle magnitude of less than 60°, regardless of the presence of tropism, allow performing total arthroplasty. If the facet angle is more than 60°, the rigid stabilization of the operated segment is indicated; in the absence of tropism, a contralateral transfacetal fixation is possible, and in its presence – a bilateral transpedicular stabilization is reasonable.
Key Words: lumbar spine, degenerative diseases, facet joint, artificial intervertebral disc prosthesis, transforaminal interbody fusion, facet fixation, transpedicular stabilization.
Please cite this paper as: *Byvaltsev VA, Okoneshnikova AK, Kalinin AA, Rabinovich SS. Interrelation of tropism and angulation parameters of facet joints and results of stabilization surgeries for degenerative diseases of the lumbar spine. Hir. Pozvonoc. 2018;15(4):70–79. In Russian.*
DOI: http://dx.doi.org/10.14531/ss2018.4.70-79.

Rigid stabilization is the gold standard for treating most degenerative diseases of the lumbar spine [1–3]. However, there still remain a significant number of unsatisfactory clinical postoperative results due to progression of the degenerative process in the operated and adjacent segments, which is associated with biomechanical disorders [2–4].

Degeneration at the adjacent level develops due to an increased load on the facet joints and intervertebral discs, which is associated with the development of pathological mobility of the functional spinal unit superjacent to the level of rigid stabilization [1–3]. Potential predisposing factors promoting accelerated degeneration of the adjacent level include degenerative changes in the facet joints, the type and length of spinal fusion, changes in the spinal column configuration in the sagittal plane, and preceding surgical manipulations at the adjacent segment [1–4].

In 1928, Brailsford [5] coined the term "facet joint tropism" meaning asymmetry of the right and left facet joints or a more sagittal orientation of one of them. Masharawi et al. [6] claimed that facet tropism is a normal feature of the thoracic spine. Lumbosacral facet tropism is the cause of degenerative diseases [7–11].

To choose the adequate approach to surgical treatment of patients with degenerative diseases of the facet joints, it is necessary to define and substantiate the optimal amount of surgery with allowance for individual degenerative changes in the joint, articular surface orientation and facet angle value, and presence or absence of tropism in order to improve long-term postoperative clinical outcomes, minimize postoperative instability, and restore normal biomechanics to prevent progression of degenerative changes in the lumbar segments [12–15].

The search for therapeutic and diagnostic approaches to optimize surgical treatment outcomes in patients with degenerative diseases of the lower lumbar spine, based on an analysis of clinical and morphological parameters of the functional spinal unit, was the impetus for this study.

The study objective was to clarify the indications for dynamic and rigid stabilization, based on analysis of the correlation between neuroimaging parameters of the facet joints and the clinical outcome of surgical treatment of patients with degenerative diseases of the lumbar spine.

Material and Methods

The study included 141 patients who underwent inpatient treatment in 2013–2016. Three representative groups were identified: group I included patients (n = 48) who underwent discectomy through the pararectal extraperitoneal approach with implantation of a M6 disc prosthesis (Fig. 1a); group II consisted of patients (n = 42) after interbody fusion with a T-PAL cage using the TLIF technique with ipsilateral transpedicular stabilization with the VIPER II system and contralateral fixation with Facet Wedge implant (Fig. 1b); group III involved patients (n = 51) after interbody spinal fusion with the T-PAL cage using the TLIF technique with bilateral transpedicular stabilization with the VIPER II device (Fig. 1c). All patients were operated on by a single surgical team.

The study inclusion and exclusion criteria were based on indications and contraindications for interbody fusion for treatment of clinically significant abnormal mobility of the functional spinal units.

The inclusion criteria were as follows:

– failed conservative therapy, prolonged or recurrent pain syndrome, and persistent neurological deficit ranging from radicular neuralgia to radiculopathy with peripheral paresis;

– a decrease in the height of interbody space by more than 1/3 as compared with the superjacent one;

– the absence of segmental instability signs (segmental angulation of more than 10°, linear translation of more than 4 mm);

–neuroimaging-based symptomatic single-level degenerative disease of the lumbar spine at the L4–L5 and L5–S1 levels.

The exclusion criteria were as follows:

– central spinal stenosis;

– spondylolisthesis with or without spondylolysis;

– severe concomitant pathology;

– significant osteoporosis (a reduction in the BMD by 2.8 SD or more according to the WHO T-score criterion, 1995);

– the need for sagittal balance correction;

– the need for surgical correction of two or more lumbar spine segments.

After surgery, the follow-up period ranged from 24 and to 48 months, with the median being 36 months. We analyzed long-term clinical data (a VAS score for pain in the lumbar spine and lower extremities, an ODI score for assessing functional status, and a MacNab score for satisfaction with the result of surgical treatment) and instrumental parameters determined by MRI of the lumbar spine (severity of degenerative changes according to Fujiwara, facet angle, and facet tropism).

Neuroimaging data were obtained using a 1.5 T Siemens Magnetom Essenza MRI system. Facet angle values were calculated from axial MRI scans using the RadiAnt DICOM Viewer software. Facet tropism was verified when the difference between angles of the right and left joints exceeded 10°.

Statistical processing of the data was carried out using Microsoft Excel and Statistica 8 software. To assess the significance of differences among sample sets, we used the Mann-Whitney nonparametric test for intergroup comparison, the Wilcoxon test for dependent samples, and Pearson 2 for binomial traits; the lower confidence limit was set at $p < 0.05$. Data are presented as the median and interquartile range Me (25; 75).

The principle for calculation of the population sample size was as follows: 37 cases per group would be sufficient to verify the smallest clinically significant difference in the functional status level with an ODI score of 10, a study power standard deviation of 15.80 %, and a statistical significance of 5%. Given this fact, more than 37 patients were recruited in each group.

Results

Basic characteristics of the study patients by gender, age, and constitutional features are presented in Table 1. It was found that operated patients were predominantly males (over 70 %) with overweight (BMI > 25.0).

Long-term (after 24 months, on average) clinical parameters in patients of the study groups in terms of the pain level, functional state (ODI), and degree of satisfaction with the result of surgery (MacNab scale) are shown in Table 2. In group I–III patients with degenerative diseases of the lower lumbar segments, functionally acceptable VAS and ODI scores as well as predominantly good MacNab scores for subjective satisfaction with the results were obtained.

The main clinical parameters that directly correlate with the clinical postoperative outcome and quality of life are the degree of pain (VAS) and the functional status (ODI). Comparison of these parameters with the degree of degenerative changes in the facet joints according to Fujiwara and values of the facet angle and facet joint tropism according to the Karacan method (Fig. 2) revealed a correlation between the long-term result of surgical treatment and the studied neuroimaging parameters (Tables 3, 4).

In group I, the facet angle value was found to significantly correlate with clinical parameters (VAS, ODI) and the sever-

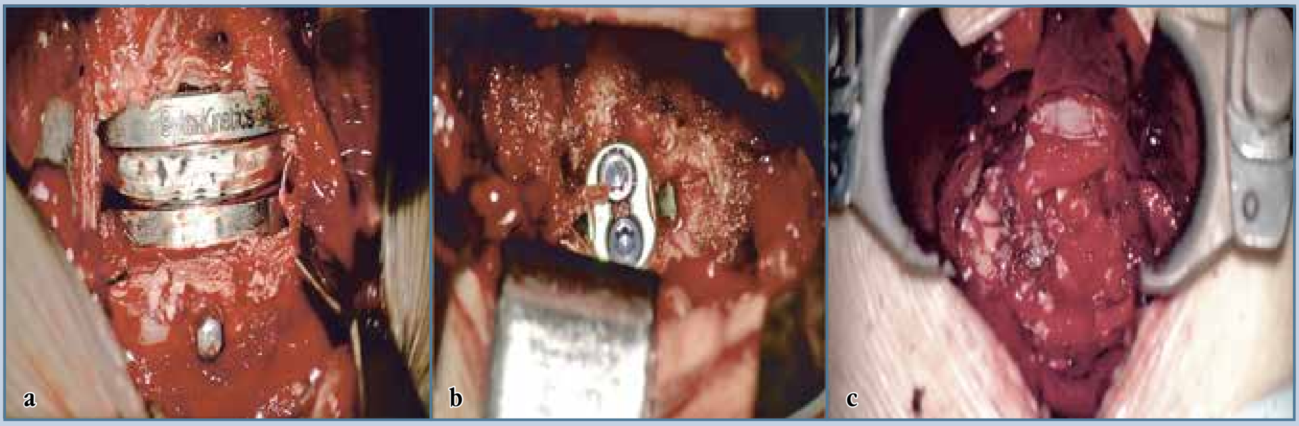

Fig. 1
Types of surgical interventions performed for degenerative diseases of the lumbar spine: **a** – total arthroplasty of the intervertebral disc; **b** – transfacet fixation; **c** – interbody spinal fusion with a cage

ity of degenerative changes according to Fujiwara; there was no correlation with the tropism indicator. In groups II and III, there was an inverse correlation with all studied parameters, except tropism where a significant direct correlation was verified.

Facet joint tropism in group I did not significantly correlate with the studied parameters; in groups II and III, there was an inverse correlation with all studied clinical parameters and a significant inverse correlation with tropism.

Therefore, the facet angle value and, in some cases, facet joint tropism values, which are determined by MRI, directly affect the long-term clinical outcome, which enables defining a potential approach to surgical treatment.

To explore the effect of studied instrumental parameters on the clinical result and investigate the possibility of optimizing the management of patients with degenerative diseases of the lower lumbar spine, the obtained results were divided into a good postoperative outcome characterized by full or almost complete recovery of the previous (before disease onset or before the last recurrence) level of social and physical activity (possible limitation of heavy physical exertion) and into an unsatisfactory outcome characterized by incomplete recovery of daily living and social activities as well as a poor surgical result or worsening of the condition.

A comparative analysis of the dependence of clinical data on the postoperative outcome in the study groups is presented in Table 5.

An analysis of the effect of studied instrumental parameters on the long-term clinical outcome and the possibility of optimizing the management of patients with degenerative diseases of the lower lumbar spine revealed that minimal long-term outcomes (according to VAS and ODI) in patients after dynamic fixation were achieved with the following preoperative parameters of facet joints: grade I–II degeneration (according to Fujiwara) and a facet angle of less than 60°, regardless of the presence of tropism.

A clinical example of the use of total arthroplasty for degenerative disease of the L5–S1 intervertebral disc is presented in Fig. 3. Preoperative clinical examination: the VAS score for pain was 78 mm in the lumbar spine and 82 mm in the lower extremities; the ODI score was 66. Preoperative planning in the L5–S1 segment: the facet angle was less than 60°; there was no tropism. Postoperative clinical examination at 24 months: the VAS score for pain was 5 mm in the lumbar spine and 2 mm in the lower extremities; the ODI score was 6; the MacNab outcome was excellent.

In the group of patients who underwent rigid stabilization, the minimum long-term outcomes, according to VAS and ODI, were achieved with the following preoperative facet joint parameters: grade III–IV degeneration (according to Fujiwara) and a facet angle of more than 60°; in the absence of tropism, contralateral transfacet fixation is possible, and in the case of tropism, bilateral transpedicular stabilization is advisable.

A clinical example of the use of interbody fusion and combined transfacet and transpedicular stabilization for degenerative disease of the L4–L5 intervertebral disc is presented in Fig. 4. Preoperative clinical examination: the VAS score for pain was 77 mm in the lumbar spine and 84 mm in the lower extremities; the ODI score was 68. Preoperative planning in the L4–L5 segment: a facet angle was more than 60°; there was no tropism. Postoperative clinical examination at 24 months: the VAS score for pain was 9 mm in the lumbar spine and 4 mm in the lower extremities; the ODI score was 10; the MacNab's outcome was excellent.

A clinical example of the use of interbody fusion and transpedicular stabilization for degenerative disease of the L4–L5 intervertebral disc is presented

Table 1

Distribution of the study patients by long-term outcomes of surgical treatment

Parameters		Group I (n = 48)	Group II (n = 42)	Group III (n = 51)
Age, years		37.0 (32; 45)	39.5 (33; 49)	40.0 (34; 54)
Gender, n (%)	male	34 (71)	31 (74)	38 (75)
	female	14 (29)	11 (26)	13 (25)
Body mass index, kg/m^2		25.6 (23.1; 29.6)	26.1 (23.3; 29.6)	26.5 (23.6; 29.9)

Table 2

Distribution of the study patients by long-term outcomes of surgical treatment

Parameters		Group I (n = 48)	Group II (n = 42)	Group III (n = 51)
VAS (lumbar spine), mm		10.5 (6; 14)	14 (9; 24)	19 (10; 29)
VAS (lower extremities), mm		8.5 (4; 12)	14 (6; 22)	15.5 (7; 24)
ODI, scores		10 (6; 16)	16 (8; 26)	16 (8; 32)
MacNab scale, n (%)	excellent	20 (42)	18 (43)	11 (21)
	good	25 (52)	15 (36)	27 (53)
	satisfactory	3 (6)	7 (16)	9 (18)
	unsatisfactory	–	2 (5)	4 (8)

in Fig. 5. Preoperative clinical examination: the VAS score for pain was 73 mm in the lumbar spine and 81 mm in the lower extremities; the ODI score was 70. Preoperative planning in the L4–L5 segment: the facet angle was more than 60°; tropism was verified. Postoperative clinical examination at 24 months: the VAS score for pain was 11 mm in the lumbar spine and 5 mm in the lower extremities; the ODI score was 12; the MacNab outcome was excellent.

To improve the surgical treatment outcome in patients with degenerative diseases of the lumbar spine, we developed a diagnostic and treatment algorithm (Fig. 6).

Discussion

In spinal surgery, there are various surgical interventions for degenerative diseases of the facet joints – from minimally invasive keyhole techniques to partial or total facetectomy with rigid stabilization, the results of which are ambiguous [1–3, 17]. This is primarily due to the lack of objective indications for choosing a surgical treatment modality without allowance for individual anatomical features of the facet joints [18].

Poor long-term clinical outcomes associated with the development of adjacent segment disease, postoperative instability, pseudoarthrosis, and cicatricial intracanal changes have encouraged researchers to search for the main causes underlying their development [19, 20]. In this case, the influence of facet angle and facet joint tropism parameters on spinal column biomechanics has been confirmed.

The relationship between individual preoperative facet joint parameters and surgical outcomes is partially analyzed upon total lumbar disc arthroplasty. For example, Shin et al. [18] analyzed the data of 42 patients with an implanted ProDisc-L prosthesis and found a direct correlation between facet joint tropism and the development of pronounced clinically significant spondyloarthrosis after endoprosthetics. There are also studies indicating significant progression of degenerative changes in the facet joints after total arthroplasty, which lack detailed data on preoperative changes in the joint. Shim et al. [19] reported facet joint degeneration in 36.4 % of cases after placement of the Charite prosthesis and in 32.0 % of cases after placement of the ProDisc-L implant. Siepe et al. [20] indicated progression of degenerative changes in the facet joints in 20.0 % of cases within a 53.4-month follow-up after total intervertebral disc replacement with the ProDisc-L implant. Park et al. [21] noted aggravation of clinical and morphologi-

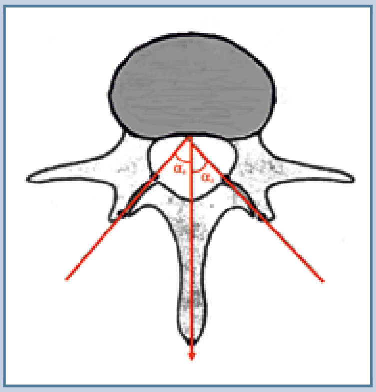

Fig. 2
Measurement of the facet angle (α_1 – for the right facet joint, α_2 – for the left facet joint) and facet joint tropism according to the Karacan method [16]

Table 3

Correlation of the facet angle with long-term clinical parameters (VAS and ODI) and the facet tropism parameter

Parameters	Group I (n = 48)		Group II (n = 42)		Group III (n = 51)	
	R	p	R	p	R	p
VAS score (lumbar spine, 24 months)	0.81	0.009	-0.91	0.005	-0.90	0.002
VAS score (lower extremities, 24 months)	0.79	0.005	-0.92	0.006	-0.89	0.004
ODI score (24 months)	0.90	0.006	-0.90	0.008	-0.85	0.009
Fujiwara grade	0.83	0.008	-0.63	0.003	-0.63	0.003
Facet joint tropism	0.09	0.250	0.95	0.001	0.95	0.001

R is the correlation index; p is the statistical significance level.

Table 4

Correlation of the facet joint parameter with long-term clinical parameters (VAS and ODI) and the facet angle

Parameters	Group I (n = 48)		Group II (n = 42)		Group III (n = 51)	
	R	p	R	p	R	p
VAS score (lumbar spine, 24 months)	-0.44	0.67	-0.98	0.005	-0.99	0.001
VAS score (lower extremities, 24 months)	-0.45	0.51	-0.97	0.007	-0.97	0.004
ODI score (24 months)	-0.18	0.70	-0.97	0.003	-0.95	0.006
Fujiwara grade	-0.41	0.83	-0.82	0.001	-0.82	0.002
Facet joint tropism	0.04	0.75	0.95	0.009	0.95	0.004

R is the correlation index; p is the statistical significance level.

cal changes in the facet joints in 29.3 % of patients after implantation of the ProDisc-L intervertebral disc prosthesis.

In this study, the interrelation between neuroimaging parameters of the facet joints and the clinical outcome of surgical treatment in patients with degenerative diseases of the lumbar spine was evaluated to clarify the indications for dynamic and rigid stabilization. It should be emphasized that the influence of facet angle and facet joint tropism parameters on the long-term clinical outcome after interbody spinal fusion as well as transfacet and transpedicular stabilization was not previously studied.

Therefore, the performed comprehensive clinical and morphological analysis demonstrates that identification of the facet joint degeneration stage according to Fujiwara with estimation of the facet angle and facet tropism parameters according to the Karacan method and allowance for the apparent diffusion coefficient value derived from DWI-MRI data during preoperative planning is one of the main components in predicting a favorable long-term clinical outcome. The obtained data were used to develop a diagnostic and treatment algorithm based on individual parameters of the facet angle and facet tropism for substantiating the choice of a surgical approach. From a clinical point of view, this clarifies and expands our predecessors' ideas [18, 19, 21] on the role of the facet angle and facet joint tropism in prediction of the long-term postoperative clinical outcome in patients with degenerative diseases of the lower lumbar segments.

Conclusion

The facet angle and facet joint tropism parameters determined by a non-invasive MRI technique enabled objective evaluating the morphological and structural characteristics of facet joints and determining a potential surgical approach. Total arthroplasty of the intervertebral disc is advisable when neuroimaging parameters of the facet angle are less than 60°, regardless of the presence of tropism.

If neuroimaging parameters of the facet angle are more than 60°, rigid stabilization of the operated segment is recommended; in this case, contralateral transfacet fixation may be used in the absence of tropism, and bilateral transpedicular stabilization is used in the presence of tropism.

The study did not have sponsorship. The authors declare no conflict of interest.

Table 5

Comparative analysis of clinical data depending on the postoperative outcome in study groups

Parameters	Group I (n = 48)		p	Group II (n = 42)		p	Group III (n = 51)		p
	good outcomes (n = 41)	unsatisfactory outcomes (n = 7)		good outcomes (n = 36)	unsatisfactory outcomes (n = 6)		good outcomes (n = 43)	unsatisfactory outcomes (n = 8)	
ODI score (24 months), score	6 (6; 8)	16 (16; 18)	0.008	8 (6; 8)	26 (20; 28)	0.001	8 (8; 10)	32 (28; 36)	0.003
VAS score (lumbar spine. 24 months), mm	6 (5; 8)	14 (14; 16)	0.007	9 (8; 10)	24 (22; 26)	0.009	10 (10; 12)	29 (27; 30)	0.001
VAS score (lower extremities, 24 months), mm	4 (3; 5)	16 (14; 18)	0.006	6 (5; 7)	22 (21; 23)	0.002	7 (7; 8)	24 (22; 25)	0.001
Preoperative facet joint angulation, degrees	50 (44; 59)	69 (62; 74)	0.003	70 (62; 78)	52 (48; 56)	0.006	69 (61; 82)	52 (49; 56)	0.008
Preoperative facet joint tropism	+/–	+/–	0.150	+	+/–	0.001	–	+/–	0.002
Fujiwara grade	I (I; II)	II (I; II)	0.220	III (II; III)	III (III; IV)	0.008	III (III; IV)	III (II; III)	0.004

p is the statistical significance level.

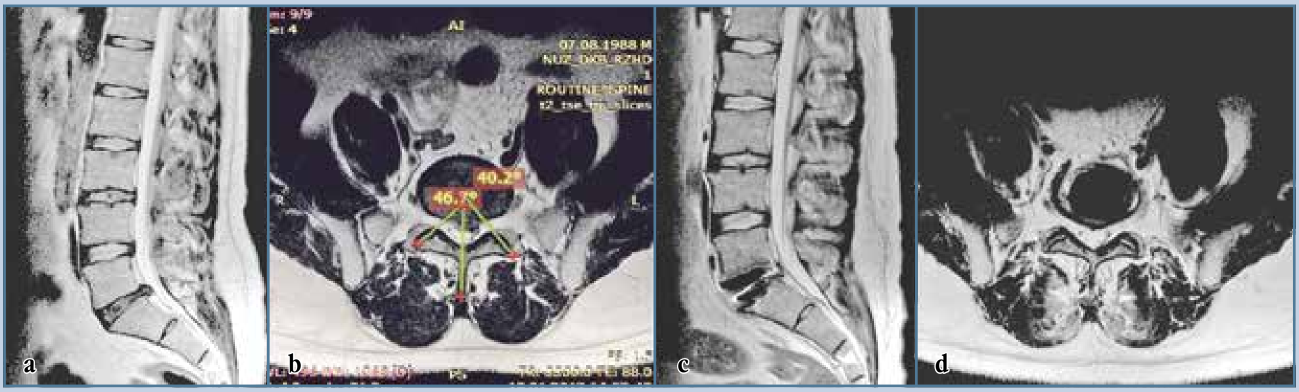

Fig. 3
MRI scans of a 35-year-old male patient R. with degenerative disease of the lumbar spine at the L5–S1 level: **a** – a herniated intervertebral disc on sagittal MRI; **b** – frontal MRI, a method for facet angle calculation; there is no facet tropism; **c** – sagittal MRI, condition after discectomy and total arthroplasty with an artificial disc prosthesis; **d** – frontal MRI, condition after discectomy and total arthroplasty with an artificial disc prosthesis

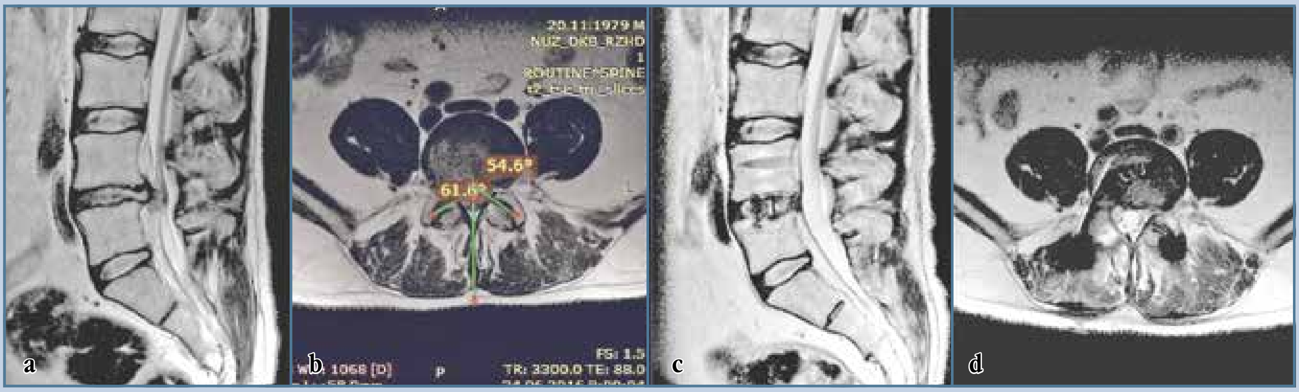

Fig. 4
MRI scans of a 43-year-old patient Kh. with degenerative disease of the lumbar spine at the L4–L5 level: **a** – a herniated L4–L5 intervertebral disc on sagittal MRI; **b** – frontal MRI, a method for facet angle calculation; there is no facet tropism; **c** – sagittal MRI, condition after L4–L5 discectomy. transforaminal interbody fusion, transpedicular stabilization on the right, and transfacet fixation on the left; **d** – frontal MRI, condition after L4–L5 discectomy, transforaminal interbody fusion, transpedicular stabilization on the right, and transfacet fixation on the left

Fig. 5
MRI scans of a 42-year-old male patient G. with degenerative disease of the lumbar spine at the L4–L5 level: **a** – a herniated L4–L5 intervertebral disc on sagittal MRI; **b** – frontal MRI, a method for facet angle calculation; facet joint tropism is verified; **c** – sagittal MRI, condition after L4–L5 discectomy, transforaminal interbody fusion. and transpedicular stabilization; **d** – frontal MRI, condition after L4–L5 discectomy, transforaminal interbody fusion, and transpedicular stabilization

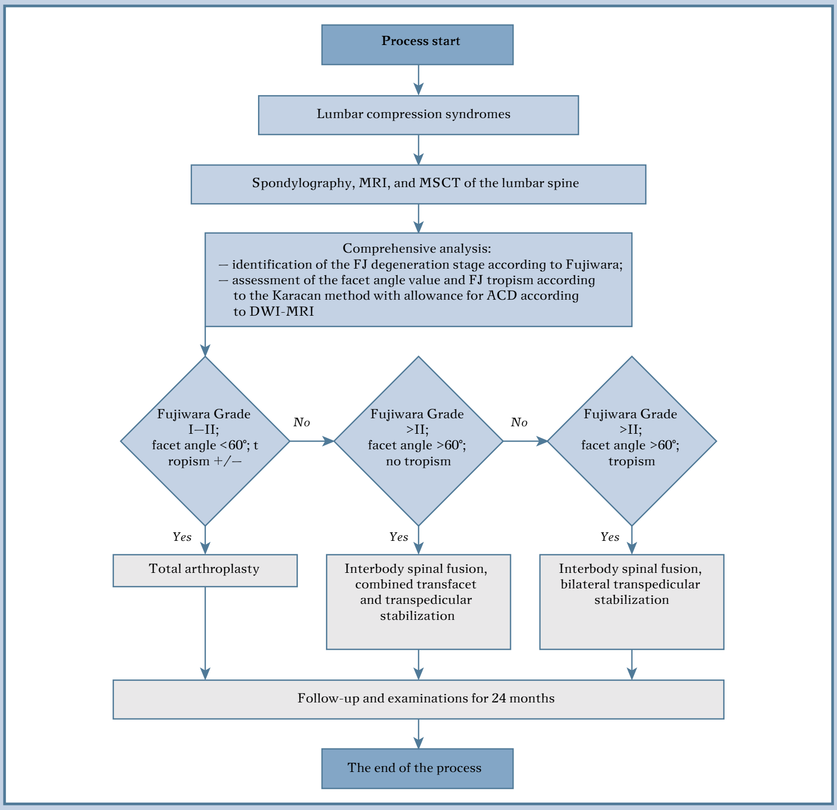

Fig. 6
Therapeutic and diagnostic algorithm based on preoperative clinical and instrumental planning in the treatment of patients with degenerative diseases of the lumbar spine: FJ – facet joint; ACD – apparent diffusion coefficient; DWI – diffusion-weighted image

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Received 27.04.2018
Review completed 17.06.2018
Passed for printing 10.07.2018

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