SEGMENTAL LORDOSIS IN LUMBAR STABILIZATION IN PATIENTS WITH DEGENERATIVE PATHOLOGY: A NON-SYSTEMATIC LITERATURE REVIEW

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Objective. To compare the capabilities of the most common open and minimally invasive TLIF techniques in the correction of segmental lordosis in patients with degenerative diseases of the lumbar spine, based on a non-systematic literature review.

Material and Methods. Study design: non-systematic structured literature review. Articles published for the last 5 years were searched using the following keywords: degenerative, lumbar open mis TLIF, segmental restoration, segmental lordosis, degenerative, spine, TLIF.

Results. Seventeen sources that met the inclusion criteria were included in the study. Among the included original studies, a large variability in the corrective capabilities of open and minimal TLIF was revealed - the achieved values of segmental lordosis/amount of correction can differ by more than 4 times among authors. A number of reasons were identified influencing this but not mentioned in systematic reviews: lack of proper preoperative examination of patients and planning of intervention, ambiguous intraoperative technique for performing correction, different initial values of the segmental angle (kyphosis), and lack of standardized technique for measuring angular parameters.

Conclusion. The corrective possibilities of open and minimally invasive TLIF still need to be clarified. The wide variation of segmental lordosis values in existing articles makes it difficult for an outside observer to correctly interpret the results and requires carefully designed meticulous studies.

Key Words: degenerative diseases of the spine; sagittal balance; segmental angle; lumbar spine; TLIF, transforaminal interbody fusion.

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Manifestations of degenerative diseases of the lumbar spine include regional and/or global sagittal deformities and loss of angular relationships [1], which can manifest themselves in various options of clinical symptoms: axial pain [2], segmental instability [3], and antalgic posture of the body [4], which ultimately reduces the patient's quality of life [1, 5, 6].

Surgical treatment of patients experiencing regional and/or global degenerative spinal deformities, particularly when using instrumentation, requires obligatory consideration of angular parameters and their correction if necessary [1, 5–7]. There are various options for decompression and simultaneous stabilization of the spine, performed to develop the necessary segmental lordosis. They all have similar outcomes regarding intraoperative blood loss, surgery duration, regression of clinical symptoms according to questionnaires and scales, and length of hospital stay [8–10]. Nevertheless, the data concerning corrective opportunities for creating the necessary segmental lordosis are quite controversial: the values for the extent of correction are either not provided or are not clear.

The most common and widely applicable techniques for decompression and stabilization surgeries are open and minimally invasive TLIF [11]. Nevertheless, according to meta-analyses and systematic reviews, the values of the achieved segmental lordosis and target correction angle are within a very wide range. For example, the following values were recorded as a result of MIS-TLIF: before surgery – 11.2°; after surgery – 13.9°; correction extent – 1.5° [12]; and the segmental angle after surgery ranged from 4.5° ± 2.1° to 16.9° ± 3.3° [13]. Following open TLIF, the segmental angle change is 1.604° ± 0.344° [15], ranging from –1.6° to 2.5° [14]. The correction range for both TLIF techniques (open and minimally invasive) varies from 0.05° ± 2.85° to 7.20° ± 11.46° [16]. Therefore, data on the corrective capabilities of the most common open and minimally invasive TLIF techniques may differ by 4 times.

We were curious about this variability in the resulting segmental lordosis following what appeared to be a well-studied procedure, which prompted us to investigate the reasons for this variability in the data.

The objective is to compare the capabilities of the most common open and minimally invasive TLIF techniques in the correction of segmental lordosis in patients with degenerative diseases of the lumbar spine, based on a non-systematic literature review.

Material and Methods

The study complies with clauses 2–10, 13, 16, 17, 19, and 23 of the PRISMA protocol; nevertheless, the review is not systematic: there is no stratification of the risks of systematic errors, and the analyzed data are not represented systematically because of the impossibility of comparing them.

The PubMed, Google Scholar, and eLibrary scientific databases were used to search for articles, with a search depth of 5 years (from 2020 to 2025). The search query included the following keywords in the English-language database: degenerative, lumbar open mis TLIF, and segmental restoration. The following combinations of words were used to search for Russian-language articles in the system: segmental lordosis, degenerative, spine, and TLIF.

Inclusion criteria for review: 1) available full-text articles in Russian or English; 2) single-segment transforaminal interbody fusion (TLIF) for degenerative disc diseases; 3) description of segmental lordosis parameters. The review excluded all articles that did not meet these criteria (Fig. 1). The analysis did not include experimental studies, animal studies, studies of non-targeted types of surgery, including revision surgery, or studies of other non-degenerative pathologies (exclusion criteria). In the same way, articles describing a three-column vertebrotomy (3–6 types according to the Schwab classification system) were excluded from the study.

The publications searched were analyzed according to the following criteria: degenerative pathology, surgical techniques described in the article, balance parameters under study, and segmental lordosis values determined before and after open and/or minimally invasive TLIF. The specific features of the surgical technique were also assessed (*in situ* stabilization of the segment, performance of any corrective maneuvers, segmental release, type of interbody cage, and its position) and specific features of segmental angle measurement (images, measurement techniques, segmental angle values before and after surgery, or angle correction extent).

Results

We found 236 full-text scientific articles corresponding to the initial criteria and published over the last 5 years. Furthermore, studies that did not specifically indicate the values of segmental lordosis before and after surgery or the extent of segmental angle correction, as well as seven non-original studies (meta-analyses, systematic reviews), were excluded from the analysis.

Therefore, 17 publications were included in the study, representing various types of retrospective studies evaluating open TLIF and/or MIS-TLIF. The main characteristics of these sources are given in Table.

The most common types of articles were case series ($n = 7$) or retrospective analyses of completed surgeries ($n = 10$). The prospective studies on the segmental angle in TLIF are presented as case series without specifying the lordosis values; therefore they were not included in the final analysis. The numbers of patients in the analyzed cases in the studies varied from 51 [29] to 192 [6].

The vast majority of articles are focused on comparing the outcomes of decompression and stabilization surgeries using different surgical techniques for interbody fusion (82.4%; 14/17):

- comparison of open or minimally invasive TLIF with ALIF (17.65%; 3/17);
- comparison with lateral techniques like OLIF, XLIF, LLIF (35.3%; 6/17);
- comparison with posterior approaches such as PLIF and PLF (11.76%; 2/17);
- comparison between each other (17.65%; 3/17).

Four articles (23.53%; 4/17) were also found that analyzed the outcomes of similar open or minimally invasive TLIF surgeries (series of clinical cases) [17, 24, 25, 29]. Single-segmental surgeries were studied more frequently (82.4%, 14/17), but there were also studies involving single-segmental and bisegmental surgeries (17.65%, 13/17).

The types of pathologies for which decompression and stabilization surgeries were performed represent the entire range of degenerative disc diseases: degenerative spondylolisthesis, degenerative spinal canal stenosis, intervertebral disc herniation, and facet joint cysts, collectively referred to as “degenerative disc diseases,” as well as isthmic spondylolisthesis.

Regarding preoperative examination to evaluate spinal angle parameters, only one study reported that the authors performed postural radiological imaging of the spine in two planes (using EOS imaging platforms) [31]. At the same time, the parameters of global sagittal balance were not determined; radiological imaging of the lumbar spine was performed in all other studies (rarely indicating that the patient was in a standing position).

Not a single study reported preoperative planning of decompression and stabilization surgery, including calculation of ideal and actual parameters of regional and/or global sagittal balance. Hung et al. [30] described the use of intervertebral cages greater than the height of the disc, which can be considered a preoperative planning option. Berlin et al. [25] straightforwardly reported that target planning of sagittal parameters and lordosis restoration had not yet been performed at the time of data collection in the hospital.

Analyzing the parameters of segmental lordosis obtained by different authors, we discovered another extremely interesting phenomenon – the use of different techniques for measuring the segmental angle. The following options can be found in the articles:

- measurement of the angle between adjacent endplates of the spinal motion segment [18]; some authors refer to this angle as segmental lordosis, while others refer to it as the disc angle [24] (Fig. 2a);
- measurement of the angle between the lower and upper endplates of the spinal motion segment [25] (Fig. 2b).

Among the 13 articles analyzed, segmental angle measurement was performed using the Cobb technique, including vertebral bodies; the segmental angle was defined as the “disc angle” in four articles. Since various measurement techniques were used, it is impossible to compare these studies with each other or to average the data in any way.

Lordotic cages were applied in seven studies (41.18%; 14/17) [19, 22, 23, 25, 29, 30, 32], neutral cages in four (23.53%; 4/17) [17, 20, 23, 24], and banana-shaped or kidney-shaped cages in four (23.53%; 4/17) [17, 20, 24, 29]; other studies did not specify the type of cage. Therefore, the evaluation of segmental lordosis correction using cages of various types was performed in seven studies (41.18%; 7/17).

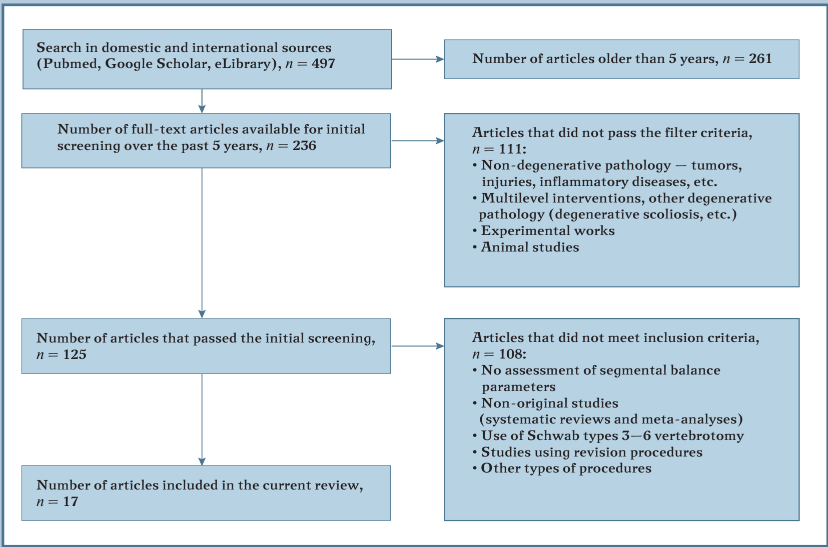

Fig. 1
Schematic algorithm for selecting thematic publications in accordance with the criteria (see the text for explanation)

Berlin et al. [25] describe supplementing the standard TLIF technique with a Schwab grade 2 osteotomy, which unreservedly allows for the creation of a greater segmental angle [33]; nevertheless, the authors achieved a mean segmental lordosis correction of only 4.8° ± 5.7°. Segmental release was not reported in any of the studies. Other reported intraoperative corrective procedures included cage placement in the anterior third of the disc space, described in five studies (29.4%; 5/17) [6, 20, 24, 25, 29]; correction using surgical table in one study (5.9%; 1/17) [17]; and posterior contraction across the rods of the pedicle screw structure in three studies [24, 28], and contraction was being used only in select cases in another study [21] (n = 3; 17.65%; 3/17). It is interesting to note that in 10 studies (58.8%; 10/17), no intraoperative correction of the segmental angle was performed, only *in situ* stabilization of the segment, although in all articles one of the main criteria for evaluating the surgical outcome was restoration of segmental lordosis.

Most of the analyzed articles describe an increased or preserved segmental lordosis after surgery, except for one study, which reported a decrease in the angle of approximately 6° after MIS-TLIF [30]. In another study, the correction range for MIS-TLIF and the use of lordotic bullet cages varied from –9° to 16° [17], i.e., in a number of cases, the authors obtained postoperative segmental kyphosis.

The highest postoperative values of segmental lordosis (31.43° ± 5.89°) were recorded in TLIF with intraoperative corrective procedures [24]; the lowest values were recorded with open TLIF (5.46° ± 3.64°) at the L3–L4 level using lordotic cages [19] and with open TLIF (7.2° ± 4.02°) with *in situ* stabilization [26]. The magnitude of correction (the difference in segmental lordosis before and after the surgery) was reported as 2.5° (range from –9° to 16°) with table-based correction for minimally invasive TLIF [17], 1.04° ± 4.34° for open TLIF with stabilization but with no correction [20], and overall lordosis change for the TLIF, PLIF, and OLIF techniques combined ranged from 6.29° ± 1.9° to 0.93° ± 2.32° [6]. Often, authors provide the mean value of segmental lordosis for all operated levels without categorizing by surgery level or lumbar lordosis type. Therefore, the original studies show a more than fourfold difference in the extent of correction.

Discussion

Nowadays, the standards for using instrumentation in degenerative disc diseases are being changed – the use is reasonable when it is necessary to correct angular relationships in a segment or in the entire sagittal balance of the spine. Previously, the presence of instability in the spinal segment was an indication for stabilization surgeries [3]; nevertheless, there is still no clear and unambiguous definition of this nosology, and therefore the use of instrumentation in this case is controversial.

Failure to account for angular parameters during instrumentation at the lumbar level can result in postoperative imbalance or the development of *de novo* deformity [34], as well as in reduced quality of life and increased postoperative pain [1]. Moreover, unrestored segmental lordosis is a reason for accelerated degeneration of a segment adjacent to bone block [12, 32, 35]. Most of the articles under review are rather difficult to analyze in terms of TLIF correction possibilities because of the unavailability or unstructured nature of data, complex presentation, and diversity of data measurement and analysis techniques [27].

Preoperative planning, harmonious profile, levels of surgery. The decision on the need for segmental angle correction is implemented according to preoperative planning with measurement of sagittal balance parameters [36]. Sagittal balance is evaluated based on postural radiological images of the spine [36, 37] or, less desirably, based on radiological images of the lumbar spine in a standing position with the proximal femurs included, thus evaluating only the spine and pelvis parameters. Nevertheless, despite the evaluation of angular parameters in each of the analyzed sources, there is no gold standard for sagittal profile impairment diagnosis: some authors used lumbar radiographs for evaluation [17], others used postural radiographs [31], and still others used different radio-

Table
The main analyzed parameters of the articles included in the review

Article	Pathology, number of patients	Surgical techniques	Balance parameters and option for segmental angle measurement	Surgical technique characteristics	Segmental lordosis in TLIF techniques before surgery, degrees*	Segmental lordosis in TLIF techniques after surgery, degrees*
Martin et al. [17]	Degenerative stenosis and spondylolisthesis, $n = 100$; isthmic spondylolisthesis, $n = 1$; facet cysts, $n = 4$; disc herniation, $n = 2$	MIS-TLIF	LL, SL with bodies, DH (disc height); measurement of SL with bodies, DA without bodies	Banana-shaped cage, table-based correction only	SL with bodies: MIS-TLIF 18.6 ± 6.4; 14.3 ± 5.7; DA without bodies: MIS-TLIF 8.4 ± 4.2	SL with bodies: MIS-TLIF 20.48; 18.68°
					Correction angle: ΔMIS-TLIF 2.5° (from –9° to 16°)	
Li et al. [18]	Degenerative stenosis, $n = 59$; disc herniation, $n = 29$	MIS-TLIF, O-TLIF	SL, DH; SL measurement without bodies	Cage type is not specified, corrective procedures is not specified	SL without bodies: MIS-TLIF 7.36 ± 3.07; SL without bodies: O-TLIF 9.05 ± 5.48	SL without bodies: MIS-TLIF 10.24 ± 4.79; SL without bodies: O-TLIF 12.34 ± 4.74
Wang et al. [6]	Degenerative spondylolisthesis, $n = 192$	TLIF, PLIF, OLIF	DH, DA, SL, LL; measurement of the L4–L5 SL with bodies, DA without bodies	Cage type is not specified, anterior cage position	SL with bodies: 10.73 ± 5.65; 18.24 ± 6.18; DA without bodies: 6.78 ± 5.10; 11.84 ± 4.79	–
					Correction angle: ΔSL 6.29 ± 1.9; ΔSL 0.93 ± 2.32	
O'Connor et al. [19]	Degenerative and isthmic spondylolisthesis, $n = 98$	ALIF, TLIF	LL, SL, PI, measurement of SL with bodies	Lordotic cage, corrective procedures are not specified	SL with bodies: L5–S1 9.52 ± 6.75, L4–L5 11.43 ± 4.06, L3–L4 8.05 ± 4.00	SL with bodies: L5–S1 16.78±6.46, L4–L5 7.56±4.08, L3–L4 5.46±3.64
Kim et al. [20]	Degenerative spondylolisthesis, $n = 113$	LLIF, TLIF	SL, LL, PI, PI-LL; measurement of SL without bodies	Banana-shaped cage, anterior cage position, indirect decompression only	Correction angle: ΔTLIF 1.04 ± 4.34	
Loubeyre et al. [21]	Degenerative spondylolisthesis, $n = 103$	TLIF, PLF	PI, PT, C7ST, SSA, LL, SL; measurement of SL with bodies	Cage type is not specified or no cage at all; posterior compression was sometimes performed	SL with bodies: TLIF 14,2 ± 6,6	SL with bodies: TLIF 15,6 ± 8,9
Farber et al. [22]	Spondylolisthesis, spondylosis, $n = 108$	MIS-TLIF, ALIF	SL, LL, DA, NH; measurement of SL with bodies, DA without bodies	Lordotic cage, indirect decompression only	SL with bodies: TLIF 19.1 ± 6.3; DA without bodies: TLIF 8.8 ± 5.5	SL with bodies; DA without bodies: TLIF 21.1 ± 5.5; DA TLIF 11.7 ± 4.1
Yingsakmongkol et al. [23]	Degenerative diseases of the lumbar spine, $n = 90$	MIS-TLIF, XLIF, OLIF	DH, FH, SL, LL; measurement of SL with bodies	Direct cage for TLIF, corrective procedures are not indicated	SL with bodies: MIS-TLIF 10,6 ± 5,93	SL with bodies: MIS-TLIF 12,8 ± 6,0
Xie et al. [24]	Degenerative spondylolisthesis, $n = 66$; isthmic spondylolisthesis, $n = 59$	Single-sided TLIF with reduction support	FJA; DH, FH, SL, IA; measurement of SL with bodies, IA without bodies	Kidney-shaped cage, anterior cage position, posterior compression was performed	SL with bodies: L4–L5 18.96 ± 5.88; L5–S1 29.10 ± 5.69; IA without bodies: L4–L5 5.27 ± 3.26; L5–S1 7.53 ± 4.40	SL with bodies: L4–L5 19.89 ± 6.11; L5–S1 31.43 ± 5.89; IA without bodies: L4–L5 6.58 ± 2.77; L5–S1 9.90 ± 4.04
Berlin et al. [25]	Degenerative diseases of the lumbar spine, $n = 121$	TLIF	SL, LL; measurement of SL with bodies	Lordotic cage, anterior cage position, supplemented with Schwab type 2 osteotomy	SL with bodies: 21,0 ± 7,2	SL with bodies: 25,8 ± 6,0

Ending of the Table.
The main analyzed parameters of the articles included in the review

Article	Pathology, number of patients	Surgical techniques	Balance parameters and option for segmental angle measurement	Surgical technique characteristics	Segmental lordosis in TLIF techniques before surgery, degrees*	Segmental lordosis in TLIF techniques after surgery, degrees*
Li et al. [26]	Degenerative diseases of the lumbar spine, $n = 63$	OLIF, TLIF	DH, FH, SL, LL, PT, PI, SS; measurement of fused segmental lordosis (FSL; with bodies)	Cage type is not specified, corrective procedures are not specified	FSL with bodies: TLIF 6,20 ± 3,27	FSL with bodies: TLIF 7,20 ± 4,02
A.V. Spiridonov et al. [27]	Degenerative diseases of the lumbar spine, $n = 98$	MIS-TLIF, O-TLIF	GLL, SLL, PI, PT, SS; measurement of SLL = L4-S1 with bodies, SL with bodies	Cage type is not specified, corrective procedures are not specified	SLL with bodies: L5–S1 22,1 ± 8,9; 22,3 ± 8,6	SLL with bodies: L5–S1 20,2 ± 9,5; 24,9 ± 6,9
Zhu et al. [28]	Low-grade degenerative spondylolisthesis, $n = 112$	MIS-TLIF, anterolateral LIF	DH, LL, SL; measurement of SL with bodies	Cage type is not specified; posterior compression was performed	SL with bodies: MIS-TLIF 14,7± 6,2	SL with bodies: MIS-TLIF 16,9 ± 5,3
Khalifeh et al. [29]	Low-grade degenerative spondylolisthesis, $n = 51$	MIS-TLIF	DH, FH, SL; measurement of SL with bodies	Banana-shaped cage, sometimes lordotic or expandable, anterior cage position	SL with bodies: total 12.2 ± 8.8; static cage 5.6 ± 3.3; expandable 13.7 ± 9.0	SL with bodies: total 16.5 ± 7.7; static cage 9.9 ± 2.9; expandable 18.0 ± 7.7
Hung et al. [30]	Degenerative diseases of the lumbar spine,$n = 62$	MIS-TLIF, OLIF	SL, DH; measurement of SL with bodies	Lordotic bullet cage was selected with size larger than the disc height, no corrective procedures are no specified	SL with bodies: MIS-TLIF 17,12 ± 8,73	SL with bodies: MIS-TLIF 11,43 ± 5,89
Bassani et al. [31]	Degenerative diseases of the lumbar spine, $n = 72$	ALIF, TLIF	PI, PT, SS, LL, LLL, SL; measurement of SL with bodies	Cage type is not specified, corrective procedures are not specified, preoperative postural radiographs (EOS imaging)	SL with bodies: TLIF 19,8 ± 12,3	SL with bodies: TLIF 22,9 ± 5,7
Oikonomidis et al. [32]	Degenerative diseases of the lumbar spine, $n = 138$	TLIF, PLIF	PI, PT, SS, LL, SL; measurement of SL with bodies	Lordotic cage in TLIF, corrective procedures are not specified	SL with bodies: TLIF 21,7 ± 10,1	SL with bodies: TLIF 25,9 ± 10,1

* Segmental lordosis values are presented only for open TLIF and/or minimally invasive TLIF described in the sources. ALIF — anterior lumbar interbody fusion; AL (anterolateral) LIF — anterolateral lumbar interbody fusion; MIS — minimally invasive surgery; TLIF — transforaminal lumbar interbody fusion; PLIF — posterior lumbar interbody fusion; OLIF — oblique lumbar interbody fusion; PLF — posterior lumbar fixation; PI — pelvic incidence; PT — pelvic tilt; SS — sacral slope; LL — lumbar lordosis; SA — segmental angle; SL — segmental lordosis; SSL — segmental lumbar lordosis; DA — disc angle; DH — disc height; FH (NH) — (neuro) foramen height; GLL — global lumbar lordosis; LLL — lower lumbar lordosis; FJA — facet joint angle; C7ST — C7 sagittal tilt; SSA — spinosacral angle.

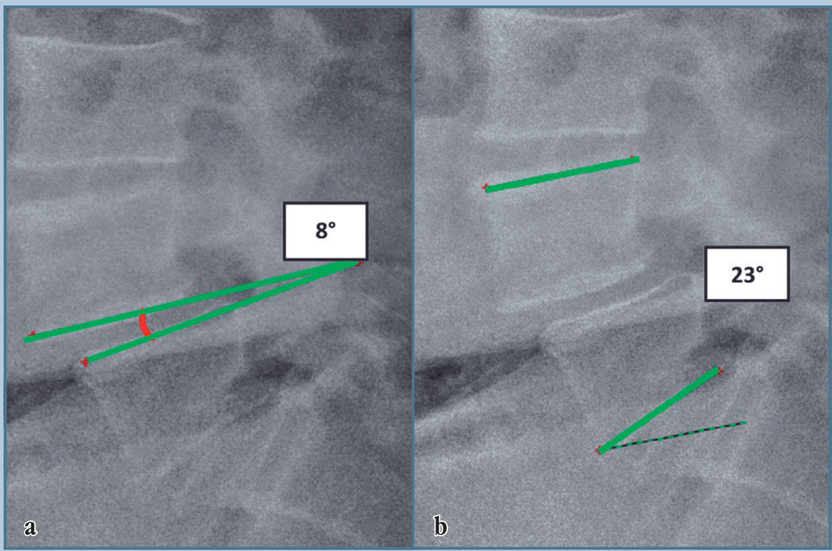

Fig. 2
Examples of measuring the segmental angle without including the vertebral bodies **(a)** and with including the vertebral bodies **(b)** in the measurement

logical techniques for different groups of patients [38].

Many authors [18, 21, 27, 29, 30, 32] give mean values of the segmental angle achieved for all operated levels (L1–S1). It is reasonable to plan the lordosis on each of them in accordance with its harmonious distribution throughout the lumbar spine and in accordance with Roussouly's types, where the lower lumbar lordosis should account for at least 70% of the total lumbar lordosis [39]; it will improve the surgical outcomes for patients with degenerative disc diseases. However, there were no articles presenting similar data on the harmonious distribution of segmental lordosis before and/or after surgery at the lumbar level. The formation of a segmental lordosis of 25.9° ± 10.1° at the same level from L3 to S1 [32] either does not seem to be based on preliminary calculations or is a shortcoming of the methodology used to evaluate the parameters.

Changes in angle values of up to 4° may be associated with inaccuracy of the angular measurement technique [17]; thus, reports of such differences in segmental lordosis before and after surgery (correction extent) provided by many authors [6, 17, 20, 21, 23, 24, 26–28] should be considered carefully.

Interoperative correction. If the segmental angle requires restoration, it is reasonable to perform intraoperative corrective procedures, since the isolated use of a lordotic cage does not always create the desired segmental lordosis: even with a large cage angle, its formation is limited by bone and ligament structures [12]. If there is no intraoperative correction, we consider the use of instrumentation at the lumbar level to be stabilization of the segment *in situ*, and, according to the sources analyzed, the vast majority of surgeons engage in this practice. This may be a possible explanation for such a minor correction only with a lordotic cage or measurement error of segmental lordosis. It should be remembered that the less segmental lordosis (the more segmental kyphosis) before surgery, the more correction may be achieved after surgery [12, 29]. Therefore, when performing the same standard TLIF surgical technique but with consideration of the preoperative segmental angle (kyphosis), the extent of segmental lordosis correction can vary significantly, as we have illustrated with our clinical cases. As an illustration of the corrective capabilities of the same technology, we provide clinical cases from our practice: open TLIF with identical corrective procedures but different final extent of segmental correction.

Clinical case 1. A female patient E., 55 years old, was admitted with polyradicular compression syndrome resistant to conservative treatment for 6 months. Diagnosis: extended degenerative changes of the lumbar spine, grade I degenerative spondylolisthesis at the L4 level and degenerative spinal canal stenosis at the L4–L5 level (Shizas grade C), a segmental kyphotic deformity at the L4–L5 level, neurogenic intermittent claudication syndrome, and polyradicular compression syndrome.

Surgery performed: the L4 decompressive laminectomy, transpedicular fixation, and transforaminal interbody fusion using a graft at the L4–L5 level. During the surgery, a reduction procedure and contraction on the rods were performed to correct the sagittal angular deformity according to the preoperative plan. The radiological parameters two years after surgery are given in the caption to Fig. 3. There were no complications during the entire follow-up period, and the patient is satisfied with the treatment outcome.

Clinical case 2. A female patient S., 67 years old, was admitted with moderate, flaccid, distal lower paraparesis, polyradicular compression syndrome, and resistance to conservative treatment for 4 months. Diagnosis: extended degenerative changes of the lumbar spine, grade I degenerative spondylolisthesis at the L4 level, degenerative spinal canal stenosis at the L4–L5 level (Shizas grade C), neurogenic intermittent claudication syndrome, and compressive-ischemic polyradiculopathy.

Surgery performed: the L4 decompressive laminectomy, transpedicular fixation, transforaminal interbody fusion at the L4–L5 level. During the surgery, a reduction procedure and contraction on the rods were performed to correct the sagittal angular deformity according to the preoperative plan. The radiological parameters two years after surgery are given in the caption to Fig. 4. The regression of neurological deficit as the restoration of all muscle groups to five points was observed 12 months after surgery. There were no complications during the follow-up period, but the patient continued to experience persistent lumbar pain (above and below the level of surgery) that could not be relieved by conservative treatment. The patient rated the treatment outcome as "slightly better than it was initially." This circumstance necessitated the performance of two puncture-based treatment procedures. Residual pain syndrome in the lower extremities is significantly reduced with conservative treatment.

Therefore, clinical cases demonstrate that the implementation of identical surgical techniques and intraoperative corrective procedures produced different outcomes when comparing angular parameters before and after surgery. In the first case, a good correction of the segmental angle (~11°) was found during the procedure from kyphosis to lordosis, and other angular relationships were harmonized. In the second case, there was practically no correction (~2°), and standard corrective procedures to develop greater lordosis were not enough. The initial values of the segmental angle (kyphosis) largely define the extent of correction that can be achieved, despite corrective procedures performed during TLIF.

Measurement technique, error of a procedure. Segmental lordosis, or, as some authors call it, the "disc angle," is an absolute value and does not involve any additional structures other than the object of surgery in fusion – the intervertebral space. The vertebral bodies are trapezoid-shaped, and the angle between the upper and lower endplates of a single vertebra is not standard, typical, or constant. It is impossible to compare the values of segmental lordosis obtained by measuring the Cobb angle, considering the vertebral bodies in different patients. Only the correction angle (the difference between pre- and postoperative lordosis values) in this case provides an indication of the corrective capabilities of the technique. Therefore, there is considerable heterogeneity in evaluation techniques and their results, which complicates the external observer's understanding of the final lordosis formation.

A wide range of segmental lordosis values during TLIF is confusing. It has been proposed that such significant differences are associated with differences in the technique used to perform individual stages of the surgery [40], including correction or fixation of the segment *in situ*. Yet, we reached additional conclusions based on our analysis of the literature:

– correction of segmental lordosis was not the target of surgery in any of the articles; it is unknown whether this was necessary, as none of the authors calculated the actual and/or harmonious parameters of sagittal balance.

– different techniques for measuring the segmental angle, the initial value of the segmental angle (kyphosis), and the levels of surgery do not provide a reasonable basis for comparing the results of different authors, and therefore the conclusions of existing meta-analyses and systematic reviews should be interpreted with reasonable doubt.

Therefore, the corrective capabilities of TLIF still need to be clarified. Prospective studies using a uniform protocol are required, where preoperative examination of patients, planning of surgery, intraoperative correction techniques, and measurement of angular parameters will be carried out in accordance with established standards. The results of such studies can be extrapolated to other hospitals and other patient cohorts.

Limitations of the study. This review is unsystematic and focuses only on the

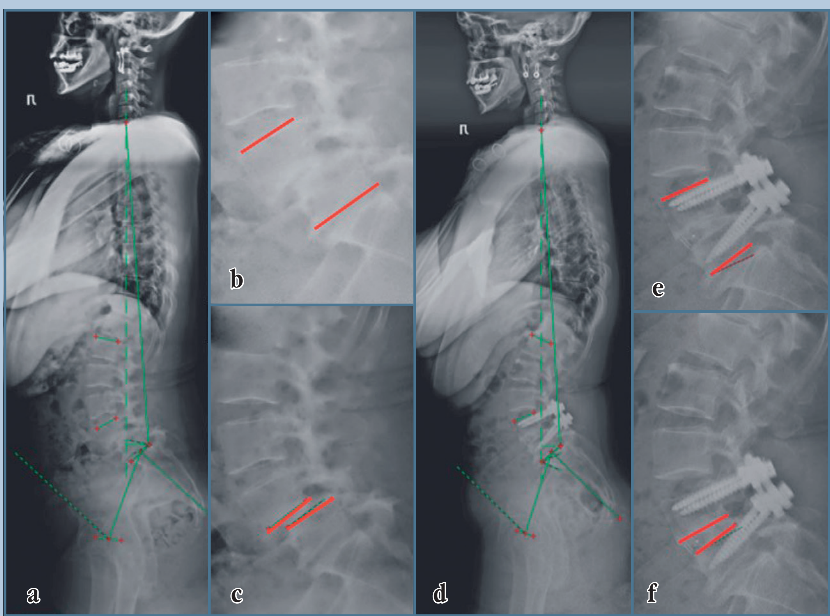

Fig. 3
Postural radiography of the spine (sagittal planes) of a female patient E., 55 years old. Sagittal parameters before surgery: PI – 64°, SVA – 32 mm, LL – 57°, LLL – 13° **(a)**, SL with vertebral bodies is 1° **(b)**, SL without vertebral bodies is –4.0° **(c)**. Calculated (optimal) balance parameters for the patient: LL – 60°, LLL – 40°, SVA – ⩽ 40 mm. Sagittal parameters 2 years after surgery: PI – 64°, SVA – 29 mm, LL – 66°, LLL – 23° **(d)**, SL with vertebral bodies is 13° **(e)**, SL without vertebral bodies is 7°, correction is 11° **(f)**. Considering the segmental kyphosis before surgery, a significant correction of the segmental angle was achieved and segmental lordosis was restored

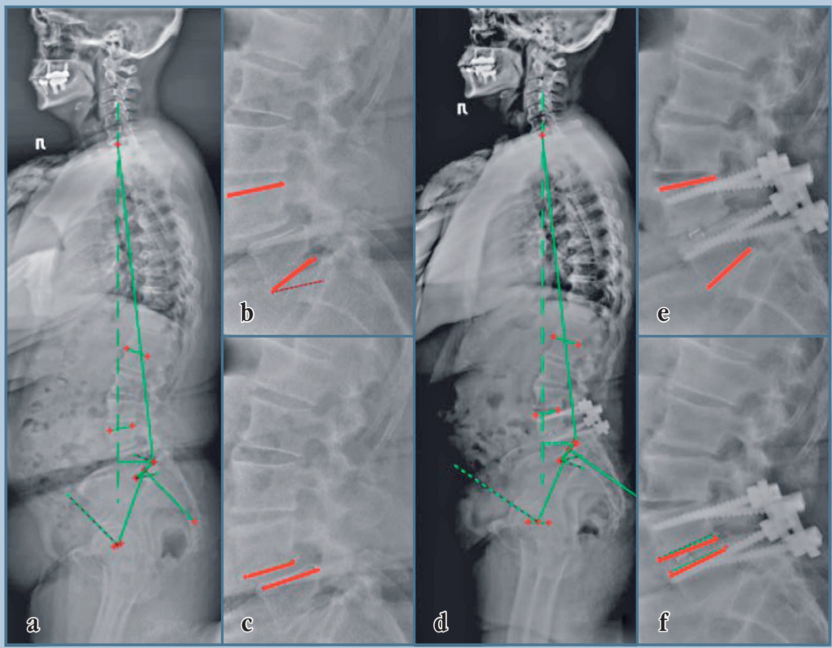

Fig. 4
Postural radiography of the spine (sagittal planes) of a female patient S., 67 years old. Sagittal parameters before surgery: PI – 68°, SVA – 50 mm, LL – 64°, LLL – 30° **(a)**, SL with vertebral bodies is 26° **(b)**, SL without vertebral bodies is 1° **(c)**. Calculated (optimal) balance parameters for the patient: LL – 61°, LLL – 40°, SVA – ⩽ 40 mm. Sagittal parameters 2 years after surgery: PI – 68°, SVA – 48 mm, LL – 69°, LLL – 35° **(d)**, SL with vertebral bodies is 26° **(e)**, SL without vertebral bodies is 3° **(f)**. Despite a significant increase in LLL, the SL value remained almost unchanged

corrective capabilities of open or minimally invasive TLIF. A systematic review of homogeneous sources with error stratification can provide data with a higher level of evidence.

Conclusion

The corrective options for open and minimally invasive TLIF need to be clarified. The existing literature data, including highly evidence-based meta-analyses and systematic reviews, cannot be methodically and systematically evaluated because of the different targets of surgeries, unspecified baseline values of the segmental angle (kyphosis), different levels of surgery, and the lack of a generally accepted/uniform approach to measuring the segmental angle. The authors use a variety of TLIF techniques, both with osteotomy and with *in situ* fixation, which in turn results both in the preservation of an insufficient segmental angle and even in the creation of local kyphosis. It is necessary to perform prospective, including multicenter, studies using a uniform protocol for preoperative examination of patients, planning of surgery, uniform intraoperative correction techniques, and measurement of angular parameters.

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The study was approved by the local ethics committee of the institution.
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