



TRANSFORAMINAL INTERBODY FUSION: POSSIBILITIES OF SEGMENTAL LORDOSIS CORRECTION

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Objective. To determine the possibilities of transforaminal lumbar interbody fusion (TLIF) in creating/correcting a segmental angle at a single lumbar level in case of its degenerative lesion.

Material and Methods. A retrospective analysis included data from prospectively enrolled patients with single-level degenerative stenosis and symptomatic spondylolisthesis. Open TLIF was performed in the first group ($n = 31$), and minimally invasive TLIF – in the second group ($n = 20$). Posterior screw fixation was performed in both groups. Both surgical options included intraoperative correction of the segmental lordosis. Radiographic results at discharge were assessed, and predictors of segmental lordosis value achieved after intervention were identified.

Results. The postoperative segmental lordosis was greater in the open TLIF group than in the minimally invasive group (8° [5.0; 9.0] vs. 6° [4.0; 7.3]; $p = 0.006$). The preoperative segmental lordosis was a predictor of the achieved postoperative segmental lordosis ($\beta = 0.229–0.587$; $p < 0.05$). The postoperative segmental lordosis value had a strong inverse correlation with the value of lordosis correction (r ranged from -0.719 to -0.488 ; $p < 0.000$).

Conclusion. The L4–L5 segment is the most commonly operated level in patients with degenerative stenosis and spondylolisthesis. The median postoperative segmental angle after TLIF (open or minimally invasive) is 7° , when using all arsenal available to the spine surgeon. The smaller the preoperative segmental angle, the greater the potential for intraoperative correction.

Key Words: transforaminal interbody spondylodesis; segmental lordosis; sagittal balance.

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Patients with degenerative spine diseases seek surgical treatment significantly more frequently than those with other spinal pathologies [1]. Spinal fusion is an essential component in the management of various degenerative spine diseases, particularly when sagittal profile correction is required. In such cases, decompression and correction surgeries are performed, where establishing functional segmental conditions within both the motion segment and the entire spinal region is critical. A correctly executed procedure is paramount to ensuring long-term freedom from reoperation, potentially for the remainder of the patient's life [2]. The persistence or worsening of malalignment in the lumbar spinal segment following rigid fixation leads to a reduced quality of life, higher reoperation rates, progression of sagittal imbalance, and the development of adjacent segment disease [4, 5].

Planning decompression and correction procedures with considering of sagittal balance parameters has become

firmly established in the daily practice of spine surgeons. Performing full body X-Ray, measuring actual and ideal sagittal balance parameters, and subsequently determining intraoperative strategy are essential elements in planning spinal fusion. However, which surgical approach should be selected?

The diversity of surgical techniques can be confounding, with each method having its own proponents. However, data regarding the corrective capabilities of transforaminal lumbar interbody fusion (TLIF) – the most widely used method – vary more than fourfold among different authors [6]. If greater correction is required, many authors recommend a multistage procedures [7] or vertebrotoomy (osteotomy) [8]. The optimal approach involves the preoperative selection of an accessible, single-stage method based on its corrective capacity to achieve or adjust the lumbar segmental lordosis.

The objective of this study is to evaluate the capability of TLIF to achieve and correct the segmental lordosis at a single

lumbar level in patients with degenerative spine disease.

Material and Methods

The study is a retrospective analysis of prospectively enrolled patients with degenerative spine diseases. The study protocol was pre-registered (NCT04594980, clinicaltrials.gov), and the study was approved by the Ethics Committee of the N.N. Priorov National Medical Research Center for Traumatology and Orthopedics (Meeting Minutes No. 1/20 dated August 17, 2020, and No. 1/24 dated February 26, 2024). All patients presented with vertebrogenic pain and/or neurological deficit secondary to monosegmental degenerative lumbar spinal stenosis combined with low-grade spondylolisthesis. All patients underwent single-level decompression and stabilization surgery (TLIF and posterior pedicle screw fixation) via either an open or a minimally invasive approach. Preoperative planning of

surgical intervention with considering of actual and ideal parameters of sagittal balance was mandatory.

Interbody fusion was performed with intraoperative correction of segmental lordosis utilizing the surgeon's full technical maneuvers, including anterior cage placement, operating table adjustment, and compression of the transpedicular screw-rod system.

Baseline data were recorded preoperatively (Visit 1) and at discharge (Visit 2) to analyze the following parameters of global and regional sagittal balance and their dynamics, measured on full-body X-ray: spinopelvic parameters, including Pelvic Incidence (PI), Pelvic Tilt (PT), Sacral Slope (SS), Lumbar Lordosis (LL), and Low Lumbar Lordosis (LLL); global balance parameters, including Sagittal Vertical Axis (SVA) and C2-Horizontal Axis (C2-HA); Gille spondylolisthesis type; and regional balance parameters, specifically the segmental lordosis at the index level. The segmental lordosis was measured between the adjacent vertebral endplates (excluding the vertebral bodies). Lumbar spine CT scans were performed in all patients to determine vertebral body Hounsfield unit (HU) values and evaluate the risk of fusion instability.

Continuous data were compared between and within groups using the unpaired Mann–Whitney U test with calculation of the location shift, while categorical data were compared between groups using the two-tailed Fisher's exact test. The correlation between continuous variables and the segmental lordosis was assessed using Spearman's rank correlation coefficient. A generalized multivariate linear regression model was constructed to identify multidimensional associations between continuous variables and the segmental lordosis value. Statistical hypotheses were tested at a critical significance level of $p = 0.05$. The lower limit of statistical power is set at 80%.

Results

The total cohort comprised 31 patients in the open TLIF group and 24 in the minimally invasive TLIF group. The

majority of the cohort were women (76.4%, 42/55), with a median age of 57 [IQR 49–65] years. HU values were sufficient to ensure stable metal fixation, measuring 155 [128; 184] HU.

To ensure a homogeneous cohort, the current analysis included only cases with involvement at the symptomatic L4–L5 level (Table 1), accounting for 92.7% of the total cohort, including 31 and 20 patients for TLIF and minimally invasive TLIF (100.0% and 83.3%), respectively ($p = 0.031$). Preoperatively, the segmental lordosis demonstrated hypolordosis (averaging up to 4° across the entire cohort); therefore, maximal feasible intraoperative lordosis correction was performed in all cases.

The postoperative segmental lordosis was significantly greater in the open TLIF group compared to the minimally invasive group (8° [5.0; 9.0] vs. 6° [4.0; 7.3], $p = 0.006$). Other sagittal balance parameters showed no significant differences between the groups ($p > 0.05$).

Regression analysis revealed that the preoperative segmental lordosis was the only significant predictor of the postoperative segmental lordosis (beta = 0.229–0.587; $p < 0.05$; Table 2), while no other parameters showed significant associations.

Correlation analysis revealed a strong and significant inverse association between the postoperative segmental lordosis and the correction volume (delta), with r values ranging from 0.719 to 0.488 ($p < 0.000$). This indicates that a smaller preoperative segmental lordosis is associated with a greater capacity for postoperative segmental lordosis restoration, provided that targeted intraoperative lordosis correction is performed.

Clinical cases from our practice are presented below to illustrate the corrective capabilities of open and minimally invasive TLIF (Fig.).

Discussion

Recently, spinal surgeons have become more cautious about performing fusion procedures for degenerative spine diseases, such surgeries long considered a near-universal treatment, due to

complications, extensive surgical trauma, and blood loss. [9]. One of the critical factors is restoring functional segmental position, as this significantly influences the patient's future well-being; therefore, restoring lordosis is crucial, even in short-segment fixation [10].

Preoperative considering of actual and ideal sagittal balance parameters, including the segmental lordosis, provides the spine surgeon with a clear understanding of the required lordosis correction volume [11]. The surgical treatment plan is determined by the PI value, the presence of sagittal imbalance, and the activation of compensatory mechanisms.

According to several authors [12, 13], ALIF provides the greatest amount of lordosis correction, while lateral fixation techniques, including DLIF, XLIF, and TLIF, offer a comparable value of correction; though precise quantitative values remain undetermined. According to our data, the mean correction of the segmental lordosis achieved through intraoperative corrective maneuvers during TLIF did not exceed 7° on average in the overall group. According to published data, the amount of correction achieved with TLIF can range from 2.5°, $0.93^\circ \pm 2.32^\circ$, $1.04^\circ \pm 4.34^\circ$, to $1.0^\circ/0.0^\circ$ (–5°; 7°). However, the authors of these studies did not utilize the full spectrum of intraoperative correction maneuvers, more frequently leaving the segmental lordosis *in situ*. Other studies reporting pre- and/or postoperative lordosis values cannot be extrapolated, as the authors utilized different measurement techniques [6], making it impossible to standardize the results.

More predictable and accurate lordosis correction volumes have been identified when performing osteotomies [8], which, depending on the type, provide lordosis restorations ranging from 3° to over 50°, but require greater surgical skill and are associated with a higher rate of complications. The extent of bone resection in minimally invasive TLIF (MI-TLIF) is comparable to a Schwab Grade 1 osteotomy (yielding up to 3–5° of correction), whereas traditional open TLIF is equivalent to a Schwab Grade 2 osteoto-

Table 1

Comparison of sagittal balance parameters and baseline characteristics between open and minimally invasive TLIF groups

Parameter	Open TLIF (n = 31)	Minimally invasive TLIF (n = 20)	Total (n = 51)	p-value
PI, degrees	55.5 [50.0; 64.0]	55.0 [47.5; 59.0]	55 [48.0; 63.3]	0.284
PT, degrees	19.0 [15.0; 27.0]	17.5 [12.3; 24.5]	18 [13.0; 25.5]	0.323
SS, degrees	37.0 [32.0; 42.0]	36.5 [29.3; 43.0]	37 [30.0; 42.0]	0.349
LLL, degrees	28.0 [19.0; 32.0]	29.5 [18.8; 37.5]	28 [19.0; 33.0]	0.140
LL, degrees	52.0 [43.0; 58.0]	52.0 [46.5; 61.8]	52 [46.0; 58.0]	0.249
SVA, cm	3.5 [2.0; 5.5]	3.0 [2.0; 5.5]	3 [2.0; 5.5]	0.483
C2-HA, degrees	3.0 [1.0; 6.0]	4.0 [3.0; 6.0]	4 [2.0; 6.0]	0.170
Gille Type	1A	6.5% (2/31)	5.9% (3/51)	0.103
	1B	54.8% (17/31)	51.0% (26/51)	
	2A	38.7% (12/31)	43.1% (22/51)	
Preoperative segmental lordosis, degrees	3 [2.0; 4.0]	3 [1.3; 3.8]	3 [2.0; 4.0]	0.172
Postoperative segmental lordosis, degrees	8 [5.0; 9.0]	6 [4.0; 7.3]	7 [5.0; 9.0]	0.006

my (yielding up to 5–7°). This difference may account for the greater segmental lordosis achieved with the open TLIF approach. However, a lordosis correction volume of 7° represents the maximum achievable without vertebral body resection or extensive interbody space release, provided intraoperative correction is performed rather than *in situ* fixation. If greater correction is required, alternative osteotomy techniques (such as Schwab type 3 and others) are recommended.

We determined that the magnitude of achievable segmental lordosis obtained via intraoperative corrective maneuvers depends on its preoperative value. Several authors reported similar findings, demonstrating that the preoperative segmental lordosis is a strong, and in some cases the sole, independent predictor of the achieved segmental lordosis [20–22]. These findings hold true for both classic TLIF utilizing a single bullet-shaped cage and interbody cages of alternative designs.

Our findings confirmed that the preoperative segmental lordosis inversely correlates with its postoperative change, demonstrating that a smaller preopera-

Table 2

Predictors of postoperative segmental lordosis

Predictor	β coefficient	p-value
Total cohort, adjusted R ² = 0.25.		
Preoperative segmental lordosis	0.229	0.039
The open TLIF group, adjusted R ² = 0.38.		
Lower lumbar lordosis	0.296	0.010
The minimally invasive TLIF group, adjusted R ² = 0.607		
Preoperative segmental lordosis	0.587	0.000

tive lordosis (or larger kyphosis) allows for a significantly greater magnitude of surgical correction. Achieving a greater segmental lordosis in the presence of an existing yet inadequate lordosis poses a more complex intraoperative challenge [21, 23, 24].

Limitations of data validity. The current study examines only the immediate radiographic outcomes of TLIF decompression and correction performed by the spine surgeon intraoperatively. In the long term, key radiographic outcomes include potential implant subsidence, the rate and development of interbody fusion, loss of correction, and the dynam-

ics of regional and global sagittal balance parameters.

Conclusion

The L4–L5 segment is the most frequently operated level in cases presenting with combined degenerative stenosis and spondylolisthesis. The median postoperative segmental lordosis following TLIF (open or minimally invasive) is 7° using all maneuvers available to a spine surgeon. The smaller the preoperative segmental lordosis, the greater the potential for its intraoperative correction.

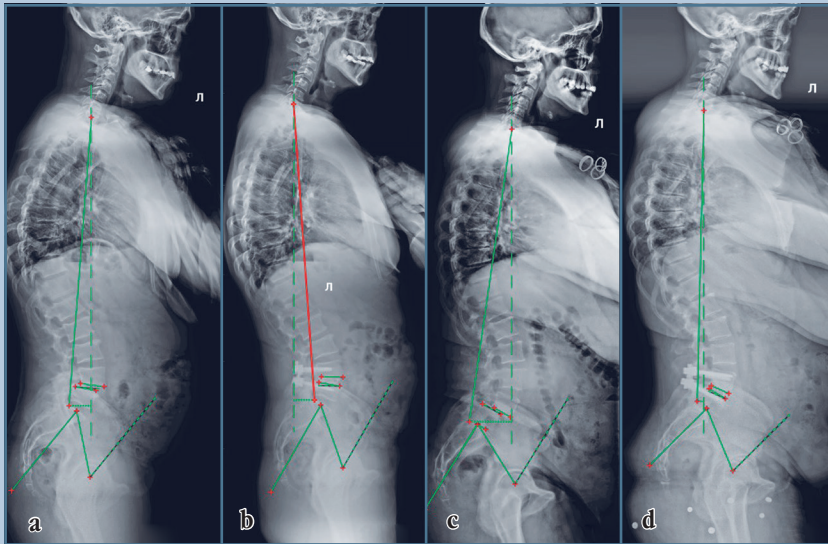


Fig.

Full-body X-Ray of the spine in patients before and after open TLIF (**a, b**) and minimally invasive TLIF (**c, d**): **a** – PI = 53°, PT = 11°, SS = 42°, LLL = 44°, LL = 64°, SVA = 4 cm, C2-HA = 0°; preoperative L4–L5 segmental lordosis – 3°; **b** – postoperative L4–L5 segmental lordosis – 8°; **c** – PI = 69°, PT = 32°, SS = 37°, LLL = 10°, LL = 51°, SVA = 7 cm, C2-HA = 1°; preoperative L4–L5 segmental lordosis – 1°; **d** – postoperative L4–L5 segmental lordosis – 7°

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Informed consent for publication. All participants provided written informed consent prior to enrollment in the study.

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