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Peculiarities of the sagittal balance of patients with post-traumatic deformities of the thoracic and lumbar spine

A.E. Shulga✉, V.V. Zaretskov, V.V. Ostrovskij, S.P. Bazhanov, S.V. Likhachev, A.A. Smolkin

Saratov State Medical University named after V.I. Razumovsky, Saratov, Russian Federation

Corresponding author: Alexey E. Shulga, doc.shulga@yandex.ru

Abstract

Purpose To determine the specificity of sagittal compensatory mechanisms in patients with post-traumatic deformities of the thoracic and lumbar spine, and also to study their correlation with pain and the life quality of patients. **Materials and methods** Using X-ray analysis of growth profile spondylograms of 103 patients we studied the effect of segmental post-traumatic deformity (SD) and anatomic shape of the spine (Roussouly type) on regional (TK, LL), pelvic (SS, PT) and global (SVA) parameters of sagittal balance. In addition, the analysis of dependence of pain (VAS) and the life quality of patients (ODI, SF-36) on the above parameters was done. **Results** SD of the thoracic spine (Th1–Th10) increased TK, which led to hyperextension of LL and a decrease in SS. These compensatory mechanisms were reflected in significant correlations SD-TK, TK-LL, TK-SS, and LL-SS. In the thoracolumbar spine (Th11–L2) SD at the level of Th11 and Th12 increased TK (SD-TK r = 0.553), and at the level of L1 and L2 they caused reactive hypokyphosis (SD-TK r = –0.687). A compensatory increase in LL was typical for injuries of Th11–Th12 (TK-LL r = 0.831) and L1 (TK-LL r = –0.629). Deformities at the L2 level led to hypolordosis (SD-LL r = –0.710), the magnitude of which, in turn, significantly influenced the TK, SS, and PT (LL-TK r = 0.690; LL-SS r = 0.832; SS-PT r = 0.597). The effectiveness of sagittal alignment in thoracic and thoracolumbar SD was confirmed by normal SVA values, as well as their lack of correlation with TK, LL and SS. In the lumbar spine (L3–L5), SD in 75 % of cases led to a critical decrease in LL and sagittal imbalance, which was reflected in significant correlations SD-LL, SD-PT, and SD-SVA. Compensatory correction of regional (TK, LL) and pelvic sagittal parameters (SS, PT) depended on the anatomical features of the spine (PI, Roussouly type) at all levels of the spinal column. However, a significant effect of PI on global sagittal alignment was noted only in lumbar SD (SVA-PI r = –0.617). Correlation of sagittal modifiers with pain intensity and quality of life was also typical only for patients with SD of the lumbar spine (PT-VAS r = 0.777; PT-ODI r = 0.752; PT-SF36 (PH) r = 0.651; SVA-VAS r = 0.775; SVA-ODI r = 0.762; SVA-SF36 (PH) r = 0.703). **Conclusion** Sagittal balance in fixed thoracic and thoracolumbar kyphosis is satisfactorily supported by changes in the curvature of adjacent parts of the spine, in contrast to lumbar deformities, in which in 75 % of cases, decompensation of the spine profile alignment occurs.

Keywords: spinal injury, rigid kyphosis, sagittal balance

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INTRODUCTION

Changes in the geometry of the spinal column with fixed post-traumatic deformities of the thoracic and lumbar location often lead to progressive functional impairment of the spine, reduced resistance to static loads and impaired sagittal balance parameters [1, 2, 3].

The normal profile configuration of the spinal column provides balanced relations between the pelvis and the spine, supporting the physiological position of the limbs and horizontal look [4, 5, 6]. In these conditions, the minimal muscle efforts are used to stabilize the posture and balance [7, 8, 9]. Damage to the vertebrae and the kyphotic deformity due to the axial weight-bearing trigger a pathological cascade of compensatory mechanisms aimed at maintaining the "comfortable" upright walking [4, 10, 11]. The energy intensive process of the imbalance compensation is associated with excessive tension of the skeletal muscles and pain syndrome [12, 13, 14]. Recent studies indicate that global spinal imbalance is closely correlated with disability and quality of life, and may also be a predictor of the outcome of almost any spinal pathology in adults [15, 16]. Regardless the relevance of publications related to sagittal balance disorders in post-traumatic deformities of the spine, they are scarce and do not fully disclose the problem [17, 18]. The above-mentioned dictates the need for a more detailed study of the regularities of compensatory mechanisms development that depends on the level of damage and the shape of the spine.

Purpose of the study Using the systematization of the X-ray parameters of patients with post-traumatic deformities of the thoracic and lumbar spine, to determine the specificity of sagittal compensatory mechanisms at different levels of the spine, and to analyze their correlation with the pain and the quality of life of the patients.

MATERIALS AND METHODS

The follow-up of 103 patients aged 19 to 66 years (38 (28–50); hereinafter referred to as quartiles) with rigid post-traumatic deformities of the thoracic and lumbar spine, who underwent operation within the period from

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2016 to 2019, were analyzed. The male incidence was higher (57 cases – 55.3 %) than females (46 cases – 44.7 %). According to the location of deformity, the patients were distributed as follows: thoracic area (Th1–Th10) – 20 cases (19.4 %), thoracolumbar spine (Th11–L2) – 59 cases (57.3 %) and lumbar spine (L3–L5) – 24 patients (23.3 %). The follow-up from the moment of injury averaged 168 (86–671) days. The inclusion criteria for the study were segmental post-traumatic deformities of the thoracic and lumbar spine. The study excluded patients with spinal cord injury who were unable to carry out daily activities in an orthostatic position, and the patients with a background of rough degenerative pathology of the spine. In addition, neurogenic pain syndromes associated with the effect on the structures of the spinal cord and its roots were referred to the exclusion criteria.

On admission, all patients underwent clinical examination and filled out a questionnaire. A visual analogue scale (VAS) was used to interpret the intensity of pain syndrome. The quality of life of patients before and after surgical interventions was assessed using the Oswestry questionnaire (ODI) and SF-36. To study the characteristics of the sagittal profile, the spondylograms of the patients involving the bones of the skull, pelvis and upper third of the femur in a standing position were performed. The images were evaluated using the Surgimap 2.3.1.2 software. This study was able to measure the angle of segmental deformity, and to evaluate a number of standard parameters of the sagittal balance: TK (Thoracic kyphosis), LL (Lumbar lordosis), PT (Pelvic tilt), SS (Sacral Slope), PI (Pelvic incidence), SVA (Sagittal vertical axis), and PI–LL difference.

Statistical analysis of obtained data was carried out using the IBM SPPS Statistics 23 software. The "regularity" of the distribution was assessed using the Kolmogorov-Smirnov test and the abnormal distribution was revealed for all parameters. Therefore, the median and quartiles were used to present the final quantitative data. Correlation analysis was performed using Spearman's non-parametric method. The results were considered significant at $p < 0.05$.

RESULTS

The study of profile spondylograms in the patients with post-traumatic deformities allowed us to assess a number of sagittal parameters, which changes turned out to be specific for different areas of the spine (Table 1).

In particular, segmental kyphotic deformities (SD) in the thoracic spine (Th1–Th10) proportionally increased the thoracic kyphosis up to 50.5 ° (47.3–55.5 °). The direct dependence of these parameters was observed in the SD–TK correlation ($r = 0.703$, $p = 0.001$). At the same time, TK increase led to compensatory extension of the column in the lumbar spine – TK–LL ($r = 0.843$, $p < 0.001$), as well as retroversion of the pelvis – TK–SS ($r = –0.572$, $p = 0.008$), TK–PT ($r = 0.595$, $p = 0.008$). The effectiveness of the above compensatory mechanisms can be judged by the normal indices of global sagittal modifiers (PI–LL, PT, SVA) (Table 1; Fig. 1).

In patients with SD of the thoracic spine, significant correlations of LL–PI ($r = 0.577$, $p = 0.009$) and SS–PI ($r = 0.722$, $p < 0.001$) were observed, which, we think, indicates the effect of the constitutional shape of the spinal column on its ability to positional correction of regional and pelvic parameters. On the other hand, normal SVA values – 11.5 mm (1.00–20.3) – and their absence of correlation with PI characterize the sufficiency of regional compensatory mechanisms in all anatomical forms of the spine (Roussouly type) [19, 20]. It should be also noted that the LL values depend on the age of patients ($r = -0.498$, $p = 0.027$), that might be caused age-related stiffness of the spine and reduction of its ability to positional hyperextension of the lumbar spine. Anyway, acceptable SVA parameters and the absence of their correlation with the age of patients indicate that in post-traumatic SD of the thoracic spine, age-related degenerative changes in the spine do not significantly affect the mechanisms of regional compensation. Pain syndrome in rigid thoracic kyphosis was located directly in the area of spinal deformity and was characterized by moderate intensity – 5.0 (4.0–6.0) points by VAS. The analysis revealed a direct dependence of pain intensity on the severity of local VAS-SD ($r = 0.589$, $p = 0.006$) and thoracic VAS-TK ($r = 0.735$, $p < 0.001$) kyphosis. The effect of segmental kyphosis severity on the quality of life indicators was also noted: ODI-SD ($r = 0.639$, $p = 0.002$) and SF36(PH)-SD ($r = –0.815$, $p < 0.001$), that was manifested by moderate reduction in the functional activity of patients (Table 1). The absence of significant correlations between clinical criteria (VAS, ODI, SF36) and global sagittal parameters (SVA) indirectly characterizes the compensated and subclinical condition of the global balance in the patients with rigid post-traumatic kyphosis of the thoracic spine.

Sagittal alignment in thoracolumbar post-traumatic (Th11–L2) deformities occurred due to positional correction of both adjacent parts of the spinal column, and the nature of these changes was to some extent defined by the level of injury (Fig. 2).

Table 1

X-rays indices of sagittal balance in patients with post-traumatic deformities of the thoracic and lumbar spine

Area	Thoracic			Thoracolumbar			Lumbar		
Quartiles	25	50	75	25	50	75	25	50	75
SD*, °	25.8	34.5	39.5	25.0	28.0	37.0	-0.8	6.0	10.8
TK, °	47.3	50.5	55.5	16.0	25.0	46.0	17.3	22.5	26.0
LL, °	-44.5	-53.0	-58.0	-48.0	-59.5	-67.0	-4.0	-17.5	-27.8
SS, °	33.0	39.0	41.8	31.0	37.0	40.0	26.3	33.0	37.8
PT, °	12.0	14.0	15.0	11.0	12.0	16.0	18.3	20.0	21.8
PI, °	46.3	51.0	54.8	47.0	50.0	54.0	46.0	51.0	54.0
PI – LL, °	-8.0	-4.0	-1.25	-5.0	-3.0	1.0	23.5	28.0	31.0
SVA, mm	1.00	11.5	20.3	-8.0	5.0	18.0	24.3	39.5	65.5
VAS (points)	4.0	5.0	6.0	4.5	5.0	7.0	5.3	7.0	8.0
ODI, %	33.0	39.5	54.5	32.5	38.0	59.0	45.5	61.0	68.0
SF36 (PH)	26.8	36.3	47.5	23.2	34.4	44.5	14.4	20.5	32.3
SF36 (MH)	28.0	38.6	48.2	22.6	37.2	46.4	12.2	22.2	35.5

* – angle of segmental deformity.

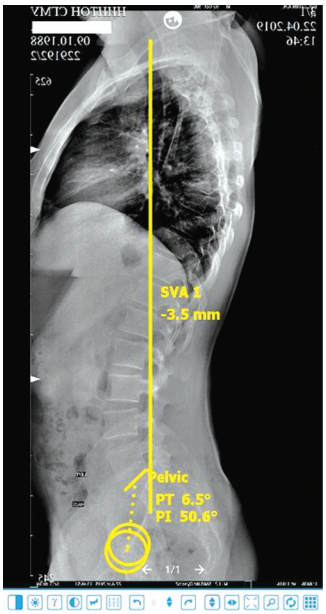

Fig. 1 Spondylogram of the Patient P. with consequences of Th7 injury

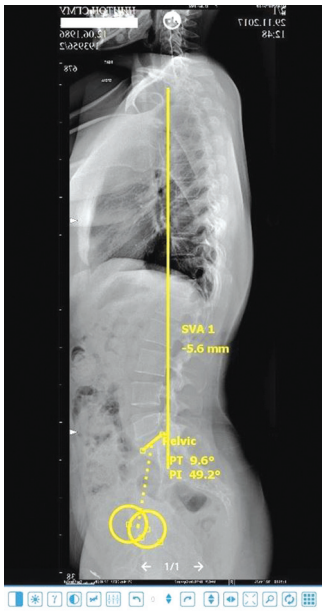

Fig. 2 Spondylogram of Patient M. with fixed deformity of the thoracolumbar spine

In particular, Th11 and Th12 injury caused local fixed kyphosis of the lower thoracic spine, which, due to compensatory extension of the upper segments, was not accompanied by significant increase in thoracic kyphosis – TK 42.5 (39.3–46.5). In addition, the standard response of the spinal column to SD (Th11–Th12) was positional increase of lumbar lordosis – LL -57.0° (-48.0° – -61.0°). These regularities were observed in SD–TK ($r = 0.553$, $p = 0.014$) and SD–LL ($r = 0.861$, $p < 0.001$) correlations. The inclusion of pelvic retroversion in the compensatory process reflected in the dependence of regional and pelvic parameters: TK–SS (r -0.550, $p = 0.01$) and LL–SS ($r = 0.520$, $p = 0.02$). The above-mentioned mechanisms of sagittal alignment enabled to sufficiently maintain global balance in SD at the level of Th12–L1, that was indicated by normal SVA values.

Typical compensatory response of the spinal column for deformities at the level of the L1 was symmetrical reduction of thoracic kyphosis by 20.0° (12.3–25.0°) and increase of lumbar lordosis to mean -54.0° (-50.3° – -56.0°). At the same time, the degree of reactive hyperextension of the lower lumbar segments did not depend on the severity of local kyphotic deformity that was indicated by the absence of correlation between SD and LL. In addition, the parameters of thoracic kyphosis were closely related to the amount of SD-TK segmental kyphosis ($r = -0.687$, $p < 0.001$) and LL–TK lumbar lordosis ($r = -0.629$, $p < 0.001$). Lumbar lordosis change, in return, caused a compensatory reaction from the pelvic sagittal parameters as a decrease in SS: LL–SS ($r = -0.732$, $p < 0.001$) and an increase in PT: LL–PT ($r = 0.706$, $p < 0.001$). In this context, normal PT and

SVA values and the absence of statistical dependence between regional (SD, TK, LL) and global (SVA) parameters, indicate the efficiency of sagittal alignment of patients with SD at the level of L1.

In old L2 injury the segmental deformity caused hypolordosis with mean value of -28.0° (-24.5° – -33.0°), and these values, according to the study, were not critical for the global balance, but led to significant positional thoracic hypokyphosis of 12.0° (4.0–19.0°). The above mechanism of sagittal adaptation of the spine to the deformity at L2 level was observed in the SD-LL ($r = –0.710$, $p = 0.032$) and LL-TK ($r = 0.690$, $p < 0.001$) correlations. The close relationship between the lumbar lordosis amount and pelvic parameters – LL–SS ($r = 0.832$, $p < 0.001$) and LL–PT ($r = 0.657$, $p = 0.005$) – characterized the active participation of pelvic retroversion in the imbalance compensation process. In case of L2 injury large depression of the lumbar lordosis was observed, therefore, the changes of sagittal modifiers were more significant. However, the borderline values of these parameters – PT 18.0° (15.5–20.0°) and SVA 24.0 mm (23.0–40.0) – once again confirm the efficiency and the dominant role of regional positional alignment in thoracolumbar kyphosis.

In patients with thoracolumbar SD it was found that the severity of positional correction of regional and pelvic parameters depended on the constitutional shape of the spinal column. These type-specific features (Roussouly type) were reflected in TK–PI ($r = 0.577$, $p = 0.009$), LL–PI ($r = 0.577$, $p = 0.009$) and SS-PI ($r = 0.722$, $p < 0.001$) correlations and characterized different ability of any anatomical variants of the spine to compensatory change of their geometry. At the same time, satisfactory condition of the global balance in patients with thoracolumbar SD (PT 12.0° (11.0–16.0°), SVA 5.0 mm (-8.0–18.0)) allows us to speak about the sufficient compensatory reserves in all constitutional types of the spine. In addition, the dependence of regional parameters TK ($r = 0.556$, $p = 0.002$) and LL ($r = –0.698$, $p < 0.001$) on the age of patients in thoracolumbar SD comes under notice. This specific character is caused by plastic reduction of the spine and its ability to positional self-correction in patients of the older age group. Nevertheless, the study indicated that these factors did not have a critical effect on the standard mechanisms of compensation for thoracolumbar SD, evidenced by normal indicators of the global sagittal balance (Table 1).

Pain in thoracolumbar SD was mainly located at the kyphosis apex, its intensity was moderate – VAS 5.0 (4.5–7.0) points – and closely correlated with the severity of local VAS-SD deformity ($r = 0.839$, $p < 0.001$). At the same time, patients often (71.2 %; 42/59) noted generalization of pain at the parts of the spine adjacent to segmental kyphosis (TK and LL), and it was difficult to differentiate the intensity of the main and adjacent myotonic pain syndromes. Therefore, the parameters of the total VAS (back pain) were taken into account, that together with SD also correlated with the indicators of TC ($r = -0.730$, $p < 0.001$) and LL ($r = 0.488$, $p = 0.029$). This situation, in return, underlines the significant role of regional mechanisms of sagittal alignment (changes of TK and LL curvature) in the pathogenesis of pain syndrome in thoracolumbar SD. In addition, in patients with segmental thoracolumbar deformities, a moderate decrease in the volume of daily physical activity was noted – ODI 38.0 (32.5–59.0) and SF36(PH) 34.4 (23.2–44.5), that, probably, was associated with the severity of regional parameters changes and the intensity of the pain syndrome. This fact, in addition, was indicated by the statistical dependence of quantitative indicators of the quality of life and a number of sagittal regional parameters: ODI–SD ($r = 0.645$, $p = 0.008$), SF36(PH)–SD ($r = -0.713$, $p = 0.002$), as well as ODI–TK ($r = 0.675$, $p = 0.008$), ODI–LL ($r = 0.535$, $p = 0.018$) and SF36(PH)–LL ($r = -0.511$, $p = 0.022$). Since the significant correlations between clinical criteria (VAS, ODI, SF36) and global sagittal parameters (SVA) were not observed, we can speak about the efficiency of regional vertical alignment mechanisms and the subclinical state of global balance in patients with rigid thoracolumbar SD.

Post-traumatic deformities of the lumbar spine (L3–L5) often caused significant changes in the sagittal profile of the spine (Fig. 3).

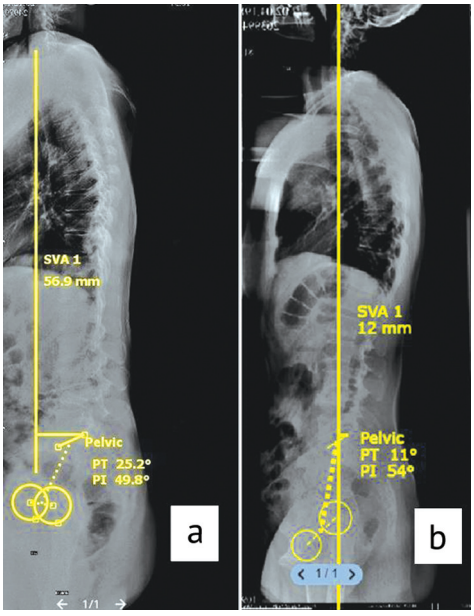

Fig. 3 Spondylograms of the Patients (a) C., 60 years old, and (b) U., 27 years old, with rigid post-traumatic deformities at L4 level

This regularity primarily referred to the indicators of lumbar lordosis, which parameters significantly depended on the sverity of segmental deformity: SD–

LL (r = –0.788, p < 0.001). A decrease of LL up to -17.5° (-4.0° – -27.8°) excluded it from the processes of vertical alignment and triggered a cascade of compensatory mechanisms. In particular, the stereotypical responses of the spinal column to lumbar hypolordosis were thoracic hyperextension: LL–TK (r = 0.786, p < 0.001), and the pelvic retroversion: LL–SS (r = 0.905, p < 0.001) and LL–PT (r = -0.547, p = 0.006). The failure of these standard mechanisms in 9 cases (37.5 %, 9/24) led to moderate imbalance (SVA 25–50 mm), and in 9 patients (37.5 %, 9/24) caused significant disorders of the sagittal balance (SVA more than 50 mm). Significant negative impact of lumbar SD and LL parameters on the processes of global vertical alignment was reflected in the SD–SVA (r = -0.569, p = 0.004) and LL–SVA (r = -0.569, p = 0.004) correlations.

It should be noted that PI indicators in lumbar SD significantly correlated not only with regional and pelvic parameters: LL–PI (r = 0.783, p < 0.001) and SS–PI (r = 0.827, p < 0.001), but were also heavily tied to global sagittal modifiers: PI–PT (r = -0.417, p = 0.043) and PI–SVA (r = -0.617, p = 0.003). The obtained results characterize the impact of the constitutional shape of the spine on its ability to stabilize the global sagittal balance. In other words, the efficiency of sagittal compensation in patients with lumbar SD depends on the anatomical type of the spine (Roussouly). Therefore, it is necessary to clarify that a small group of vertically balanced patients (25.0 %, 6/24) was represented exclusively by patients with constitutional types III and IV of the spinal column (Fig. 3b). It should also be stated that all patients from the above group were not older than 45 years, that might indicate higher compensatory potential in young people. Unfavorable effect of age-related hypomobility of the spine on its sagittal alignment in lumbar SD was reflected in significant age-SVA correlation (r = 0.677, p = 0.004) and characterized the insufficiency of regional compensatory mechanisms in elderly people (Fig. 3a).

Patients with lumbar SD, regardless of the sagittal balance condition of the sagittal balance, were concerned about generalized pain in the lumbar and thoracic spine, when clear correlation of its intensity with SD (r = 0.520, p = 0.003), LL (r = -0.803, p < 0.001) and TK (r = -0.776, p < 0.001) was observed. The data obtained indicate the polyetiology of clinical symptoms, when the pain syndrome from the apex of the lumbar SD and the myotonic pain associated with compensatory geometric change in the adjacent sections of the spine are directly involved. The intensity of pain in the back in lumbar SD reached 7.0 (5.3–8.0) points, that significantly exceeded similar indicators for thoracic (p < 0.001) and thoracolumbar kyphosis (p = 0.002). This fact is caused by excessive muscle hypertonicity, that is required in this group of patients for maximal extension of the spine. It should also be noted that all sagittally decompensated patients with lumbar SD (75.0 %, 18/24) had pain in the lower limbs. The severity of fatigue muscle pain in the legs (VAS of the legs 6.0 (5.0–7.6) points) depended on the severity of profile imbalance: SVA–VAS of the legs (r = 0.775, p < 0.001).

Life quality indicators in patients with lumbar SD were significantly lower than the same in the patients with deformities of the thoracic (ODI p < 0.001; SF36 p < 0.001) and thoracolumbar (ODI p = 0.009; SF36 p = 0.01) location. It should be stated that in the group of patients with lumbar SD, the quantitative indicators of functional activity differed significantly in patients with compensated and decompensated sagittal alignment (ODI p < 0.001; SF36 p < 0.001). Therefore, the significant correlations of SVA-ODI (r = 0.762, p < 0.001) and SVA-SF36(PH) (r = 0.703, p < 0.001) indicate the direct dependence of patients' quality of life with lumbar SD on the severity of sagittal imbalance.

DISCUSSION

Rigid kyphotic deformities at the level of the thoracic spine launched regional compensatory mechanisms that maintained the values of global sagittal modifiers (PT and SVA) within acceptable limits. The stereotypical adaptive response of the spine to post-traumatic thoracic hyperkyphosis was pelvic retroversion (decreased SS, increased PT) and increased lumbar lordosis. In young patients, moderate extension of the thoracic spine in the segments adjacent to kyphosis was also noted. The medians of the parameters characterizing the sagittal orientation of the pelvis (SS, PT) and the vertical alignment of the spine (SVA) were within the normal range, that indicates a high adaptive potential in the patients with thoracic SD. Age-related degeneration and hypomobility to a certain extent limited the ability of the spinal column for positional correction (overextension of LL, retroversion of the pelvis), that is confirmed by the inverse correlation of age indices and LL. Despite the above, no significant relationship between the values of global sagittal modifiers (PT, SVA) and patients' age was revealed, reflecting the efficiency of vertical alignment regardless of the age. The analysis also revealed correlations between the pelvic index and regional sagittal parameters that again underline the type-specificity (Roussouly type) of the compensatory response and the influence of the anatomical shape of the spine on the potential for its geometric stability. In particular, the reactive changes of regional and pelvic parameters close to critical ones (TK, LL, SS) were recorded mainly in patients with constitutional types I and II of the spine. Therefore, it can

be said that patients with more pronounced physiological curvatures (types III and IV) have more significant reserve of regional compensation. Despite this fact, it should be noted that in patients with thoracic SD the mechanisms of regional sagittal alignment are sufficient, regardless of the anatomical type of the spinal column that can be judged by normal SVA values and absence of their correlation with PI.

The location of the leading pain syndrome in patients with rigid thoracic SD corresponded to the apex of the deformity, and its intensity was clearly associated with the severity of kyphosis. We should also indicate the presence of satellite myotonic pain in the thoracic spine, being of moderate nature and, according to the data, directly correlated with the severity of segmental (TK) compensatory changes in the spine. Therefore, it can be said that the hypertonus of the skeletal muscles, "resisting" the drive of gravitation center anteriorly, and the local pain syndrome are involved in the formation of clinical symptoms (VAS – back pain) in patients with rigid thoracic kyphosis [21, 22]. The decrease in the quality of life in this group of patients was caused exclusively by the regional pain syndrome and was characterized by moderate incidence, indicating the efficiency of the mechanisms for the spine sagittal alignment.

Thoracolumbar vertebrae are located at the boundary of two contra-directional physiological curvatures, that satisfactorily compensated the kyphotic deformities of the spine due to curvature changes. The data indicate the exclusive role of regional compensatory mechanisms in maintaining sagittal balance in patients with rigid thoracolumbar deformities. Fixed local kyphosis at the level of Th11 and Th12 was compensated by extension of the upper segments of the thoracic spine and increased lumbar lordosis. In the patients with severe kyphotic deformity, in the patients with type I and II lumbar lordosis (Roussouly) and in elderly patients, this mechanism was supplemented by pelvic retroversion. Moderate correlations of TK, LL and SS underline the dependence of the compensatory rotation of the pelvis on the above circumstances. Similar adaptive reaction of the vertebral column was observed in L1 injury, but at the same time definite inverse correlation of LL–SS and SS-PT was observed. It seems that location of the deformity apex at L1 level promotes an offset of the positional alignment force application point to the lumbar segments and their significant hyperextension that, correspondingly, increases the "torque" and retroversion of the pelvis. Deformities at L2 level unlike the overlying levels of the transitional thoracolumbar area led to depression of the upper part of the lumbar lordosis; therefore, compensatory extension was limited by the underlying segments. Accordingly, vertical alignment compensation occurred due to maximum thoracic hyperextension and pelvic retroversion; therefore, the changes of the sagittal parameters of the spine (TK, SS, PT, SVA) were more significant. Anyway, given that the medians of these indicators stayed within acceptable values, we can say that there was no critical impact on the global balance and condition of sub-compensation. In thoracolumbar kyphosis, the dependence of the positional correction of sagittal parameters on the anatomical shape of the spine (Roussouly type) was also observed. This peculiarity was caused by the difference in the amounts of physiological curvatures and, accordingly, original large compensatory reserves in patients with types III and IV. In patients with hypokyphotic-hypolordotic shape of the spine (types I and II), the maximal positional correction of sagittal parameters often approaching critical values is required in order to maintain vertical alignment. Nevertheless, the compensated sagittal balance, as well as the absence of correlation dependence of sagittal modifiers (PT and SVA) and pelvic index (PI) indicate the efficiency of positional alignment in patients with rigid thoracolumbar kyphosis, regardless of the constitutional shape of the spine. The correlation of patients' age with a number of profile parameters (TK, LL) characterizes the effect of degenerative changes in the spine on its ability to vertical self-correction. At the same time, this effect can be characterized as insignificant since there were no positive correlations of age with PT and SVA.

Pain syndrome in patients with thoracolumbar SD and rigid thoracic kyphosis involved local symptoms from the apex of the deformity and concomitant regional myotonic pain in adjacent areas of the spine. Definite correlation of pain intensity with the amount of LL change under the character of clinical and radiological specificity should be noted in this group of patients. Probably, more extension of the spine in the lumbar region, compared with the one for thoracic kyphosis and, consequently, a more significant tension of its muscles are required for effective sagittal compensation of thoracolumbar SD. Despite a greater incidence of myotonic pain syndrome in the spine, its intensity was moderate and did not cause a significant decrease in the quality of life. This fact, along with normal values of sagittal modifiers (PT, SVA), allows us to state the effectiveness of regional compensatory mechanisms and the subclinical condition of the global balance in patients with thoracolumbar SD.

Lumbar deformities cause the significant loss of lordosis. We think, that is the lumbar curvature due

to its hypermobility plays a key role in maintaining the sagittal balance. The study indicated that the exclusion of lumbar lordosis from the processes of vertical alignment launched alternative compensation mechanisms, that were ineffective in 75 % of cases. In particular, hyperextension of the thoracic spine and pelvic retroversion to a certain extent resisted to anterior offset of the gravitation center, but the possibilities of these reactive changes were limited by the anatomical peculiarities of the spinal column and the age of the injuried. It should be noted that compensated global sagittal parameters were observed only in young patients with a harmonic (type III) or hyperlordotic (type IV) profile. Therefore, during kyphotization of the lumbar area compensatory overextension occurs in the adjacent segments of the spine (thoracic region, pelvis), and at the same time the original possibilities for maintaining sagittal balance are greater in patients with high pelvic index. The age of patients (over 45 years) presumes the reduction of the spinal mobility and muscular tonus, therefore, the weakened muscles of the elderly individuals are either unable to change the curvature of the degenerativ spine or stand the prolonged postural weight-bearing [23, 24].

Suprathreshold increase in PT and SVA was evaluated as sagittal imbalance, and close correlations of these parameters with VAS, ODI and SF-36 indices underlined the dependence of the functional consistency of the spine on the degree of vertical alignment decompensation. Finalizing the findings we can say that compensatory processes in lumbar SD were accompanied by muscular tonic pain associated with hyperextension of the thoracic and lumbar regions. In the case of effective sagittal alignment, the pain syndrome was limited to the back, and its location coincided with the same in thoracolumbar SD, but the severity of symptoms was higher due to more pronounced muscular hypertonus. In sagittal decompensation of the lumbar SD, positional back pain was combined with fatigue muscular pain in the lower limbs and, as the study showed, these parameters directly depended on the degree of imbalance. This combination of clinical manifestations caused an excessive asthenia in the patients and significant reduction of their quality of life.

CONCLUSION

Global sagittal balance in patients with thoracic and thoracolumbar SD is satisfactorily maintained by compensatory correction of physiological curvature of the spine and pelvic position. The constitutional type and age of patients do not demonstrate significant effect on these processes. The clinical picture in this category of atients is represented by moderate pain in the back, associated with positional change in the geometry of the spine. Therefore, eliminated regional symptoms together with the subclinical state of the global balance do not apply significant impact on the quality of life of the patients with thoracic and thoracolumbar SD.

In lumbar SD, the above-mentioned regional compensation mechanisms were ineffective in 75 % of cases. This statistic highlights the key role of lumbar lordosis in maintaining sagittal balance. The constitutional type and age of patients with lumbar deformities also have a significant impact on the global geometric stability of the spine. Pain symptoms in patients with compensated profile, similar to thoracic and thoracolumbar SD, have regional nature, but are more intense. In sagittal decompensation there is a combined myotonic pain syndrome of the torso and limbs and its severity definitely depends on the degree of imbalance and significantly reduces the quality of life of patients.

Therefore, sagittal stabilization of the spine in post-traumatic deformities of the thoracic and lumbar spine is a complex and multifactorial process and its understanding is of great importance both for diagnostics and choice of the most appropriate treatment tactics.

Study limitations The limitations of the study include the lack of systematization of the examined population according to the type of injury and deformity. This decision was taken due to narrow selection criteria for patients. In particular, exclusion of the patients with complicated trauma and neurogenic pain syndromes and patients with the background of degenerative deformities of the spine from the study, presumed, with rare exceptions, a choice of post-traumatic pathology of mild and moderate severity. Therefore, the examined population was represented by fixed kyphotic deformities of type IIA (90.3 %, 93/103) and much less often IIIA (9.7 %, 10/103) according to Rajasekaran (2018). Analysis of the severity of primary injuries according to AO/Spine (2013) also focuses on the specifics of patient selection: type A (56.3 %, 58/103), type B (34.0 %, 35/103) and type C (9, 7 %, 10/103). Probably, the search for the patients with the consequences of severe (type C, type IIIA) uncomplicated spinal injury will make it possible to systematize patients into comparable groups and subsequently perform a higher-level study.

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Information about the authors:

1. Alexey E. Shulga – Candidate of Medical Sciences, doc.shulga@yandex.ru;
2. Vladimir V. Zaretskov – Doctor of Medical Sciences, vvzaretskov@mail.ru;
3. V.V. Ostrovskij – Doctor of Medical Sciences, ostrw@mail.ru;
4. Sergey P. Bazhanov – Doctor of Medical Sciences, baj.s@mail.ru;
5. Sergey V. Likhachev – Candidate of Medical Sciences, likha4@mail.ru;
6. Alexey A. Smolkin – M.D., 4-4-2@mail.ru.