DOI 10.18019/1028-4427-2018-24-3-341-348

IInfluence of local lordosing transforaminal lumbar interbody fusion on adjacent segments and spino-pelvic relationships. Radiographic study

A.Ia. Aleinik, S.G. Mliavykh, A.E. Bokov, M.V. Taramzhenin

Privolzhsky Research Medical University, Nizhny Novgorod, Russian Federation

Introduction Until now, the rates of poor results of lumbar spinal fusion remain high. It is associated with the development of adjacent segment disease and spinopelvic imbalance. The use of lordosing transforaminal lumbar interbody fusion (cTLIF) is aimed at normalizing the sagittal profile of the operated and adjacent segments. The purpose of this study was to evaluate changes in radiological segmental parameters at the level of spinal fusion, as well as their influence on adjacent segments and spinopelvic relationships. **Methods** The study included 30 patients who underwent 1- or 2-level lumbar fusion using the cTLIF technique. Radiography of the lumbar spine with hip joints prior to surgery and in the early postoperative period was used in all patients. The measurements of sagittal parameters at the level of intervention, in adjacent segments, as well as of spinopelvic relations were made. **Results** Segmental lordosis before the surgery was 4.85 ± 8.021° (-11° to 20°), and 12.58 ± 6.031° (4° to 25°) after it, p < 0.0001; average segmental correction was 8.35 ± 6.64°. Lumbar lordosis increased from 44.97 ± 17.58° to 51.8 ± 11.61°, p = 0.01; negative correlation was found between the correction value of lumbar lordosis and the initial lordosis (r = -0.7510, p = 0.0001). There was a significant decrease in lordosis in the adjacent segment from 8.77 ± 4.57° to 6.83 ± 3.96°, p = 0.015. Spino-pelvic relations improved (PI-LL before the operation was 13.1 ± 11.022° and 7.93 ± 5.97, p = 0.018 after it). There were no significant changes in the pelvic tilt (20.9 ± 7.18° versus 19.1 ± 8.58°, p = 0.13). **Conclusions** cTLIF provides correction of segmental lordosis by 8° on average. In the adjacent segment, there is a significant decrease in the severity of lordosis. Improvement of spinopelvic relations is achieved due to the normalization of the lumbar lordosis pro rata to the pelvic incidence. The use of cTLIF technique does not correct the angle of the pelvic tilt.
Keywords: lumbar spine, lumbar fusion, TLIF, spinopelvic relations, adjacent segment disease, sagittal balance

INTRODUCTION

Back pain associated with degenerative processes in the lumbar spine appears in up to 85 % of the population (according to the literature) throughout their life [1, 2]. Moreover, back pain is the most common cause of temporary disability at the age from 45 to 65 years [2]. Degenerative changes that are initiated in the intervertebral discs may lead to a loss of segmental lordosis, redistribution of axial loads to the functional spinal units with overload of the facet joints and imbalance in the tension of flexors and extensors. This cascade causes chronic pain in the back, having a discogenic, arthrogenic and reflectory nature [3, 4]. With the loss of lordosis in the functional spinal segment, compensatory mechanisms are activated to maintain pelvic balance in space. The main ones are increased lordosis and retro-lysthesis in the adjacent segments, retroversion of the pelvis, flexion in the knee and hip joints [5]. If not treated, the progression of imbalance can result in decompensation of the adaptation mechanisms and chronic pain [6].

Spondylodesis has been currently the "gold standard" for treatment of patients with chronic pain in the back if prolonged conservative treatment fails [1, 7]. The concept of performing this operation is based on the interruption of the degenerative cascade by transferring it to the final stage. One of the most common options for lumbar spinal fusion is a transforaminal one (TLIF) [8]. The first description of TLIF was given by Harms and Jeszenszky in 1998. The main advantages of this spondylodesis variant are the absence of ventral access to the spine and of the need to approach the spinal canal [9].

The main task of the operation as seen by most surgeons at the end of the last century was adequate decompression of neural structures and formation of a complete bony unit. However, it was revealed that the formation of a complete bony unit does not always correlate with a good clinical outcome and does not always advantageous as compared with the operations not associated with spondylodesis, and even with conservative treatment [7, 10, 11]. One of the reasons

Aleinik A.Ia., Mliavykh S.G., Bokov A.E., Taramzhenin M.V. Influence of local lordosing transforaminal lumbar interbody fusion on adjacent segments and spino-pelvic relationships. Radiographic study. *Genij Ortopedii*. 2018. T. 24. No 3. pp. 341-348. DOI 10.18019/1028-4427-2018-24-3-341-348. (In Russian)

for unsatisfactory clinical results after spondylodesis is the development of pathological changes in adjacent segments and disorders of the spino-pelvic relations resulting from adaptation to segmental imbalance [12]. In the recent literature, the importance of restoring the configuration of the functional spinal unit and, above all, its sagittal profile, has been emphasized in the performance of spondylodesis [13, 14, 15, 16]. In 2006, N. Anand and co-authors described an improved technique for TLIF implementation focusing on restoring segmental lordosis, the so-called cantilever TLIF (cTLIF). The main difference of this variant of the operation is the rotation of the functional spinal unit in the sagittal plane around the support cage, installed in the transverse direction to the axis of rotation [17, 18, 19].

Despite a large number of clinical and biomechanical studies, there is a lack of data on the effect of transforaminal spondylodesis on the parameters of the spino-pelvic sagittal balance. The purpose of this research is to study the changes in radiological segmental parameters at the level of spinal fusion with the cTLIF method, as well as their influence on adjacent segments and spino-pelvic relations.

MATERIAL AND METHODS

The study included 30 patients with symptomatic degenerative diseases of the lumbar spine (ICD-10 M48 – spinal stenosis, M43 – degenerative spondylolisthesis) who had not responded to conservative treatment rendered for more than eight weeks. Exclusion criteria were expressed body balance disorders (offset of the vertical axis drawn through C7 vertebra for more than 5 cm anteriorly relative to the rear point of the upper S1endplate), presence of scoliotic deformity of more than 10° of Cobb, oncologic and traumatic injuries of the spinal column. The average age of the patients (20 females and 10 males) was 57 years (range: 18 to 76 years).

All patients underwent a cTLIF procedure at one (13 patients) or two levels (17 patients) by one surgeon. In total, spondylodesis was performed at 48 levels: L3-L4 (8 cases), L4-L5 (25 cases), L5-S1 (15 cases).

Surgical technique

1. The patients were in a prone position on the orthopedic frame with abutments under the chest and iliac spine and thighs with their lower limbs straightened. This position creates lumbar lordosis, avoids pressure on the abdominal cavity and lowers the pressure in the basin of the inferior vena cava.

2. The following surgical approaches were used: A – a classical posterior median access with skeletization of arches, facet joints and transverse processes on both sides. It opens the overlying joint, so special attention was paid to preserving the joint capsules intact at the higher level (this approach was used in 21 patients); B – L. Wiltse's paramedian intermuscular approach and its modifications [20]. The advantage of this option is preservation of the paravertebral musculature; in addition, the access direction provides a comfortable trajectory for performing discectomy without the need for significant muscle retraction, especially in overweight patients (this option was used in 4 patients); C – a mini-access using tubular retractors by separating muscle bundles. The latter option is a technological development of Wiltse approach. This type of access provides minimal trauma to soft tissues, but imposes additional requirements to the instrumentation used because of the limited operational port (this variant was used in 5 patients).

3. All patients underwent unilateral complete facetectomy from the side of the most pronounced clinical manifestations. If detection of more intensive clinical manifestations was not possible, facetectomy was performed on the left (according to the preferences of the surgeon). If mobility in the segment was absent and correction of lordosis was not possible, partial resection of the facet joint on the contralateral side was performed to achieve adequate segment mobility.

4. Decompression of the spinal cord roots was performed on the basis of clinical data supported by the results of MRI and CT, and in the amount necessary for free neural elements. Criteria for sufficient decompression were the appearance of dural sac pulsation, complete mobility of the spinal cord roots in the zone of intervention, as well as free passage of a buttoned 2-mm probe in the region of the lateral pocket and root foramina.

5. Discectomy was performed at the maximum volume through unilateral transforaminal access. The height of the disk was gradually restored with the use of enhancing rotary disk expanders. In some cases, to facilitate the removal of the disc, a dilator was installed

in-between the arches; or distraction was performed with the transpedicular screws on the contralateral side.

6. Prior to cage placement, crushed autografts from bone structures resected by decompression (at least 5 cm3) were placed in the ventral areas of the disk; spongy allografts were used if bone material was not sufficient.

7. Curved banana-shaped cages were used, located perpendicular to the sagittal plane. Initially, the cage is introduced in an oblique direction and then is reversed into a transverse position after reaching the ventral parts of the disk. To achieve the greatest correction of lordosis, the cage was moved in the dorsal direction; we consider the border between the front and middle third of the disk to be the optimal. The position of the cage was controlled radiographically by anteroposterior and lateral views.

8. After the adjustment of the cage, a final fixation of the transpedicular system was carried out; a compressive force was applied to the screws on both flanks in order to strengthen segmental lordosis. Next, the condition of the spinal canal was checked again to avoid secondary compression.

X-rays of the lumbosacral spine before surgery and in the early postoperative period after verticalization (2-3 days after the operation) were studied in all patients. Radiography was performed in a standing position without additional support on 30 inch cassettes with capture of the lumbar spine and hip joints. The radiographs were assessed by an independent radiologist in the Vidar Dicom Viewer 2.1 system.

The following parameters were evaluated: lumbar lordosis (LL) – the angle between the cranial endplates of L1 and S1 (LLbs – before surgery, LLas – after surgery), pelvic incidence (PI) – the angle between the line connecting the center of rotation of the femoral heads with the center of S1 endplate and the perpendicular to the plane of the superior endplate of the sacrum; pelvic tilt (PT) – the angle between the line connecting the center of the upper S1 endplate with the center of rotation of the femoral head and the vertical line (PTbs – before surgery, PTas – after surgery); the sacral slope(SS) – the angle between the upper S1plate and the horizontal line; segmental lordosis (SL) – the angle between the cranial endplate of the upper lying vertebra and caudal endplate of the lower vertebra at the level of spondylodesis; lordosis on the adjacent segment above the intervention level (ASL) – the angle between the cranial plate of the vertebra located above the spondylodesis zone and the caudal plate of the upper vertebra of the spondylodesis zone (**Fig. 1**). The magnitude of the angular correction was calculated as the difference between parameters LL, PT, SL or ASL before and after the operation.

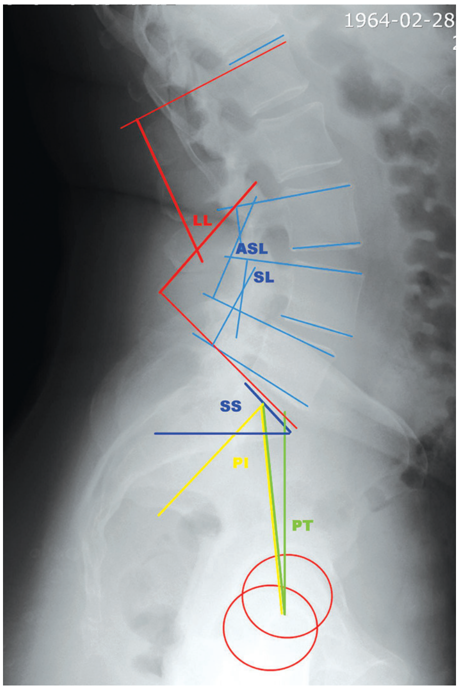

Fig. 1 Parameters of segmental and spino-pelvic balance: lumbar lordosis – LL, pelvic tilt – PT, segmental lordosis – SL, lordosis in the adjacent segment above the intervention level – ASL, sacrum slope – SS, pelvic incidence – PI

StatSoft Statistica 6.0 was used for statistical data processing. To determine the reliability of the differences of independent variables, the Mann-Whitney test was applied and the Wilcoxon test criterion was used for dependent ones. To determine correlation relationships, Pearson's linear correlation method was used after checking the normality of distribution of specific variables. To compare the binary data, the two-sided Fisher's exact test is used.

RESULTS

Table 1 shows the measurement results in all the patients included into the study.

A significant increase in segmental lordosis (SL) after the operation was noted: 4.85 ± 8.021° (-11° to 20°) before the operation versus 12.58 ± 6.031° (4° to 25°) after surgery, $p < 0.0001$. The magnitude of the correction (SLbs-SLas) varied over a wide range, from 0 to 25°, with an average value of 8.35 ± 6.64°.

Table 1

Radiographic parameters before and after surgery

Case No	Segment	Age (years)	ICD code	Approach	Before surgery						After surgery					
					LL (°)	SS (°)	PT (°)	PI (°)	SL (°)	ASL (°)	LL2 (°)	SS2 (°)	PT2 (°)	PI2 (°)	SL2 (°)	ASL2 (°)
1	L3–4	58	M43	TLIF	64	48	18	66	20	13	60	38	28	66	20	11
	L4–5								5						17	
2	L5–S1	71	M43	TLIF	66	51	14	66	0	8	60	42	24	66	17	8
3	L4–5	65	M43	TLIF	46	33	29	52	9	4	65	34	18	52	25	9
	L5–S1								0						15	
4	L4–5	54	M43	TLIF	46	29	28	57	-10	5	60	32	25	57	12	2
	L5–S1								5						13	
5	L3–4	73	M48	TLIF	56	36	18	54	14	12	47	36	18	54	18	8
	L4–5								11						11	
6	L4–5	71	M48	TLIF	32	26	21	47	5	10	39	25	22	47	5	11
	L5–S1								8						10	
7	L4–5	50	M48	TLIF	63	40	8	48	11	15	62	39	9	48	21	15
8	L4–5	50	M43	TLIF	66	40	20	60	15	7	52	32	28	60	15	5
	L5–S1								21						22	
9	L4–5	42	M48	miniTLIF	23	28	23	51	0	4	45	33	18	51	8	2
10	L4–5	44	M48	TLIF	0	10	25	35	-7	-2	30	16	19	35	10	0
	L5–S1								0						15	
11	L6–S1	18	M48	TLIF	65	52	28	80	0	8	84	47	33	80	6	12
12	L4–5	64	M48	miniTLIF	62	38	14	52	8	10	45	30	22	52	12	8
13	L3–4	61	M48	miniOPENTLIF	20	27	31	58	3	11	33	25	33	58	5	4
	L4–5								0						6	
14	L4–L5	68	M43	TLIF	47	31	25	56	17	8	60	38	18	56	25	2
	L5–S1								1						20	
15	L4–5	60	M48	miniOPENTLIF	43	32	25	57	0	20	57	32	25	57	8	6
	L5–S1								20						25	
16	L4–5	74	M43	TLIF	48	24	34	58	-3	15	52	25	33	58	19	17
17	L3–4	64	M48	TLIF	12	22	23	45	-8	4	50	41	4	45	4	4
	L4–5								-2						12	
18	L4–5	72	M48	miniTLIF	45	24	16	40	7	6	42	24	16	40	7	5
19	L3–4	59	M48	miniOPENTLIF	53	31	12	43	7	9	47	30	12	42	5	4
	L4–5								11						8	
20	L4–5	54	M48	TLIF	56	39	16	55	8	6	63	40	15	55	13	7
	L5–S1								0						12	
21	L4–5	38	M48	TLIF	38	37	13	50	10	12	40	36	13	49	18	3
22	L4–5	50	M48	TLIF	44	38	16	54	2	14	52	46	5	51	8	6
	L5–S1								5						18	
23	L4–5	69	M48	miniTLIF	68	40	20	60	12	9	68	52	8	60	12	10
24	L4–5	40	M48	miniOPENTLIF	59	39	9	48	8	9	55	40	7	47	9	8
	L5–S1								16						15	
25	L4–5	76	M48	miniTLIF	56	33	24	57	15	15	47	38	19	57	6	10
26	L3–4	70	M43	TLIF	20	8	26	34	-5	4	33	21	20	41	4	4
27	L4–5	59	M43	TLIF	32	33	37	70	-11	9	59	50	34	84	14	8
	L5–S1								-10						6	
28	L4–5	46	M43	TLIF	28	30	14	44	2	2	44	34	10	44	9	3
	L5–S1								9						20	
29	L3–4	51	M43	TLIF	48	31	17	48	3	8	56	32	13	45	5	8
	L4–5								1						10	
30	L3–4	44	M43	TLIF	43	38	23	61	0	8	47	39	24	63	9	5

Note: TLIF is the standard median access, miniOPEN TLIF – Wiltse paramedian access , miniTLIF – with the use of tube retractors

The mean lumbar lordosis (LL) before surgery was 44.97 ± 17.58° (from 0° to 68°) and 51.8 ± 11.61° after surgery, p = 0.01. The increase in lordosis was reliable.A significant increase in lumbar lordosis was noted in 16 patients (53 %); in 8 (27 %) patients lumbar lordosis the change was not significant (changes within 1-5°), and in 6 (20 %) it decreased significantly . During the analysis, a negative correlation between the correction value of lumbar lordosis and the initial value of lordosis (r = -0.7510, p = 0.0001) was revealed.

The mean value of adjacent segment lordosis (ASL) before surgery was 8.77 ± 4.57° and 6.83 ± 3.96° after surgery, p = 0.015. There was a significant decrease in the severity of lordosis in the adjacent segment. We noted reduction of lordosis at a level higher than the level of the operation in 16 patients (53 %).

The literature shows that the target level of spino-pelvic relations is the ratio of the lumbar lordosis and pelvic incidence (PI-LL), which should not exceed 9° [21]. The determining parameter is PI, since it is morphological and does not significantly change in adults and, therefore, can be a guide for planning corrective operations on the spine [22]. Based on these data, before surgery, disorders of spino-pelvic relations (PI-LL > 9°) were detected in 15 patients. After the operation, deviations were preserved in 5 patients (p = 0.0127). The mean PI-LL before surgery was 13.1 ± 11.022° and 7.93 ± 5.97° after surgery, p = 0.018.

PT before the operation averaged 20.9 ± 7.18°, after surgery it was 19.1 ± 8.58° (p = 0.13). Correlation of lumbar lordosis correction (LLas /LLbs) and PT changes (PTas-PTbs), (r = -0.6010, p = 0.0004) was noted. At present, with certain restrictions, the target level PT ≤ 20° has been adopted [21]. Prior to surgery, retroversion of the pelvis was noted in 16 patients and after surgery it persisted in 12 patients (p = 0.4379). There were no significant changes in the angle of pelvic tilt after surgery.

DISCUSSION

The study gives an idea of what parameters of the spinal and spino-pelvic balance change after local lumbar spinal fusion using the cTLIF technique. Segmental lordosis (SL) at the intervention level is the variable which change is most predictable. According to the literature, the effect of TLIF on segmental lordosis is contradictory. So, according to R.G. Watkins and M. Ould-Slimane, the effect of this procedure is very slight with an average correction of 0.8° for one segment [23, 24]. At the same time, a number of authors noted an increase in segmental lordosis after transforominal spondylodesis [25, 26, 27]. Such significant differences, apparently, are related to the technique of performing the stages of the operation. Our data show that the implementation of spondylodesis using the cTLIF technique allows achieving significant improvement in segmental lordosis, with the greatest effect being achieved in patients with a complete loss of segmental lordosis or local kyphosis, with correction values exceeding 20° per segment (**Fig. 2**, case 1).

Changes in lumbar lordosis after a local spondylodesis using the cTLIF method were not so predictable. At the same time, a significant increase in LL after surgery was noted. However, in 20 % of patients the LL value decreased. The increase in lumbar lordosis was noted mainly in the patients with its loss before surgery. In patients with preserved lumbar lordosis or with lordosis intensification, there was a tendency to reduction of lordosis after surgery, while the ratio of lumbar lordosis and pelvic incidence remains within the target values (**Fig. 3**).

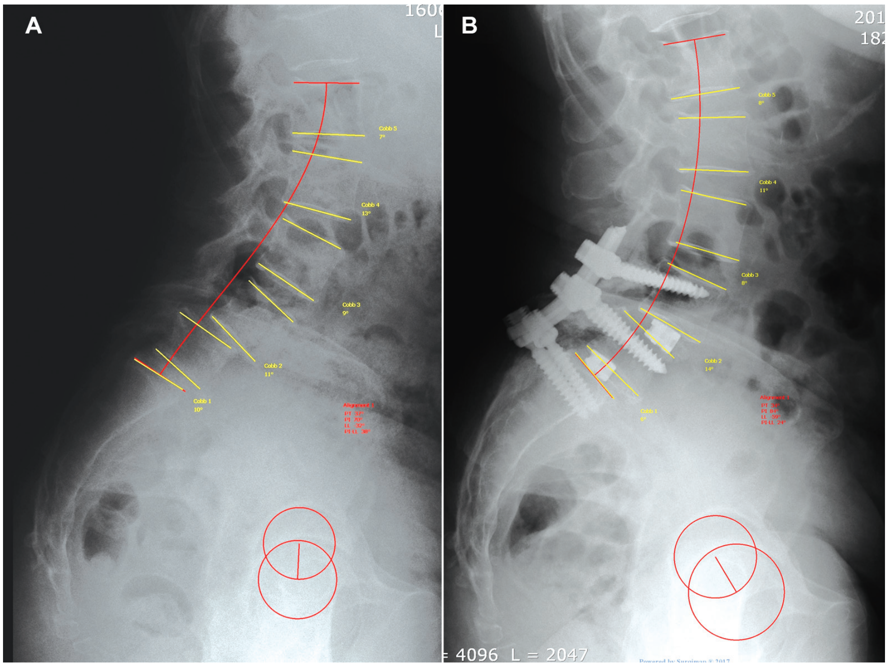

Fig. 2 Clinical case 1 (patient No. 27 from Table 1, 59 years old): A – before the operation there was a loss of segmental lordosis at the level of L4–5, L5–S1 and formation of segmental kyphosis at the level of L4–5 (14°), at the level of L5–S1 (10°); B – restored segmental lordosis after the operation at the level of L4–5 (14°), at the level of L5–S1 (6°). Thus, the segmental correction at the level of L4–5 was 25° and 16 ° at the level of L5–S1. At the adjacent level of L3–4, a decrease in segmental lordosis was noted (8° before surgery and 4° after surgery). Lumbar lordosis increased from 32° to 59°

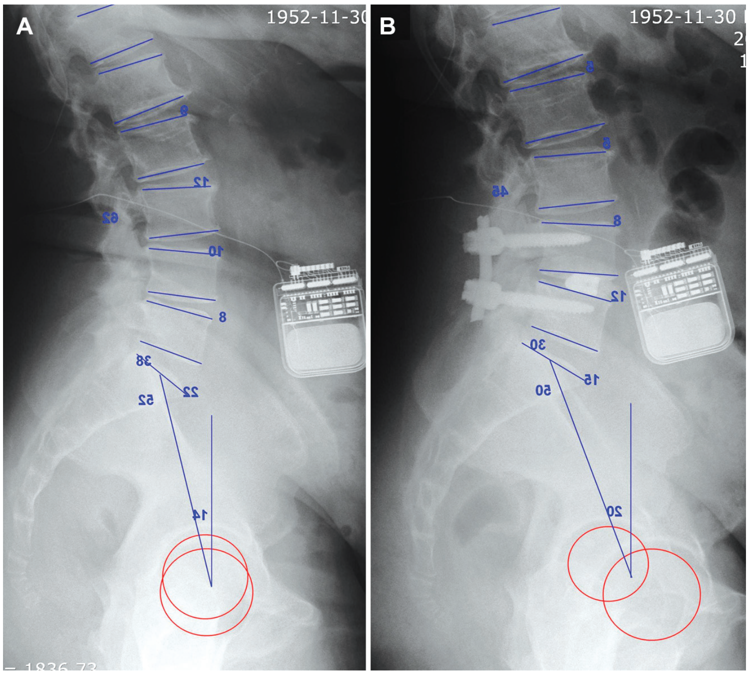

Fig. 3 Clinical case 2 (patient No. 12 from Table 1, 65 years old): A – before surgery: SL – 8°, ASL – 10°, LL – 65°, PT – 14°, PI–LL – 10°; B – after operation: SL – 12°, ASL – 8°, LL – 45°, PT – 20°, PI–LL – 7°

The value of pelvic tilt (PT) is an indicator reflecting the activity of adaptive mechanisms. Thereby, retroversion of the pelvis is an adaptation to a decrease in lumbar lordosis. It was proven that the value of this parameter directly correlates with the intensity of pain [6, 28]. In our study, there were no significant changes in the angle of pelvic tilt (PT) after surgery, which may be associated with short follow-up periods, insufficient for reorganization of adaptive spino-pelvic mechanisms. Thus, lumbar lordosis can be predictably normalized using one- or two-level spondylodesys performed with the cTLIF method in the early period, but there is no reliable correction of pelvic retroversion.

An important problem after performing spondylodesis is the development of a symptomatic syndrome at an adjacent level. According to the literature, the incidence of progressive degeneration of the adjacent segment in the lumbar spinal fusion is 30 %, and of the symptomatic adjacent level disease is 5 %. One of the leading causes of this pathology is the disruption of the biomechanical parameters of the functional spinal unit in spondylodesis [29, 30]. Reduction of segmental lordosis in the proximal adjacent segment occurred in 53 % of our patients. A significant increase in lordosis in the adjacent segment was noted only in two patients. It can be assumed that the normalization of the biomechanical parameters of the operated segment would reduce the tension of adaptive mechanisms in the adjacent segment and decrease the likelihood of a symptomatic adjacent level syndrome in the future.

As can be seen from the data obtained, spinal fusion with the cTLIF method allows significant elimination of lumbar lordosis disorders. However, the possibilities of complete correction of spino-pelvic relations with this technique are limited. The literature shows that a greater angular correction of lumbar lordosis (more than 30°) [21] is needed to correct a significant sagittal imbalance accompanied by a forward shift of the body's balance center [21] than that which is possible with a one- or two-level transforaminal spondylodesis (mean of 8° per segment). This task can be solved by inclusion of more segments in the correction zone in patients with pronounced sagittal imbalance (**Fig. 4**, case 3).

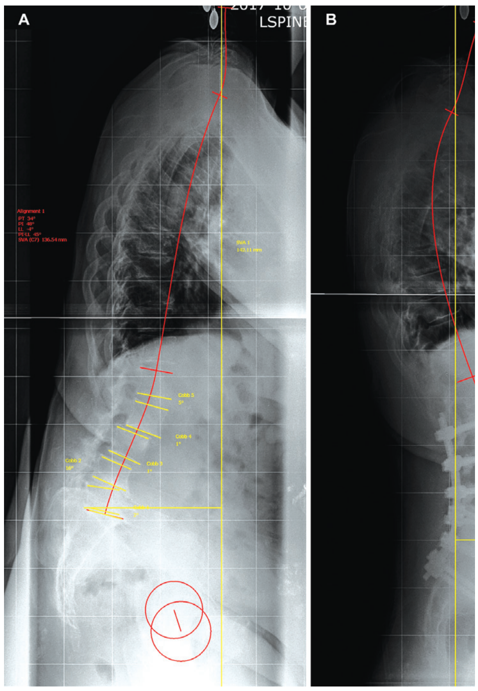

Fig. 4 Clinical case 3 of a 65-year-old patient: A – before surgery, significant spino-pelvic imbalance, loss of lumbar lordosis (LL = 4 °, PT = 34 °, PI–LL = 45 °), a 14-cm anterior vertical shift of the axis conducted through the C7 vertebra (SVA); B – cTLIF on 4 levels with fixation of L2-S2 allowed to completely eliminate this deformity (LL = 50 °, PT = 20 °, PI–LL = 2 °, SVA = -2 cm)

CONCLUSION

Lordosing transforaminal spondylodesis may be used to achieve significant improvement in segmental lordosis from one posterior approach (8° of average correction; can exceed 20° in local kyphosis). Restoration of segmental lordosis leads to normalization of biomechanical parameters of the functional spinal unit located above the spondylodesis level. cTLIF, performed at one or two levels, improves the spino-pelvic balance by normalizing the ratio of lumbar lordosis and the angle of pelvic incidence. However, in a pronounced sagittal imbalance, focal transforaminal spondylodesis does not adequately correct the shift in the equilibrium of the body's axis. In severe sagittal imbalance, this technique can be used as one of the elements of corrective interventions.

REFERENCES

1. Fritzell P., Hägg O., Wessberg P., Nordwall A.; Swedish Lumbar Spine Study Group. 2001 Volvo Award Winner in Clinical Studies: Lumbar fusion versus nonsurgical treatment for chronic low back pain: a multicenter randomized controlled trial from the Swedish Lumbar Spine Study Group. *Spine* (Phila Pa 1976), 2001, vol. 26, no. 23, pp. 2521-2534.
2. Frank J.W., Kerr M.S., Brooker A.S., DeMaio S.E., Maetzel A., Shannon H.S., Sullivan T.J., Norman R.W., Wells R.P. Disability resulting from occupational low back pain. Part I: What do we know about primary prevention? A review of the scientific evidence on prevention before disability begins. *Spine* (Phila Pa 1976), 1996, vol. 21, no. 24, pp. 2908-2917.
3. Jang J.S., Lee S.H., Min J.H., Han K.M. Lumbar degenerative kyphosis: radiologic analysis and classifications. *Spine* (Phila Pa 1976), 2007, vol. 32, no. 24, pp. 2694-2699. DOI: 10.1097/BRS.0b013e31815a590b.
4. Takemitsu Y., Harada Y., Iwahara T., Miyamoto M., Miyatake Y. Lumbar degenerative kyphosis. Clinical, radiological and epidemiological studies. *Spine* (Phila Pa 1976), 1988, vol. 13, no. 11, pp. 1317-1326.
5. Barrey C., Roussouly P., Le Huec J.C., D'Acunzi G., Perrin G. Compensatory mechanisms contributing to keep the sagittal balance of the spine. *Eur. Spine J.*, 2013, vol. 22, no. Suppl. 6, pp. S834-S841. DOI: 10.1007/s00586-013-3030-z.
6. Lazennec J.Y., Ramaré S., Arafati N., Laudet C.G., Gorin M., Roger B., Hansen S., Saillant G., Maurs L., Trabelsi R. Sagittal alignment in lumbosacral fusion: relations between radiological parameters and pain. *Eur. Spine J.*, 2000, vol. 9, no. 1, pp. 47-55.
7. Phillips F.M., Slosar P.J., Youssef J.A., Andersson G., Papatheofanis F. Lumbar spine fusion for chronic low back pain due to degenerative disc disease: a systematic review. *Spine* (Phila Pa 1976), 2013, vol. 38, no. 7, pp. E409-E422. DOI: 10.1097/BRS.0b013e3182877f11.
8. Brislin B., Vaccaro A.R. Advances in posterior lumbar interbody fusion. *Orthop. Clin. North Am.*, 2002, vol. 33, no. 2, pp. 367-374.
9. Harms J.G., Jeszenszky D. Die posteriore, lumbale, interkorporelle Fusion in unilateraler transforaminaler Technik. *Oper. Orthop. Traumatol.*, 1998, vol. 10, no. 2, pp. 90-102. DOI: 10.1007/s00064-006-0112-7.
10. Boos N., Webb J.K. Pedicle screw fixation in spinal disorders: a European view. *Eur. Spine J.*, 1997, vol. 6, no. 1, pp. 2-18.
11. Bridwell K.H., Sedgewick T.A., O'Brien M.F., Lenke L.G., Baldus C. The role of fusion and instrumentation in the treatment of degenerative spondylolisthesis with spinal stenosis. *J. Spinal Disord.*, 1993, vol. 6, no. 6, pp. 461-472.
12. Bredow J., Löhrer L., Oppermann J., Scheyerer M.J., Sobottke R., Eysel P., Siewe J. Pathoanatomic Risk Factors for Instability and Adjacent Segment Disease in Lumbar Spine: How to Use Topping Off? *Biomed. Res. Int.*. 2017, vol. 2017, pp. 2964529. DOI:10.1155/2017/2964529.
13. Booth K.C., Bridwell K.H., Lenke L.G., Baldus C.R., Blanke K.M. Complications and predictive factors for the successful treatment of flatback deformity (fixed sagittal imbalance). *Spine* (Phila Pa 1976), 1999, vol. 24, no. 16, pp. 1712-1720.
14. Akamaru T., Kawahara N., Tim Yoon S., Minamide A., Su Kim K., Tomita K., Hutton W.C. Adjacent segment motion after a simulated lumbar fusion in different sagittal alignments: a biomechanical analysis. *Spine* (Phila Pa 1976), 2003, vol. 28, no. 14, pp. 1560-1566.
15. Kwon B.K., Berta S., Daffner S.D., Vaccaro A.R., Hilibrand A.S., Grauer J.N., Beiner J., Albert T.J. Radiographic analysis of transforaminal lumbar interbody fusion for the treatment of adult isthmic spondylolisthesis. J. *Spinal Disord. Tech.*, 2003, vol. 16, no. 5, pp. 469-476.
16. Recnik G., Košak R., Vengust R. Influencing segmental balance in isthmic spondylolisthesis using transforaminal lumbar interbody fusion. *J. Spinal Disord. Tech.*, 2013, vol. 26, no. 5, pp. 246-251. DOI: 10.1097/BSD.0b013e3182416f5c.
17. Fukuta S., Miyamoto K., Hosoe H., Shimizu K. Kidney-type intervertebral spacers should be located anteriorly in cantilever transforaminal lumbar interbody fusion: analyses of risk factors for spacer subsidence for a minimum of 2 years. *J. Spinal Disord. Tech.*, 2011, vol. 24, no. 3, pp. 189-195. DOI: 10.1097/BSD.0b013e3181e9f249.
18. Hioki A., Miyamoto K., Hosoe H., Sugiyama S., Suzuki N., Shimizu K. Cantilever transforaminal lumbar interbody fusion for upper lumbar degenerative diseases (minimum 2 years follow up). *Yonsei Med. J.*, 2011, vol. 52, no. 2, pp. 314-321. DOI: 10.3349/ymj.2011.52.2.314.
19. Anand N., Hamilton J.F., Perri B., Miraliakbar H., Goldstein T. Cantilever TLIF with structural allograft and RhBMP2 for correction and maintenance of segmental sagittal lordosis: long-term clinical, radiographic, and functional outcome. *Spine* (Phila Pa 1976), 2006, vol. 31, no. 20, pp. E748-E753. DOI: 10.1097/01.brs.0000240211.23617.ae.
20. Anand N., Baron E.M., Bray R.S. Jr. Modified muscle-sparing paraspinal approach for stabilization and interlaminar decompression: a minimally invasive technique for pedicle screw-based posterior nonfusion stabilization. *SAS J.*, 2008, vol. 2, no. 1, pp. 40-42. DOI: 10.1016/SASJ-2007-0120-MIS.
21. Schwab F., Patel A., Ungar B., Farcy J.P., Lafage V. Adult spinal deformity-postoperative standing imbalance: how much can you tolerate? An overview of key parameters in assessing alignment and planning corrective surgery. *Spine* (Phila Pa 1976), 2010, vol.35, no. 25, pp. 2224-2231. DOI: 10.1097/BRS.0b013e3181ee6bd4.

22. Mac-Thiong J.M., Berthonnaud E., Dimar J.R. 2nd, Betz R.R., Labelle H. Sagittal alignment of the spine and pelvis during growth. *Spine* (Phila Pa 1976), 2004, vol. 29, no. 15, pp. 1642-1647.
23. Watkins R.G. 4th, Hanna R., Chang D., Watkins R.G. 3rd. Sagittal alignment after lumbar interbody fusion: comparing anterior, lateral, and transforaminal approaches. *J. Spinal Disord Tech.*, 2014, vol. 27, no. 5, pp. 253-256. DOI: 10.1097/BSD.0b013e31828a8447.
24. Ould-Slimane M., Lenoir T., Dauzac C., Rillardon L., Hoffmann E., Guigui P., Ilharreborde B. Influence of transforaminal lumbar interbody fusion procedures on spinal and pelvic parameters of sagittal balance. *Eur. Spine J.*, 2012, vol. 21, no. 6, pp. 1200-1206. DOI: 10.1007/s00586-011-2124-8.
25. Hsieh P.C., Koski T.R., O'Shaughnessy B.A., Sugrue P., Salehi S., Ondra S., Liu J.C. Anterior lumbar interbody fusion in comparison with transforaminal lumbar interbody fusion: implications for the restoration of foraminal height, local disc angle, lumbar lordosis, and sagittal balance. *J. Neurosurg. Spine*, 2007, vol. 7, no. 4, pp. 379-386. DOI: 10.3171/SPI-07/10/379.
26. Kida K., Tadokoro N., Kumon M., Ikeuchi M., Kawazoe T., Tani T. Can cantilever transforaminal lumbar interbody fusion (C-TLIF) maintain segmental lordosis for degenerative spondylolisthesis on a long-term basis? *Arch. Orthop. Trauma Surg.*, 2014, vol. 134, no. 3, pp. 311-315. DOI: 10.1007/s00402-014-1925-8.
27. Jagannathan J., Sansur C.A., Oskouian R.J. Jr., Fu K.M., Shaffrey C.I. Radiographic restoration of lumbar alignment after transforaminal lumbar interbody fusion. *Neurosurgery*, 2009, vol. 64, no. 5, pp. 955-964. DOI: 10.1227/01.NEU.0000343544.77456.46.
28. Lafage V., Schwab F., Patel A., Hawkinson N., Farcy J.P. Pelvic tilt and truncal inclination: two key radiographic parameters in the setting of adults with spinal deformity. *Spine* (Phila Pa 1976), 2009, vol. 34, no. 17, pp. E599-E606. DOI: 10.1097/BRS.0b013e3181aad219.
29. Cheh G., Bridwell K.H., Lenke L.G., Buchowski J.M., Daubs M.D., Kim Y., Baldus C. Adjacent segment disease following lumbar/thoracolumbar fusion with pedicle screw instrumentation: a minimum 5-year follow-up. *Spine* (Phila Pa 1976), 2007, vol. 32, no. 20, pp. 2253-2257. DOI: 10.1097/BRS.0b013e31814b2d8e.
30. Saavedra-Pozo F.M., Deusdara R.A., Benzel E.C. Adjacent segment disease perspective and review of the literature. *Ochsner J.*, 2014, vol. 14, no. 1, pp. 78-83.

Received: 16.03.2018

Information about the authors:

1. Aleksandr Ia. Aleinik, M.D., Ph.D.,
Privolzhsky Research Medical University, Nizhny Novgorod, Russian Federation;
Email: aaleynik@yandex.ru
2. Sergei G. Mliavykh, M.D., Ph.D.,
Privolzhsky Research Medical University, Nizhny Novgorod, Russian Federation;
Email: serg.mlyavykh@gmail.com
3. Andrei E. Bokov, M.D., Ph.D.,
Privolzhsky Research Medical University, Nizhny Novgorod, Russian Federation;
Email: andrei_bokov@mail.ru
4. Mikhail V. Taramzhenin, M.D.,
Privolzhsky Research Medical University, Nizhny Novgorod, Russian Federation