COMPENSATION MECHANISMS FOR POST-TRAUMATIC THORACOLUMBAR KYPHOSIS

K.O. Borzykh, V.V. Rerikh
Novosibirsk Research Institute of Traumatology and Orthopaedics n.a. Ya.L. Tsivyan, Novosibirsk, Russia

Objective. To identify the mechanism of deformity compensation in patients with post-traumatic kyphosis of the thoracolumbar junction, based on the analysis of X-ray results of surgical treatment.

Material and Methods. The study included data obtained from medical records of 69 patients (47 women, 22 men) operated on for painful post-traumatic kyphosis at the levels of T12, L1 and L2 vertebra. Patients underwent staged surgical interventions in a single surgical session. Demographic data and X-ray results of surgical treatment were evaluated.

Results. As a result of surgical interventions, post-traumatic kyphosis (LK) was corrected to an average of 1.9°. After correction of kyphosis, statistically significant changes in the parameters of sagittal spinal curvatures were revealed: an increase in thoracic kyphosis (TK), a decrease in lumbar lordosis (LL), including due to lower lumbar lordosis (LowLL). At the same time, the parameters of the spinopelvic balance (PT, SS) did not change. Statistically significant correlations ($p < 0.001$) were detected between the magnitude of local kyphosis correction (LK preOP-LKpostOP), which amounted to $33.63° \pm 8.77°$, and parameters of lumbar lordosis ΔLL, thoracic kyphosis ΔTK and ΔPI-LL. Parameters of global sagittal balance and pelvic balance did not show correlations with the magnitude of kyphosis correction. The X-ray study of patients in Group I (without signs of initial sagittal imbalance) and Group II (with signs of sagittal imbalance) revealed a statistically significant difference in global balance (GT) and spinopelvic balance (PT, SS, LowLL), both before and after correction intervention in the thoracolumbar junction area, despite comparable indicators of sagittal spinal curvatures and the magnitude of post-traumatic kyphosis,.

Conclusion. The main compensation mechanism includes changes in the spinal departments adjacent to kyphosis: a decrease in thoracic kyphosis and an increase in lumbar lordosis, rather than changes in the global or spinopelvic balance.

Key Words: post-traumatic kyphosis, thoracolumbar spine, anterior spinal fusion, sagittal balance, staged surgical interventions.

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Post-traumatic kyphosis is often the cause of pain syndrome, functional inability, and advanced neurologic impairment [1–4].

Most frequently (59 %), injuries occur in the area of the thoracolumbar junction, representing 39% of all spinal injuries [5, 6]. Thoracolumbar localization is typical for most post-traumatic kyphosis that highlights its relevance in terms of quantitative superiority over injuries to other departments of the spine.

Post-traumatic deformities, in their majority, are presented by local rigid kyphosis, sometimes very pronounced which cannot but result in compensatory changes in posture.

Post-traumatic kyphosis may be accompanied by initial degenerative changes in the spine, particularly in elderly people. They frequently have a low-energy spinal injury that results in gross rigid post-traumatic deformities due to secondary changes in vertebrae and the formation, for example, of avascular osteonecrosis of the vertebral bodies [7, 8]. Compensatory alterations typical of degenerative disease will accompany compensatory changes associated with post-traumatic kyphoses in this circumstance.

The hypothesis of our study is as follows: it is presupposed that the gross acquired local thoracolumbar kyphosis will be met by pronounced characteristic compensatory responses of the physiological spinal curvatures and the pelvis position, which can be registered after surgical release of the kyphosis factor and reduction of compensatory changes.

The objective is to identify the mechanism of deformity compensation in patients with post-traumatic kyphosis of the thoracolumbar junction based on the analysis of X-ray results of surgical treatment.

Design: the study is retrospective and monocentric.

Material and Methods

The analysis included the data obtained from the case report forms of patients who underwent surgical treatment for post-traumatic spine deformities during the period of 2016–2021.

Patients

Inclusion criteria: patients with post-traumatic kyphosis of the thoracolumbar junction with the apex of kyphosis at the levels of T12, L1, and L2 vertebrae and local kyphotic deformity of at least 30°, able to hold the posture in the upright position.

A total of 69 out of 264 reviewed case report forms met the inclusion criteria.

Patients underwent two- and three-stage single-day circumferential surgeries. Correction of kyphotic deformity at the mentioned levels was carried out by anterior spinal fusion in a single surgical session; the second stage was performed by transpedicular fixation of the corresponding level (Fig. 1).

Release surgeries such as facetectomy or surgical hardware removal were conducted as a preliminary stage in the presence of posterior spontaneous bone fusion and surgical hardware (Fig. 2).

Follow-up period included the entire period of hospital stay.

Techniques

Before and after the surgery, demographic (age, gender) and radiological parameters were measured on a profile X-ray of the spine in the patient's standing position in the conventional pose, in two standard planes from the skull to the middle third of the femur bones, and in the position of the hands to opposite collarbones.

The following parameters of the sagittal contour of the spine were studied: local kyphosis (LK) according to Cobb; thoracic kyphosis (TK) from the cranial plate of the T4 body to the caudal endplate of the vertebra above the injured one; lumbar lordosis (LL) from the cranial endplate below the injured vertebra to S1; and lower lumbar lordosis (Low LL) at the L4–S1 level. The parameters of the spinopelvic balance (PI, PT, SS, and PI-LL) and the parameters of the global balance (SVA) and global tilt (GT) were measured.

In accordance with the classification of the balance status by Lamartina et al. [9] (Table 1), patients were divided into two groups depending on the SVA and PT parameters: Group I ($n = 41$) without signs of imbalance (SVA < 5 cm; PT ⩽ Pti) and Group II ($n = 28$) with signs of pronounced or hidden imbalance (SVA < 5 cm; PT > PTi or SVA > 5 cm; PT > PTi, respectively) [10]. The ideal PT has been individualized via the PI parameter and calculated by the Vialle formula: $PTi = -7 + 0.37 \times PI$ [11].

Statistical analysis

The distributions of continuous parameters were studied for compliance with the normal distribution law using the Shapiro – Wilk test. The homoscedasticity was evaluated by the Fisher's exact test. For comparison of continuous parameters between groups at a certain time point, the Mann – Whitney U test was used; comparison before and after treatment was conducted by the Wilcoxon signed-rank test. The difference between the groups was evaluated as a pseudomedian of pairwise differences in values and a standardized mean difference (SMD) with 95 % confidence intervals (95 % CI). The main descriptive responses of continuous parameters are shown as median [first quartile; third quartile] (MED [Q1; Q3]), auxiliary in the form of "mean ± standard deviation" (MEAN ± SD), and "minimum – maximum values" (min; max).

The identification of pairwise numerical associations between continuous variables was performed by calculating the Spearman's rank correlation coefficient and evaluating the achieved p-value of significance. Scatter plots were built for visual control.

Statistical hypotheses were tested at a critical value of $p = 0.05$, i.e., the difference was considered statistically significant if $p < 0.05$.

All statistical calculations were performed in the RStudio software (version 2022.07.2 Build 576, © 2009–2022, RStudio, Inc., USA, URL https://www.rstudio.com) and in R (version 4.1.3 (2022-03-10), URL https://www.R-project.org).

Results

There were 47 women and 22 men in the study group of patients. The age of patients varied from 18 to 70 years old (mean, 43.6 ± 16.8 years old). The magnitude of the initial kyphotic deformity ranged from 30° to 81° (on average, 35.5°). The patients had a history of spinal injuries with a 6 to 38 month prescription.

Comparison of radiological parameters before and after surgery. Post-traumatic kyphosis of the thoracolumbar spine (LK) was corrected during the surgery (on average from 35.5° to 1.9°). After kyphosis correction, statistically significant changes in all parameters of sagittal curvatures of the spine were revealed: an increase in thoracic kyphosis (TK), a decrease in lumbar lordosis (LL), including due to lower lumbar lordosis (LowLL), and the PI-LL index associated with lumbar lordosis. There were no changes in the parameters of the spinopelvic and global sagittal balances (Table 2).

Correlations between the local kyphosis correction magnitude and radiological parameters. The study revealed statistically significant correlations ($p < 0.001$) between the local kyphosis correction magnitude ($\Delta LK = LKpreOP - LKpostOP$) which amounted to 33.63° ± 8.77°, and parameters of lumbar lordosis ΔLL, thoracic kyphosis ΔTK, and ΔPI-LL (Table 3). Parameters of global sagittal balance and pelvic balance did not show correlations with the correction of kyphosis. Fig. 3 depicts the scatter plots of significant correlations.

Changes in radiological parameters in patients in groups with and without signs of imbalance in the preoperative period. Despite the comparable parameters of sagittal spinal curvatures and the magnitude of post-traumatic kyphosis in the study of radiological parameters of groups I and II, a statistically significant difference in global balance (SVA, GT) and spinopelvic balance (PT, SS) was observed both before and after corrective surgeries on the thoracolumbar junction (Table 4).

Discussion

Post-traumatic kyphosis is defined as "painful kyphotic angulation that can occur in any area of the post-traumatic spine" [12]. De Gendt et al. [13] and O.G. Prudnikova et al. [14] remark that the magnitude of pathological kyphosis in different parts of the spine has different functional significance. In our study, we observed a group of patients

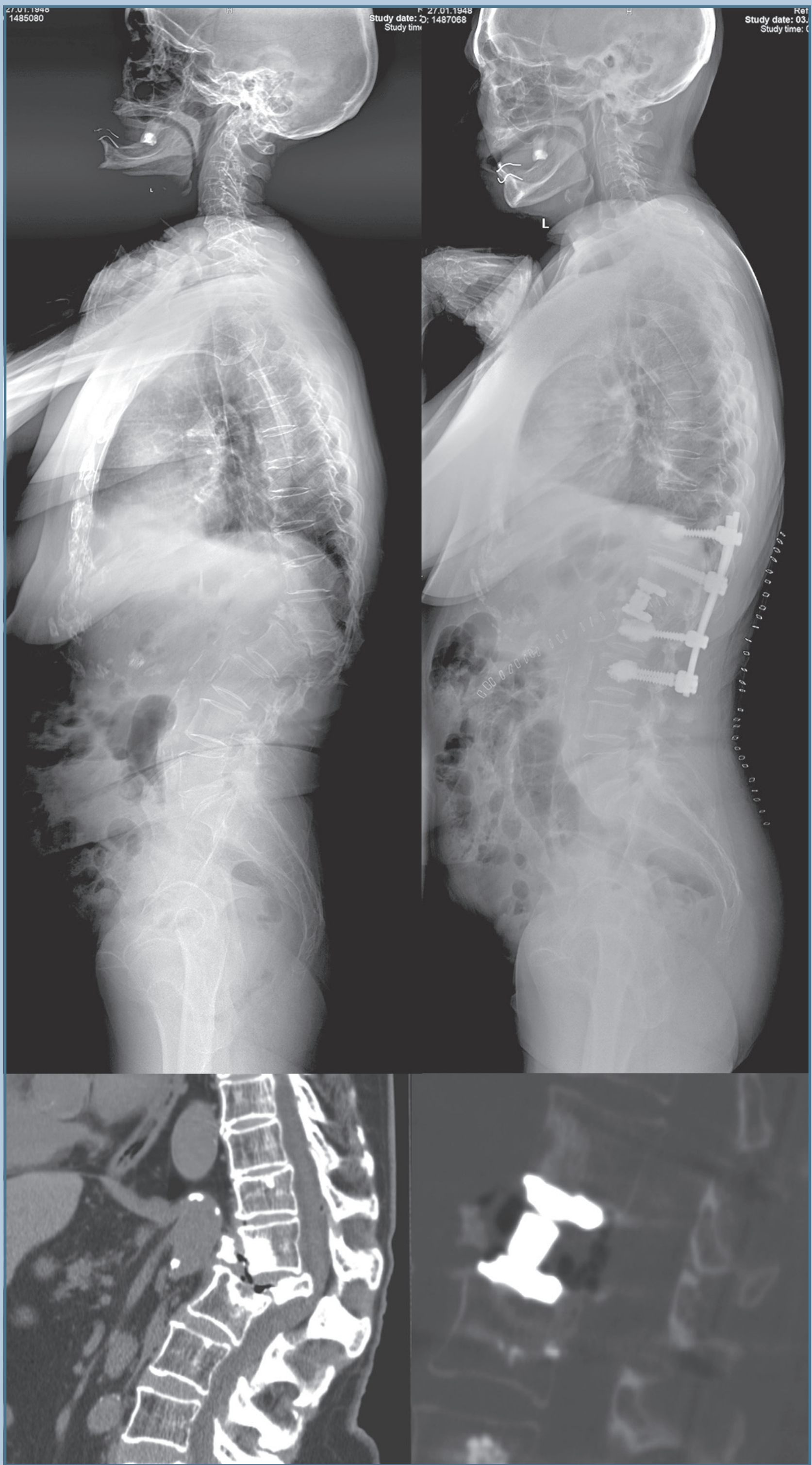

Fig. 1
Kyphotic deformity of T12–L2 (47°) due to aseptic osteonecrosis of the L1 vertebra in patient A., female, 70 years old: a two-stage surgery was performed in a single surgical session

with post-traumatic deformities at the thoracolumbar junction, i.e., T12, L1, and L2 vertebrae, homogeneous in kyphosis localization.

The patient cohort, in accordance with the parameters of pain and quality of life, had clinically significant post-traumatic spinal deformities, according to De Gendt et al. [15]; however, these parameters remained out of scope. We used the criterion for selecting patients into the study group, setting the down point for the deformity magnitude of at least 30° since, according to the literature sources [12, 15, 16], correlations of kyphosis and pain syndrome were obtained at such magnitude. It was supposed that with such a pronounced amount of deformity, compensatory responses definitely occur.

As the deformity persists, secondary compensatory changes in posture will undoubtedly occur, and gross kyphosis will correspond to a pronounced compensation of the deformity. There was an assumption that after the local kyphosis factor was removed, there would be a regression of the compensatory changes generated by it, which might be observed during the postoperative examination.

Compensatory mechanisms of thoracolumbar kyphosis are described, but literature sources are few in number and often contradictory. During the examination of the outcomes of non-surgical treatment of burst fractures, Koller et al. [17] did not find any changes in the spinopelvic balance. Matsumoto et al. [18] noted that compensation of thoracolumbar kyphosis is due to lumbar hyperlordosis; meanwhile, there are no changes in the global balance. Olivares et al. [19] described thoracolumbar kyphosis compensation due to hypermobility of the subjacent lumbar segments [19]. A number of authors point to the involvement of changes in the pelvis position in the compensation of thoracolumbar kyphosis. For example, Lamartina and Berjano [20] consider lower lumbar hyperlordosis and pelvic retroversion to be the mechanisms of compensation for thoracolumbar deformity. A.E. Shulga et al. [21] showed that deformities at the L1 level are characterized by a decrease in tho-

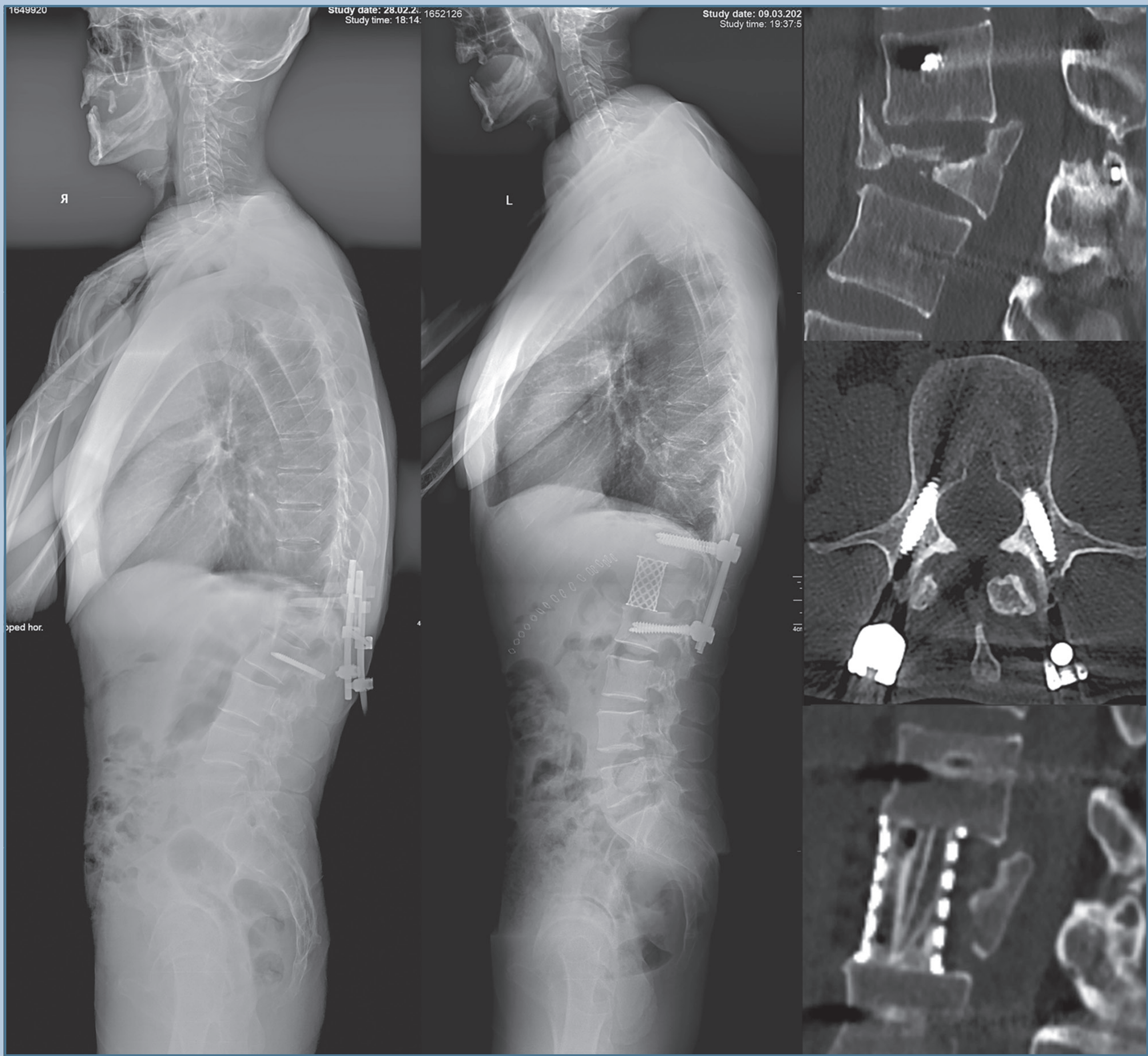

Fig. 2
Kyphotic deformity of T12–L1 (30°) after surgery, failure of the transpedicular instrumentation in patient Ch., male, 41 years old: a three-stage surgery was performed in a single surgical session

Table 1
Classification of patients by balance status according to Lamartina et al. [9], adapted by Garbossa et al. [10]

Balance status	Parameter	Compensatory mechanism
Balanced	SVA < 5 cm	PT ≤ PTi, femoral axis is vertical
Hidden imbalance	SVA < 5 cm	PT > PTi, femoral axis is not vertical
Imbalanced	SVA > 5 cm	Lost

racic kyphosis and an increase in lumbar lordosis, which results in a compensatory response from the sagittal parameters of the pelvis in the form of a decrease in SS and an increase in PT.

It has been known that pelvic retroversion is one of the compensation mechanisms for degenerative pathology of the lumbar spine [22–24]. We kept asking ourselves: is pelvic retroversion a

Table 2

Comparison of parameters of sagittal curvatures of the spine, global and spinopelvic balances before and after surgery

Parameter	Before surgery MED [Q1; Q3] MEAN ± SD (min; max)	After surgery MED [Q1; Q3] MEAN ± SD (min; max)	Difference MED [95 % CI] SMD [95 % CI]	Wilcoxon signed-rank test, p-value
LK, degree	31 [30; 37] 35.52 ± 11.11 (27; 81)	1 [-2; 4] 1.97 ± 6.43 (-8; 19)	32.00 [31.50; 32.00] 3.70 [3.15; 4.25]	<0.001*
TK, degree	16 [7; 25] 16.19 ± 13.56 (-20; 45)	33 [24; 40] 31.88 ± 11.40 (8; 54)	-15.00 [-15.50; -15.00] -1.25 [-1.62; -0.89]	<0.001*
LL, degree	-70 [-76; -62] -69.12 ± 11.41 (-97; -42)	-55 [-62; -49] -56.07 ± 10.35 (-78; -32)	-13.00 [-13.00; -12.50] -1.20 [-1.56; -0.83]	<0.001*
Low LL, degree	-47 [-51; -41] -46.52 ± 7.54 (-66; -27)	-41 [-45; -37] -40.93 ± 6.74 (-54; -24)	-5.50 [-5.50; -5.00] -0.78 [-1.13; -0.44]	<0.001*
SVA, mm	0 [-1.6; 2.1] -0.06 ± 4.53 (-23; 12)	-0.1 [-2.3; 1.8] 0.05 ± 3.28 (-7.0; 10.1)	0.20 [0.10; 0.25] -0.03 [-0.36; 0.31]	0.646
GT, degree	10 [7; 18] 12.16 ± 10.49 (-13; 38)	11 [5; 17] 11.39 ± 9.19 (-13; 35)	1.00 [1.00; 1.00] 0.08 [-0.26; 0.41]	0.216
PT, degree	12 [7; 18] 12.71 ± 9.08 (-5; 35)	10 [6; 17] 11.67 ± 8.85 (-4; 31)	1.00 [1.00; 1.00] 0.12 [-0.22; 0.45]	0.065
SS, degree	38 [36; 42] 38.42 ± 7.03 (24; 55)	39 [35; 45] 39.57 ± 7.15 (20; 58)	-1.00 [-1.50; -1.00] -0.16 [-0.50; 0.17]	0.038*
PI-LL, degree	119 [109; 130] 120.46 ± 16.36 (77; 162)	107 [97; 118] 107.42 ± 16.17 (75; 155)	13.00 [12.50; 13.00] 0.80 [0.46; 1.15]	<0.001*

compensation mechanism for local thoracolumbar kyphotic deformity, or is it the initial condition on which post-traumatic changes of the spine occurred? The fact that there is no connection between local thoracolumbar kyphosis and pelvic retroversion in patients with post-traumatic deformities of the thoracolumbar junction is not obvious. In Group II, 28 (40.5%) patients showed signs of hidden or pronounced imbalance (according to the Lamartina balance status classification). It seems challenging for the surgeon to obtain correction of the parameters of the sagittal and global balances after correction of pronounced thoracolumbar kyphosis. Nevertheless, as our study has shown, this is not always possible.

The purpose of surgical treatment of post-traumatic kyphosis is to correct the deformity and create conditions for the formation of bone or bone-metal blocks in the spinal segments of interest. Due to staged surgeries performed in a single-day surgical session, a complete correction of post-traumatic kyphosis was achieved in our study.

During the evaluation of the dynamics of changes in radiological parameters before and after corrective surgery, statistically significant changes in segments adjacent to gibbus were noted: an increase in thoracic kyphosis and a decrease in lumbar lordosis, including due to lower lumbar lordosis. There was no significant change in the pelvic position. The same outcomes were obtained when studying the correlation between the magnitude of correction of local kyphosis (33.63° ± 8.77°) and perioperative changes in radiological parameters. Statistically significant correlations were observed only in thoracic kyphosis and lumbar lordosis adjacent to post-traumatic deformities. For this reason, it can be argued that the main mechanism of compensation for thoracic post-traumatic kyphosis is a decrease in thoracic kyphosis and an increase in lumbar lordosis, including due to the lower lumbar component.

Table 3

Correlation between local kyphosis correction magnitude (LKpreOP – LkpostOP = 33.63° ± 8.77°) and difference in radiological parameters before and after surgery

Parameter	PreOP – PostOP MEN ± SD (min; max)	p-value, r	p-value, p
TK preOp – TK postOP	-14.0 [-20.0; -9.0] -15.70 ± 10.70 (-41.0; 8.0)	-0.43	<0.001*
LL preOp – LL PostOP	-12.0 [-19.0; -6.0] -13.04 ± 8.95 (-33.0; 4.0)	-0.42	<0.001*
L4–S1preOP – L4–S1postOp	-5.0 [-9.0; -1.0] -5.59 ± 6.27 (-24.0; 8.0)	-0.20	0.098
SVA.preOp – SVA.postOp	0.4 [-2.2; 2.6] -0.10 ± 4.29 (-17.4; 11.0)	-0.14	0.240
GT.preOp – GT.postOp	1.0 [-3.0; 6.0] 0.77 ± 6.95 (-22.0; 15.0)	0.00	0.989
PT.preOp – PT_PostOP	1.0 [-2.0; 4.0] 1.04 ± 4.76 (-10.0; 12.0)	-0.02	0.872
SS.preOp – SS.PostOp	-2.0 [-4.0; 2.0] -1.14 ± 4.60 (-1.0; 10.0)	-0.06	0.639
PI-LL.preOP – PI-LL.postOP	12.0 [6.0; 19.0] 13.04 ± 8.95 (-4.0; 33.0)	0.42	<0.001*

This statement, which is quite obvious, partially coincides with the conclusions of other researchers in regard to the involvement of lumbar lordosis in the compensatory mechanisms of post-traumatic kyphosis [18, 19]. Nevertheless, we have not confirmed the statement that a change in the pelvic position and PT and SS parameters are also involved in compensation [20, 21].

Nevertheless, in order to investigate the possible involvement of pelvic balance parameters in the compensation of post-traumatic kyphosis, patients with hidden or pronounced pelvic imbalance (Group II) were separated from the general group. The selection for this group was conducted according to the SVA parameter and the correspondence between the measured PT and the perfect PT, individualized according to the Vialle formula. If we assume the involvement of PT and SS in the compensatory mechanisms of thoracolumbar kyphosis, we can expect changes once the factor of local post-traumatic kyphosis is removed. Nevertheless, there were no signs of imbalance regression in the postoperative period in Group II. This gives us the opportunity to make a statement regarding the initial, pre-injury imbalance of degenerative origin.

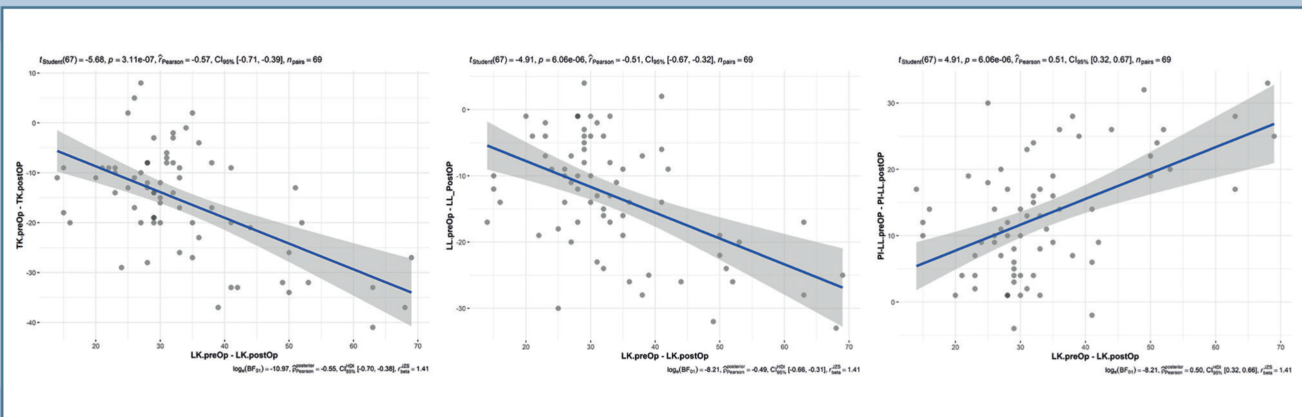

Fig. 3
Scatter plots for correlation parameters ΔLK and ΔLL, ΔTK, ΔPI-LL

Table 4

Comparison of preoperative mean radiological parameters in groups I and II

Parameter	Before surgery			After surgery		
	Group I (n = 41)	Group II (n = 28)	Mann – Whitney U test, p-value	Group I (n = 41)	Group II (n = 28)	Mann – Whitney U test, p-value
LK, degree	34.68 ± 9.56	36.75 ± 13.14	0.961	2.76 ± 7.29	0.82 ± 4.82	0.470
TK, degree	16.46 ± 13.07	15.79 ± 14.48	0.995	33.67 ± 10.54	35.45 ± 12.85	0.478
LL, degree	-69.44 ± 10.28	-68.64 ± 13.06	0.883	-55.78 ± 9.34	-56.50 ± 11.84	0.620
LowLL, degree	-46.96 ± 6.76	-46.18 ± 8.52	0.485	-40.85 ± 6.44	-41.04 ± 7.28	0.677
SVA, mm	-0.70 ± 4.05	1.43 ± 4.08	0.005*	-0.61 ± 2.79	1.27 ± 6.46	0.043*
GT, degree	8.38 ± 6.19	19.20 ± 11.06	<0.001*	9.07 ± 6.47	14.79 ± 11.44	0.023*
PI, degree	49.95 ± 8.57	53.39 ± 12.92	0.293	–	–	–
PT, degree	9.42 ± 5.67	18.61 ± 9.68	<0.001*	10.00 ± 6.22	17.23 ± 10.24	<0.001*
SS, degree	41.80 ± 7.14	36.34 ± 6.81	<0.001*	41.26 ± 7.08	37.71 ± 7.41	0.002*
PI-LL, degree	-16.06 ± 15.53	-5.78 ± 21.22	0.013*	-5.28 ± 11.16	1.52 ± 16.6	0.136

Conclusion

The analysis of the compensation mechanism for post-traumatic thoracolumbar kyphosis revealed changes in departments adjacent to kyphosis: a decrease in thoracic kyphosis and an increase in lumbar lordosis, but no changes in global or lumbopelvic balance parameters.

A reduction of compensatory changes was evidently observed during corrective surgery by direct exposure to local kyphosis of the thoracolumbar junction. There was an increase in parameters of thoracic kyphosis and a decrease in lumbar hyperlordosis, including lower lumbar hyperlordosis. Meanwhile, no changes in the position of the pelvis in the general group were reliably revealed.

After treatment of post-traumatic thoracolumbar kyphosis, there are signs of imbalance like pelvic retroversion and global balance abnormalities in a subgroup of patients with pre-existing sagittal pelvic and global imbalances of degenerative etiology.

The study had no sponsors.
The authors declare that they have no conflict of interest.
The study was approved by the local ethics committee of the institution.
All authors contributed significantly to the research and preparation of the article, read and approved the final version before publication.

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Address correspondence to:

Borzykh Konstantin Olegovich
Novosibirsk Research Institute of Traumatology
and Orthopaedics n.a. Ya.L. Tsivyan,
17 Frunze str., Novosibirsk, 630091, Russia,
KBorzykh@niito.ru

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Konstantin Olegovich Borzykh, MD, PhD, senior researcher of the Spine Surgery Department, Novosibirsk Research Institute of Traumatology and Orthopaedics n.a. Ya.L. Tsivyan, 17 Frunze str., Novosibirsk, 630091, Russia, ORCID: 0000-0001-5685-6834, KBorzykh@niito.ru;

Viktor Viktorovich Rerikh, DMSc, Head of the Spine Surgery Department, Novosibirsk Research Institute of Traumatology and Orthopaedics n.a. Ya.L. Tsivyan, 17 Frunze str., Novosibirsk, 630091, Russia, ORCID: 0000-0001-8545-0024, VRerih@niito.ru.