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CHANGES IN SAGITTAL BALANCE IN THORACOLUMBAR POSTTRAUMATIC KYPHOSIS SURGERY

ALTERAÇÕES NO EQUILÍBRIO SAGITAL NA CIRURGIA DE CIFOSE PÓS-TRAUMÁTICA TORACOLOMBAR

CAMBIOS EN EL EQUILIBRIO SAGITAL EN LA CIRUGÍA DE CIFOSIS POSTRAUMÁTICA TORACOLUMBAR

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ABSTRACT

Objective: The analysis of the X-ray results of surgical treatment performed in patients with post-traumatic thoracolumbar kyphosis and identification of the compensatory mechanism for this deformity. Methods: The data of 140 patients surgically treated for painful post-traumatic kyphosis at the level of T12, L1, and L2 vertebrae was analyzed. Results: In the studied group, the initial kyphotic deformity was 23° to 81°, with a mean of 28.1°. All patients underwent staged surgical intervention in a single surgical session. Post-traumatic kyphosis (LK) was completely corrected, on average, to -0.25°. After kyphosis correction, increased thoracic kyphosis (TK) decreased lumbar lordosis (LL), including at the expense of low lumbar lordosis (LowLL), but no changes in pelvic balance parameters were observed. Statistically significant correlations of local kyphosis correction magnitude of 28.36±8.89°, with magnitudes of lumbar lordosis (LL), thoracic kyphosis (TK), low lumbar lordosis (LowLL) were obtained. The global sagittal and pelvic balance demonstrated no correlations with the magnitude of kyphosis correction. The X-ray parameters were studied in patients of Group I with no signs of initial sagittal imbalance and in Group II patients with signs of sagittal imbalance. The groups demonstrated statistically significant differences in global balance parameters and spinopelvic parameters both before and after correction surgery. Conclusion: The study revealed that the basic compensatory mechanism for post-traumatic thoracolumbar kyphosis is implemented by changes in the curves adjacent to kyphosis – a decrease in thoracic kyphosis and an increase in lumbar lordosis but not by changes in global or spinopelvic balance. ***Level of Evidence - III; A case-control study.***

Keywords: Spine; Posture Control; Kyphosis; Lordosis.

RESUMO

Objetivo: Análise dos resultados radiográficos do tratamento cirúrgico realizado em pacientes com cifose toracolombar pós-traumática e identificação do mecanismo compensatório dessa deformidade. Métodos: Foram analisados os dados de 140 pacientes tratados cirurgicamente por cifose pós-traumática dolorosa ao nível das vértebras T12, L1, L2. Resultados: No grupo estudado a deformidade cifótica inicial foi de 23° a 81°, média de 28,1°. Todos os pacientes foram submetidos à intervenção cirúrgica estadiada em uma única sessão cirúrgica. A cifose pós-traumática (LK) foi completamente corrigida, em média para -0,25°. Após a correção da cifose foi revelado aumento da cifose torácica (TK), diminuição da lordose lombar (LL), inclusive em detrimento da baixa lordose lombar (LowLL), mas não foram observadas alterações nos parâmetros de equilíbrio pélvico. Foram obtidas correlações estatisticamente significativas da magnitude de correção da cifose local de 28,36±8,89°, com magnitudes de lordose lombar (LL), cifose torácica (TK), lordose lombar baixa (LowLL). O equilíbrio sagital global e o equilíbrio pélvico não demonstraram correlações com a magnitude da correção da cifose. Os parâmetros radiográficos foram estudados nos pacientes do Grupo I sem sinais de desequilíbrio sagital inicial e naqueles do Grupo II com sinais de desequilíbrio sagital. Os grupos demonstraram diferenças estatisticamente significativas nos parâmetros de equilíbrio global e nos parâmetros espinopélvicos antes e após a cirurgia de correção. Conclusão: O estudo revelou que o mecanismo compensatório básico da cifose toracolombar pós-traumática é implementado por alterações nas curvas adjacentes à cifose – diminuição da cifose torácica e aumento da lordose lombar, mas não por alterações no equilíbrio global ou espinopélvico. ***Nível de Evidência III; Estudo caso controle.***

Descritores: *Coluna Vertebral; Controle Postural; Cifose; Lordose.*

RESUMEN

Objetivo: Análisis de los resultados radiológicos del tratamiento quirúrgico realizado a pacientes con cifosis toracolumbar postraumática e identificación del mecanismo compensador de esta deformidad. Métodos: Se analizaron los datos de 140 pacientes tratados quirúrgicamente por cifosis postraumática dolorosa a nivel de las vértebras T12, L1, L2. Resultados: En el grupo estudiado, la deformidad cifótica inicial osciló entre 23° y 81°, con un promedio de 28,1°. Todos los pacientes fueron sometidos a una intervención quirúrgica escalonada en una única sesión quirúrgica. La cifosis postraumática (LK) se corrigió completamente, en promedio a -0,25°. Después de la corrección de la cifosis, se reveló un aumento de la cifosis torácica (TK) y una disminución de la lordosis lumbar (LL), incluso a expensas de una lordosis lumbar baja (LowLL), pero no se observaron cambios en los parámetros del equilibrio pélvico. Se obtuvieron correlaciones estadísticamente significativas

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entre la magnitud de corrección de la cifosis local de 28,36±8,89°, con las magnitudes de lordosis lumbar (LL), cifosis torácica (TK), lordosis lumbar baja (LowLL). El equilibrio sagital global y el equilibrio pélvico no demostraron correlaciones con la magnitud de la corrección de la cifosis. Los parámetros radiológicos se estudiaron en pacientes del Grupo I sin signos de desequilibrio sagital inicial y en aquellos del Grupo II con signos de desequilibrio sagital. Los grupos demostraron diferencias estadísticamente significativas en los parámetros del equilibrio global y los parámetros espinopélvicos antes y después de la cirugía correctora. Conclusión: El estudio reveló que el mecanismo compensatorio básico de la cifosis toracolumbar postraumática se implementa mediante cambios en las curvas adyacentes a la cifosis (disminución de la cifosis torácica y aumento de la lordosis lumbar), pero no mediante cambios en el equilibrio global o espinopélvico. ***Nivel de Evidencia III; Estudio de casos y controles.***

Descriptores: *Columna Vertebral; Control Postural; Cifosis; Lordosis.*

INTRODUCTION

Post-traumatic kyphosis is a painful angulation of the post-traumatic spine;[1] it is often a result of untimely diagnosis and inadequate conservative or surgical treatment of acute vertebral fractures.[2]

Even though most patients feel no discomfort after spinal injuries, deformity in some of them may be of clinical significance due to pain, functional failure, and decreased quality of life, which may require surgical correction of deformity. The most common spinal injuries occur in the area of the thoracolumbar junction – up to 59% of injuries to the thoracic and lumbar vertebrae.[3] Thoracolumbar localization is also typical for most cases of post-traumatic kyphosis. Post-traumatic kyphotic deformities are mostly manifested by local rigid deformities that are accompanied by compensatory changes in adjacent sagittal curvatures of the spine and changes in the spinopelvic and global sagittal balance.[4-6]

Post-traumatic kyphosis may be accompanied by degenerative disease of the spine. This is especially common in elderly patients when low-energy spinal injury results in the development of rigid post-traumatic kyphosis. Herewith, compensatory changes in degenerative spinal disease reflected in such parameters as Schwab modifiers,[7] will accompany compensatory changes typical for the post-traumatic spine.

This study includes the results of the surgical treatment for post-traumatic deformities in the thoracolumbar spine using the method of staged intervention, including anterior correction and posterior fixation stages that can be supported by spinal release if required.

The hypothesis of this study is the following: after correction for post-traumatic deformity with the exclusion of the local kyphosis factor, it's possible to identify the parameters that determine the compensatory changes in the post-traumatic spine.

The purpose is to analyze the X-ray results of surgical treatment of patients with post-traumatic thoracolumbar kyphosis and to reveal the compensatory mechanism of this deformity based on the evaluation of the sagittal spinopelvic and global balance parameters.

The study design is a retrospective monocentric study.

MATERIALS AND METHODS

This study was performed in line with the principles of the Declaration of Helsinki. Before study inception, a research protocol was submitted and approved by the Institution's ethics committee (extraction Nº 016/23 from protocol 006/23 dated 07/31/2023). Informed consent to the study was obtained from all patients included in the study. The analysis included the data obtained from the medical records of 140 patients (92 females and 48 males) who underwent surgical treatment for painful post-traumatic kyphosis at the T12–L1 level during the period from 2016 to December 2021. Patients were aged 18 to 70 years, with a mean of 43.6 ±16.8 years. The magnitude of the initial kyphotic deformity was from 23° to 81°, with a mean of 28.1°. Indications for surgery included vertebrogenic pain syndrome, axial pain, functional failure of the lumbar spine, and progressive neurological deficit. The inclusion criterion was the ability to maintain the posture in a standing position independently.

Patients underwent staged (two- and three-stage) interventions during a single surgical session. In the case of two-stage intervention, the first stage included kyphosis correction using anterior spinal fusion, mainly through the right transthoracic approach, by resection of a vertebral body and adjacent discs and replacement by an implant in combination with auto bone in the deformity correction position; anterior decompression of spinal cord was performed, if required. During the same surgical session, transpedicular fixation of the appropriate level was performed as the second stage, as well as the additional correction of residual kyphotic deformity, if required (Figure 1). In case of rigid deformities in the presence of posterior spontaneous bone blocks and metal implants, a three-stage intervention included deformity mobilization using facetectomy or removal of failed fixators at the first stage, anterior deformity correction with the placement of an implant and auto bone at the second stage, and final transpedicular fixation and additional correction of deformity, if required, as the third stage. (Figure 2)

The follow-up period was the entire period of hospital stay.

Examination before and after surgery included profile X-rays of the spine in a standard upright position, in two standard views, from the skull to the middle third of the femurs, with hands placed on the opposite collarbones.

Measurement of three types of X-ray parameters was performed:

- Parameters of sagittal curves of the spine: local kyphosis (LK) according to Cobb – at T12 and L1 levels in the studied cohort of patients; thoracic kyphosis (TK) - from the cranial endplate of T4 body to the caudal endplate of the vertebra above the damaged one; lumbar lordosis (LL) - from the cranial endplate of the vertebra below the damaged one till the S1; low lumbar lordosis was measured at the L4-S1 level (LowLL);
- Spinopelvic balance parameters: PI, PT, SS, PI-LL;
- Global balance parameters: SVA; spinal sacral angle (SSA); global tilt (GT), C7 vertical tilt (C7VT).

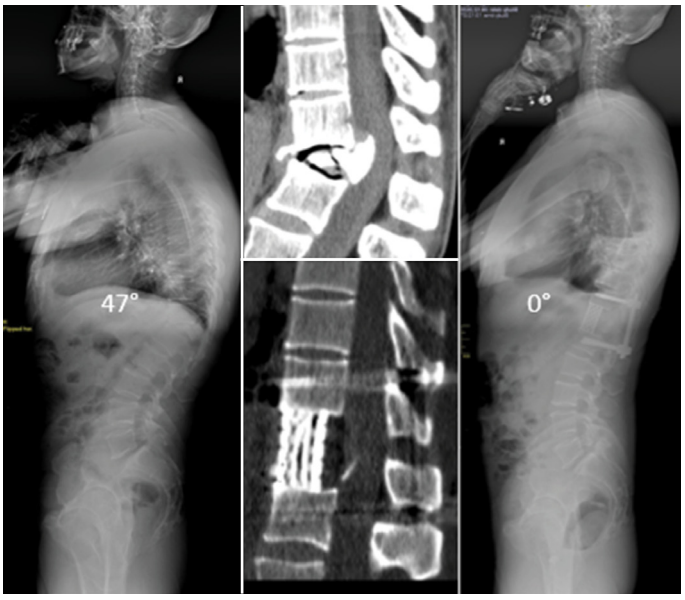

Figure 1. Patient M., male, 50 years old. Kyphotic deformity 47° of T11-L1 due to a burst fracture of the T12 vertebra. A two-stage surgical intervention was performed. The first stage was anterior decompression and anterior spinal fusion with a mesh implant and bone autograft from the resected rib. Minimally invasive transcutaneous transpedicular fixation was performed at the second stage of surgery.

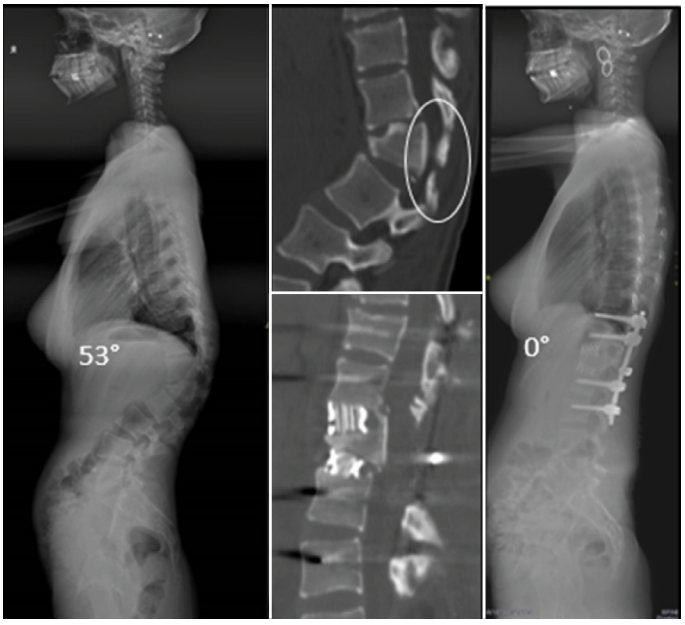

Figure 2. Patient T., female, 20 years old. Kyphotic deformity 53° of T11-L1 due to flexion-distraction injury. A three-stage surgical intervention was performed. The first stage included the installation of pedicle screws in T10, T11, L1, and L2 vertebrae and facetectomy of T11-T12. The second stage was deformity correction and anterior interbody fusion of T11-T12 T12-L1 with mesh implants and bone autograft from the resected rib. The third stage was the installation of the surgical hardware and additional kyphosis correction.

Depending on the SVA and PT parameters, patients were divided into two groups: Group I with no signs of sagittal imbalance (n=84 (SVA<5 cm; PT≤PTi)) and Group II with signs of imbalance and hidden imbalance (n=56 (SVA<5cm; PT>PTi *or* SVA>5cm; PT>PTi)).[8,9] The "ideal" PTi was personalized according to PI and calculated by the Vialle formula PTi = – 7 + 0.37xPI.[10]

Statistical Methods

Distributions of continuous variables were checked for agreement with the Shapiro-Wilk test for normality; the Fisher's F-test checked homoscedasticity. The non-parametric Mann-Whitney U test was used to compare continuous variables between groups at a time point; comparison before and after treatment was carried out using the Wilcoxon test. Difference between groups was evaluated as a pseudo-median of pairwise differences and standardized mean difference (SMD) with 95% confidence intervals (95% CI). Basic descriptive characteristics in continuous variables are provided as a median [the first quartile; the third quartile] (MED [Q1; Q3]), secondary ones as mean ± standard deviation (M±SD), and minimum–maximum values (min–max).

Pairwise associations between continuous variables were identified by calculating Spearman's correlation coefficient and estimating the achieved p-value of significance. For visual monitoring, scatter diagrams were plotted.

Statistical hypotheses were checked at a critical significance level, p-value = 0.05, i.e., the difference was considered statistically significant at $p < 0.05$.

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

RESULTS

Surgical interventions

All patients underwent staged surgery in a single surgical session. Three hundred thirty-one surgeries were performed, including 51 three-stage and 89 two-stage procedures.

Comparison of radiological parameters before and after surgery

Post-traumatic thoracolumbar kyphosis (LK) was completely corrected at an average of -0.25°. After kyphosis correction, statistically significant changes in all parameters of the sagittal curves of the spine were revealed: increased thoracic kyphosis (TK), decreased lumbar lordosis (LL), including at the expense of decreased low lumbar lordosis (LowLL). No changes in pelvic balance parameters (PT, SS) were observed. Changes in global balance parameters of SSA and C7VT were revealed, with p-value < 0.05. (Table 1)

Table 1. Comparison of parameters of sagittal curves of the spine, global and spinopelvic balance before and after surgery.

Parameters	Before surgery (M ± SD) (MIN – MAX)	After surgery (M ± SD) (MIN – MAX)	Difference MED [95% CI] SMD [95% CI]	Wilcoxon T-test, p-value
Parameters of sagittal survey of the spine				
LK	28.11±11.14 (5 - 81)	-0.25±6.64 (-19 - 19)	27 [27; 27.5]	<0.001*
TK	21.97±14.61 (-20 - 65)	34.38±11.51 (8 - 66)	-12 [-12.5; -12]	<0.001*
LL	-66.87±11.17 (-97 - -42)	-56.81±10.53 (-83 - -32)	-9.5 [-10; -9.5]	<0.001*
Low LL	-45.31±7.78 (-66 - -25)	-41.02±7.45 (-58 - -20)	-4 [-4; -4]	<0.001*
Parameters of global sagittal balance				
SVA	0.15±4.18 (-23 - 12)	0.14±4.69 (-7.7 - 40)	0.45 [0.4; 0.5]	0.163
SSA	131.72±8.88 (114 - 153)	133.04±8.48 (113 - 160)	-1.5 [-1.5; -1.5]	0.022*
GT	12.71±9.98 (-13 - 39)	12.11±9.14 (-13 - 37)	0.06 [-0.17; 0.3]	0.081
C7_VT	-0.04±4.11 (-10 - 13)	-0.63±3.72 (-9 - 15)	0.15 [-0.09; 0.38]	0.042*
Parameters of spinopelvic balance				
PT	13.09±8.76 (-5 - 35)	12.89±8.79 (-4 - 34)	0.02 [-0.21; 0.26]	0.477
SS	39.61±7.48 (24 - 56)	39.84±7.4 (20 - 58)	-0.03 [-0.26; 0.2]	0.431
PI-LL	-12.69±18.11 (-55 - 34)	-3.04±13.46 (-40 – 33)	0.62 [0.38; 0.86]	0.469

Correlation of local kyphosis correction magnitude and radiological parameters

The study revealed statistically significant correlations ($p<0.001$) of local kyphosis correction magnitude (LK preOP-LKpostOP) of 28.36±8.89° with lumbar lordosis (LL), thoracic kyphosis (TK), low lumbar lordosis (LowLL) and PI-LL parameters (Table 2). Parameters of global sagittal balance and pelvic balance demonstrated no correlations with the magnitude of kyphosis correction. Scatter diagrams for statistically significant correlations are provided in Figure 3.

Table 2. Correlation between local kyphosis correction magnitude (LKpreOP - LKpostOP=28.36±8.89°) and difference in radiological parameters before and after surgery.

Parameter	PreOP – PostOP (M ± SD) (MIN – MAX)	p-value, r	p-value, p
TK, °	-12.41±11 (-41 - 22)	-0.38	<0.001*
LL,°	-10.06±8.75 (-33 - 9)	-0.42	<0.001*
Low LL,°	-4.29±5.82 (-24 - 8)	-0.24	0.005*
SVA, mm	0.01±5.01 (-33.2 - 11)	-0.16	0.063
SSA,°	0.01±5.01 (-33.2 - 11)	-0.16	0.063
GT,°	0.6±5.91 (-22 - 15)	0.11	0.192
C7VT,°	0.59±4.54 (-15 - 12)	-0.02	0.854
PT, °	0.2±4.92 (-15 - 12)	0.09	0.295
SS,°	-0.23±4.83 (-12 - 15)	-0.14	0.105
PI-LL,°	10.06±8.75 (-9 - 33)	0.42	<0.001*

Study of changes in radiological parameters in patients of groups I and II

Despite the comparable parameters of the sagittal curves of the spine and the magnitude of post-traumatic kyphosis, the groups demonstrated statistically significant differences in global balance parameters (SVA, SSA, GT, C7VT) and spinopelvic parameters (PT, SS, LL) both before and after correction surgery in the thoracolumbar spine. (Table 3)

DISCUSSION

Post-traumatic kyphosis is a cause of pain, functional disability, and progressive neurological deficit.[11-13] As long as the deformity persists, secondary compensatory changes undoubtedly occur in the parameters of sagittal curves of the spine and other radiological parameters. Literature data on the sagittal balance of the post-traumatic spine are limited and often controversial. Koller et al.[14] analyzed the outcomes of nonsurgical treatment of burst fractures and revealed no changes in the spinopelvic balance. Matsumoto et al.[4] reported that compensation for thoracolumbar kyphosis occurs at the expense of lumbar hyperlordosis, while there are no changes in the global balance. Olivares et al.[5] described compensation for thoracolumbar kyphosis due to the hypermobility of subjacent lumbar segments. Lamartine and Berjano[9] consider low lumbar hyperlordosis and pelvic retroversion compensatory mechanisms for thoracolumbar deformity. Shulga et al.[6] demonstrated that decreased thoracic kyphosis and increased lumbar lordosis are typical for deformity at the L1 level, which caused a compensatory response of pelvic sagittal parameters in the form of decreased SS and increased PT.

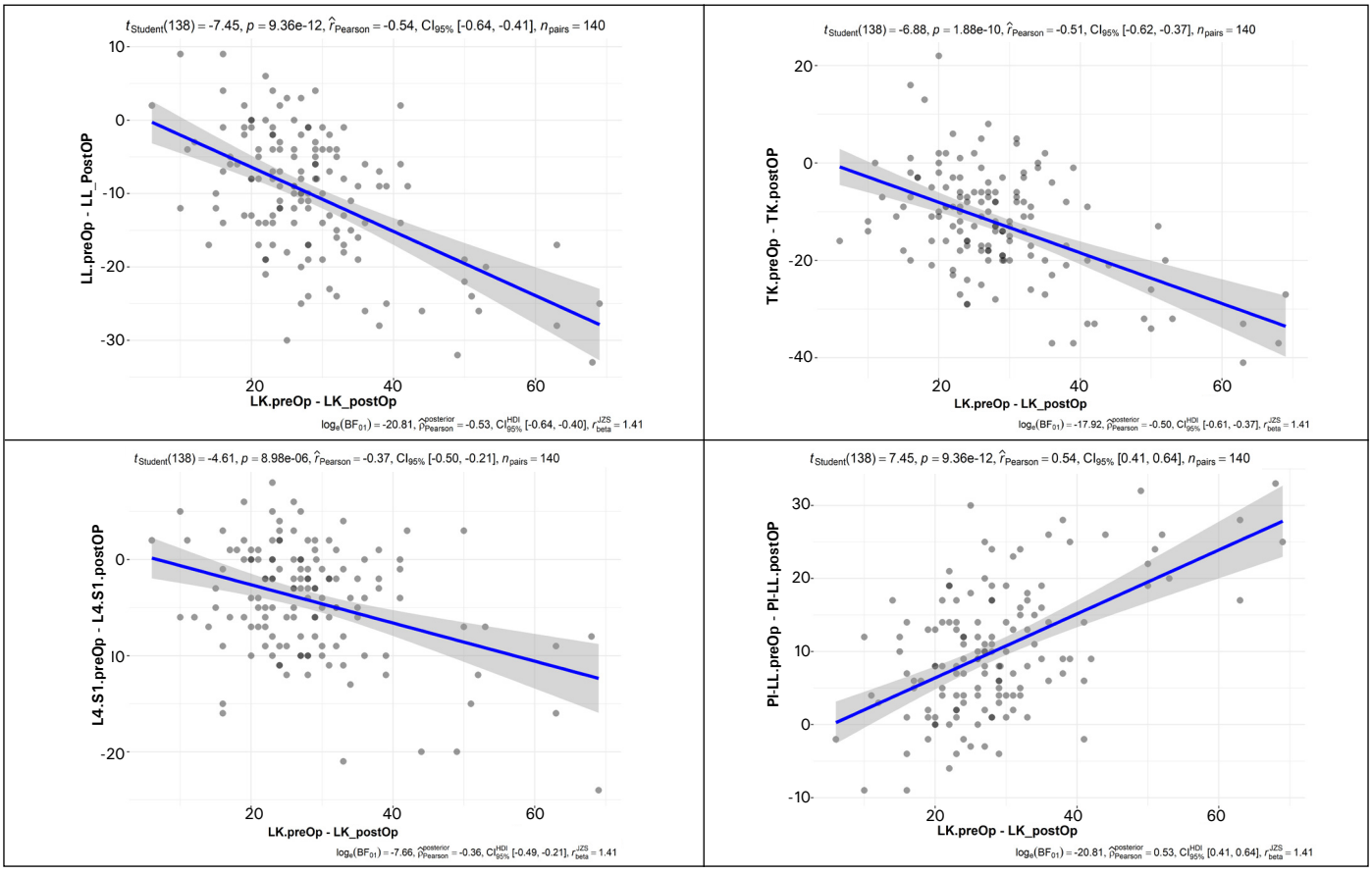

Figure 3. Scatter diagrams for correlation parameters Δ LK and Δ LL, ΔTK, ΔLowLL and ΔPI-LL.

Table 3. Comparison of preoperative average radiological parameters in groups I and II.

Parameter	Before surgery			After surgery		
	Group I	Group II	Mann–Whitney U test, p-value	Group I	Group II	Mann–Whitney U test, p-value
LK	27.96±9.77	28.32±13.02	0.689	0.42±6.99	-1.25±5.99	0.541
TK	20.7±12.75	23.88±16.97	0.300	33.67±10.54	35.45±12.85	0.478
LL	-68.96±9.96	-63.73±12.2	0.002*	-57.82±9.57	-5.29±11.76	0.166
Low LL	-46.96±6.76	-42.82±8.58	<0.001*	-42.19±6.97	-39.27±7.86	0.027*
SVA	-0.7±4.05	1.43±4.08	0.005*	-0.61±2.79	1.27±6.46	0.062
SSA	134.02±7.99	128.27±9.09	<0.001*	134.71±7.15	130.54±9.68	0.002*
GT	8.38±6.19	19.2±11.06	<0.001*	8.56±6.86	17.43±9.61	<0.001*
C7VT	-0.79±3.59	1.07±4.59	0.013*	-1.38±3.43	0.5±3.88	0.003*
PI	51.38±9.01	55±10.74	0.033*	-	-	-
PT	9.42±5.67	18.61±9.68	<0.001*	10±6.22	17.23±10.24	<0.001*
SS	41.8±7.14	36.34±6.81	<0.001*	41.26±7.08	37.71±7.41	0.002*
PI-LL	-16.06±15.53	-5.78±21.22	0.930	-5.28±11.16	1.52±16.6	0.136

The purpose of the surgical treatment for post-traumatic kyphosis is to correct deformity and to provide conditions for bone/bone-metal block formation. This study presents the results of the surgical treatment of 140 patients with local post-traumatic deformities in the area of the thoracolumbar junction using staged surgical interventions.

As a result of staged surgical intervention, a complete correction of post-traumatic kyphosis was achieved, on average, from 28.11±11.14° to -0.25±6.64°. In this study, compensatory mechanisms for post-traumatic changes were identified based on the statement that after excluding the local kyphosis factor, compensatory changes caused by it will reverse. At the same time, other factors affecting the parameters of spinopelvic and global balance, namely, radiological parameters indicating the concomitant degenerative disease of the lumbar spine, will remain unchanged.

Radiological parameters selected for the analysis include parameters of sagittal curves of the spine: thoracic kyphosis (TK), lumbar lordosis (LL), low lumbar lordosis (LowLL), standard parameters of spinopelvic balance (PI, PT, SS, PI-LL) and of global balance (SVA, SSA), as well as GT and associated C7VT that were also used to check the accuracy of measurements of the primary material (GT=C7VT+PT). This set of parameters fully describes the sagittal balance of the spine.[7-9,15-17]

Statistically significant changes in the segments adjacent to gibbous–increased thoracic kyphosis and decreased lumbar lordosis, including for the expense of low lumbar lordosis, were observed in assessing changes in these radiological parameters before and after correction surgery. No reliable changes in pelvic position were observed.

Similar results were obtained during the correlation analysis between the magnitude of local kyphosis correction and perioperative changes in the studied radiological parameters: statistically significant correlations were observed only in thoracic kyphosis and lumbar lordosis adjacent to post-traumatic deformity. On this basis, one could argue that the basic compensatory mechanism for post--traumatic thoracolumbar kyphosis is a decrease in thoracic kyphosis and an increase in lumbar lordosis, including for the expense of low lumbar component. (Tables 1 and 2)

This quite obvious statement partially coincides with the conclusions of the above authors regarding the involvement of lumbar lordosis in the compensatory mechanisms for post-traumatic kyphosis,[4,6] however, the statement that the change in the pelvis position and such parameters as PT and SS are also involved in compensatory mechanisms[6,9] were not confirmed by our study.

Nevertheless, to investigate the possible involvement of pelvic balance parameters in the compensation of post-traumatic kyphosis, a group of patients with signs of obvious or hidden pelvic imbalance was selected out of the general group. Selection to Group II with initial pelvic retroversion was carried out according to the measured PT and "ideal PT" personalized according to the Vialle formula. Group I included patients with PT value within the "ideal PT". In the preoperative period, statistically significant differences in the values of all analyzed parameters of global and spinopelvic balance, except for thoracic kyphosis, were observed between the studied groups. In other words, Group II included patients who, along with post-traumatic kyphosis, had the signs of baseline changes typical for the degenerative spine. If we assume the involvement of PT and SS parameters in the compensatory mechanisms for thoracolumbar kyphosis, we could expect their change after excluding the factor of local post-traumatic kyphosis. However, in the postoperative period, despite the full correction of post-traumatic thoracolumbar kyphosis, there were no reverse changes in sagittal spinopelvic and global balance in Group II.

CONCLUSION

After the corrective surgery and exclusion of the factor of local thoracolumbar kyphosis, a reduction of compensatory changes was observed – increased thoracic kyphosis and decreased lumbar hyperlordosis, including at the expense of the low lumbar one. In contrast, no changes in the pelvic position in the general group were reliably revealed.

In a subgroup of patients with pre-operative signs of sagittal pelvic and global imbalance due to concomitant degenerative disease, the signs of imbalance in the form of pelvic retroversion and global imbalance remain after post-traumatic thoracolumbar kyphosis correction.

Thus, the analysis of the mechanism of compensation for post-traumatic thoracolumbar kyphosis revealed that the basic mechanism of compensation for post-traumatic thoracolumbar kyphosis is implemented by changes in the curves adjacent to kyphosis – decrease in thoracic kyphosis and increase in lumbar lordosis, though not by changes in global or spinopelvic balance.

All authors declare no potential conflict of interest related to this article.

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