



COMPREHENSIVE ASSESSMENT OF THE RESULTS OF SURGICAL TREATMENT OF SEVERE FORMS OF IDIOPATHIC SCOLIOSIS WITH A PRIMARY THORACIC CURVE

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Objective. To identify main negative factors influencing the comprehensive assessment of the results of surgical treatment of severe idiopathic scoliosis with a primary thoracic curve.

Material and Methods. A total of 288 patients were operated on for idiopathic scoliosis with main thoracic curve (Lenke types 1, 2, 3 and 4) measuring 93.0° [85.0°; 105.0°] in 1999–2019. Out of them, 154 patients had the lumbar countercurvature of 62.0° [53.0°; 72.5°]. All patients were operated on using posterior segmental instrumentation with hook fixation, hybrid (hook fixation in the thoracic and transpedicular one in the lumbar and thoracolumbar spine) and transpedicular fixation. The median age of patients at the time of surgery was 15.0 [13.0; 17.0] years, and the median period of postoperative follow-up – 4.3 [3.0; 6.2] years. Clinical and radiological data in the preoperative, postoperative and in long-term postoperative periods, and data of the SRS-24 survey were analyzed. The threshold values of eight clinical parameters were evaluated based on their excess of reference parameters of the physiological norm and data substantiated by previously conducted studies.

Results. The residual thoracic curvature of more than 70° was detected in 32 (11.1%) patients, thoracic kyphosis over 60° – in 22 (7.6%), shoulder girdle tilt more than 5° – in 39 (13.5%), correction less than 50% – in 108 (37.5%), clinical frontal imbalance – in 49 (17.0%), hypokyphosis – in 79 (27.4%), hypolordosis – in 37 (12.8%), and total SRS-24 score less than 80 points – in 7 (2.4%) patients. Excellent results were stated in 123 (42.7%) patients, good – in 118 (41%), including 42 (35.6%) with one or more significant negative factors; satisfactory results were stated in 44 (15.3%) patients, including 35 (79.5%) with critical negative factors. Unsatisfactory results were noted in 3 (1.0%) patients.

Conclusion. Identification of statistically significant differences in 398 parameters made it possible to reveal eight negative factors that affect the outcome of treatment of severe thoracic scoliosis, and to determine their threshold values. Three critical negative factors have the greatest impact on the result of surgical treatment: the residual thoracic scoliotic curve more than 70°, thoracic hyperkyphosis more than 60° and shoulder girdle tilt more than 5°.

Keywords: severe idiopathic scoliosis; classification of results; negative factors.

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Severe forms of idiopathic scoliosis include spinal deformities exceeding 70° or 80° according to Cobb [1–3]. The surgical treatment strategy for these patients may differ from the standard one because of the increased risk of complications and unsatisfactory outcomes [4]. The goals for the surgical treatment of scoliosis are to get an optimal spinal correction, balance the body, preserve the achieved results, and ensure patient satisfaction [5, 6]. Therefore, it is reasonable to evaluate its results using radiological parameters, clinical changes, and the patient's subjective opinion about the treatment outcome,

as determined by a questionnaire. There are many parameters to consider when evaluating treatment outcomes, including frontal and sagittal balance, the evolution of physiological kyphosis and lordosis, and changes in the contour of the back surface [7].

Some authors [8–10] evaluate the surgical outcomes based on the corrective force applied to the apex of the scoliotic curve, with the absence of neurological complications and improvement in external respiratory function being of significance [11].

There are still no uniform criteria for objectively assessing the surgical out-

comes of severe scoliosis, and outcomes may be assessed in a different way by several orthopedic surgeons; in addition, there is often no correlation between expert judgement and patient satisfaction with treatment outcomes [12].

We only managed to find a report on the modified Clavien–Dindo–Sink (CDS) classification of complications in the surgical treatment of idiopathic scoliosis. The severity of complications is determined by the need for and frequency of unplanned additional examinations and unavoidable repeated procedures to manage emerging risks [13]. We have tried to assess the treatment outcomes

of severe idiopathic scoliosis, given the factors that integrally influence the final outcome.

The objective is to identify the main negative factors influencing the comprehensive assessment of the results of surgical treatment of severe idiopathic scoliosis with a primary thoracic curve.

Material and Methods

A retrospective, single-center, cohort, non-randomized, controlled study was performed to assess the surgical outcomes of 288 patients with severe idiopathic scoliosis with a primary thoracic scoliotic curve (Lenke types 1–4) of 93.0° [85.0°; 105.0°]; 154 patients had lumbar countercurvature of 62.0° [53.0°; 72.5°] according to Cobb. All patients underwent surgery using posterior segmental instrumentation with hook, hybrid, and transpedicular fixation from 1999 to 2019. There were 243 female patients (84.4%) and 45 male patients (15.6%). The mean age of patients at the time of surgery was 15.0 [13.0; 17.0] years. The mean postoperative follow-up period was 4.3 [3.0; 6.2] years.

We also assessed the history, radiographs of the spine (C7–S1) in frontal and lateral views with the patient in a standing position, data of orthopedic examination before surgery, after surgery, and at the end of follow-up, as well as the results of the SRS-24 questionnaire in 6 months, 1 year, and 2 years after surgery and at the end of follow-up.

Using criteria for assessment of outcomes for idiopathic scoliosis treatment by M.V. Mikhaylovskiy [7], we tried to identify the most significant parameters out of the 398 clinical and radiological ones studied in our clinic to define their threshold values, the crossing of which may indicate the presence of a negative factor affecting the treatment outcome. Finally, we assessed eight key parameters with specific threshold values, crossing which indicated a negative impact on the surgical outcome.

According to V.V. Novikov [14], the threshold value of the residual scoliotic curve, crossing which the risk of mechanical complications and further

loss of correction increases, is 70° according to Cobb. Moreover, this value may also be the lower threshold value for severe scoliosis [2].

Severe and rigid scoliotic deformities are more often characterized by initial thoracic hyperkyphosis [15].

The threshold value for residual thoracic kyphosis was assessed as exceeding the conditional norm (40°) [16] by 50% or 60° according to Cobb. The progression of thoracic kyphosis to 65°–70° inevitably worsens the patient's appearance and may be an independent indication for correction [4]. Thoracic kyphosis over 60° results in increased rotation of the apical vertebra, according to Sullivan et al. [17], even with a moderate residual thoracic scoliotic curve.

The threshold value for clinical shoulder level angle was set at 5°, which was higher than the assumed crucial value of 2° [18], to completely eliminate subjective measurement errors.

The threshold value of 50% correction of the primary scoliotic curve is defined in accordance with the concept of the minimum acceptable degree of optimal impact on spinal deformity [14, 19].

The threshold values for thoracic hypokyphosis and lumbar hypolordosis were defined in accordance with the conditional limits of 20° and 40°, respectively [4, 16].

A clinical frontal imbalance (distance from the plumb line to the navel and intergluteal cleft greater than 15 mm) corresponded to a state of sub- and decompensation of the radiological frontal balance (central sacral vertical line, CSVL) [5, 20].

The crucial parameter for the total SRS-24 score of less than 80 was defined using a threshold of maximum statistical significance of difference from other patients, $p < 0.001$.

The groups of patients were formed considering each of the eight negative factors. The groups were compared to identify statistically significant differences in the examined 398 clinical and radiological parameters. Depending on the number of statistically significant differences with the comparison group, the relevance of the eight negative elements

under research was assessed as follows: crucial factors are residual primary scoliotic curve after surgery greater than 70° (Group 1), thoracic kyphosis after surgery greater than 60° (Group 2), shoulder imbalance greater than 5° (Group 3); significant factors are correction of the primary scoliotic curve less than 50% (Group 4), frontal imbalance in the form of an increased distance from the plumb line anteriorly (from the suprasternal notch of the sternum) to the navel, and posteriorly (from the C7 spinous process) to the intergluteal cleft by more than 15 mm (Group 5), acceptable factors are thoracic kyphosis less than 20° (Group 6), lumbar lordosis less than 40° (Group 7), total SRS-24 score less than 80 (Group 8). The surgical outcomes of all 288 patients were then assessed using the identified number and combination of the eight negative factors.

An excellent surgical outcome was defined as the lack of negative factors, a good outcome as the lack of crucial negative factors, a satisfactory outcome as the presence of at least one crucial negative factor or several significant negative factors in combination with acceptable factors, and an unsatisfactory outcome as the presence of severe persistent uncontrollable complications (grade IVb according to the CDS classification) [13].

Because of the non-compliance between the majority (91%) of continuous data and the normal distribution according to the Shapiro–Wilk test, the nonparametric Mann–Whitney Non-Parametric U-test was used to compare them. Descriptive characteristics are given as the median with the first and third quartiles (MED [Q1; Q3]) for continuous data and as a number (percentage) for categorical data. Fisher's exact test was used to compare categorical and binary data. Multiple comparison errors were corrected using the Benjamini–Hochberg procedure. Paired relationships between indicators were evaluated using Spearman's Rank Correlation Coefficient. In order to study the relationship between the indicators and changes in BDNF levels, univariate and multivariate linear regression models were used. The differences were considered statis-

tically significant at $p < 0.05$. Statistical analysis was performed using the RStudio IDE (version 2025.05.0 Build 496, URL: <https://www.rstudio.com/>) in the R language (version 4.4.2 (2024-10-31 ucrt), URL: <https://www.R-project.org/>).

The study has been approved by the Institutional Biomedical Ethics Committee (extract 002/25 from the minutes of meeting 001/25 dated February 24, 2025) and corresponds to international and Russian legislative documents such as the ethical standards of the World Medical Association's Declaration of Helsinki "Ethical Principles for Medical Research Involving Human Participants" and the Order of the Ministry of Health of the Russian Federation dated April 1, 2016, No. 200n, "On the Approval of Rules for Good Clinical Practice." All participants provided voluntary consent to be included in the study.

Results

The initial magnitude of the primary scoliotic curve was 93.0° on average [85.0° ; 105.0°]. The magnitude of the lumbar countercurvature was 62.0° [53.0° ; 72.5°]. The correction rate for thoracic scoliosis at the end of the follow-up period was 58.6% [46.9; 68.0], and for lumbar countercurvature, 65.35% [57.4; 73.3]. Thoracic kyphosis before surgery was 44.0° [29.0° ; 65.0°], lumbar lordosis was 55.0° [46.0° ; 62.0°], and at the end of the follow-up period they were 28.0° [20.0° ; 41.0°] and 55.0° [46.0° ; 62.0°], respectively. The shoulder imbalance was 4.0° [2.0° ; 5.0°] before surgery and 3.0° [3.0° ; 5.0°] at the end of the follow-up period. Distance from the plumb line anteriorly (from the suprasternal notch of the sternum) to the navel, and posteriorly (from the C7 spinous process) to the intergluteal cleft was 10.0 [5.0; 20.0] cm before surgery, and 10.0 [10.0; 15.0] cm at the end of the follow-up period.

Repeated surgeries were not necessary for 214 (74.3%) patients; a significant number of repeated surgeries (53 (18.4%) cases) were resections of residual rib humps.

A survey using the SRS-24 questionnaire was conducted after 6 months

in 158 (53%) patients. The total score remained virtually unchanged over the two years following surgery – 89.0 [82.3; 94.0], 90.0 [83.3; 96.0] and 89.0 [83.5; 94.0], respectively, and it decreased slightly in patients with the longest follow-up periods – 86.5 [80.8; 92.5].

The magnitude of the primary scoliotic curve at the end of the follow-up period in 32 patients in Group 1 was 77.0° [74.0° ; 79.6°] compared to 40.0° [32.0° ; 50.0°] in the main group ($p < 0.001$). These patients show worsened clinical and radiological parameters: lumbar and upper thoracic countercurvature, thoracic kyphosis and lumbar lordosis, apical vertebra rotation according to Sullivan, sitting height, decreased vital capacity of the lungs, height of the residual rib hump, and distance from the plumb line anteriorly and posteriorly (Table 1).

There were no differences in the results of the SRS-24 patient questionnaire, types of surgeries, number and nature of complications, or types of additional surgeries.

Twenty-two patients in Group 2 had a thoracic kyphosis of 74.0° [63.0° ; 79.0°] at the end of the follow-up period, compared with 27.0° [19.5° ; 37.5°] in the main group ($p < 0.001$); they also showed six significantly worsened clinical and radiological parameters: primary thoracic scoliotic curve and Sullivan rotation at the end of the follow-up period, standing and sitting height, residual rib hump height, and scapular asymmetry (Table 2).

No other relevant differences from the main group of patients were observed.

Shoulder imbalance at the end of the follow-up period was measured in 123 patients. Shoulder imbalance of more than 5° (Group 3) at the end of the follow-up period was recorded in 39 of them and amounted to 8.0° [6.0° ; 8.5°] compared to 3.0° [3.0° ; 5.0°] in the main group ($p < 0.001$). The comparison of Group 3 with the main group revealed differences in the results of the patient questionnaire study (SRS-24) in terms of pain scores – 3.2 [2.9; 3.5] points versus 4.0 [3.6; 4.3] points ($p = 0.035$), overall appearance – 2.8 [2.6; 3.1] versus 3.3 [3.0; 3.7] points ($p = 0.028$), and total score –

76.5 [71.8; 81.5] versus 90.0 [83.0; 94.8] points ($p = 0.013$) at the end of the follow-up period.

The correction of less than 50% (Group 4) was reported in 108 patients and amounted to 42.3% [35.0; 45.1] versus 63.9% [57.6; 71.0] in the main group ($p < 0.001$).

Four clinical and radiological parameters in patients in Group 4 were worse: the primary scoliotic curve at the end of the follow-up period was 60.0° [53.0° ; 74.0°] versus 36.0° [29.8° ; 45.0°] ($p < 0.001$), thoracic kyphosis at the end of follow-up – 42.0° [25.0° ; 56.0°] versus 26.0° [19.0° ; 34.0°] ($p < 0.001$), scapular asymmetry – 9.0° [6.0° ; 12.0°] versus 7.0° [5.0° ; 8.0°], and residual rib hump height after surgery – 35.0 [25.0; 45.0] mm versus 25.0 [20.0; 35.0] mm, respectively ($p < 0.001$).

The indicators of clinical frontal balance at the end of the follow-up period were defined in 66 patients with a follow-up period of 2 years or more. Among them, 49 patients (Group 5) had changes in the form of a deviation of the plumb line anteriorly from the navel and the plumb line posteriorly from the intergluteal cleft – 20.0 [15.0; 20.0] mm versus 10.0 [7.0; 10.0] mm in the remaining 17 patients ($p < 0.001$). Patients in Group 5 showed two worsened radiological parameters: residual scoliotic curve and rotation of the apex vertebra of the primary scoliotic curve according to Sullivan at the end of the follow-up period – 69.0° [41.0° ; 74.8°] versus 43.0° [30.0° ; 55.0°] ($p = 0.026$) and 23.3° [16.6° ; 42.6°] versus 14.4° [10.0° ; 20.1°], respectively ($p = 0.005$).

At the end of the follow-up period, thoracic hypokyphosis was reported in 79 patients and lumbar hypolordosis in 37 patients – 16.0° [13.0° ; 19.0°] versus 34.0° [27.0° ; 48.0°] and 35.0° [32.0° ; 38.0°] versus 57.0° [50.0° ; 63.0°] ($p < 0.001$), respectively (groups 6 and 7). No statistically significant differences from the main group of patients were identified for any other indicators at the end of the follow-up period.

The data collected using the SRS-24 questionnaire 6 months after surgery were obtained from 141 patients. In 32

patients, the total score was less than 80 (Group 8) – 75.0 [73.0; 78.0] points versus 91.5 [88.0; 96.5] in the main group ($p < 0.001$).

There were no statistically significant differences in gender distribution, age at the time of surgery, correction of the primary scoliotic curve, follow-up period, number of complications, or additional procedures.

The assessment of the surgical outcome by patients in the study group 6 months after surgery was significantly lower in all main domains: pain – 2.9 [1.7; 3.7] points versus 4.0 [3.7; 4.3] points ($p < 0.001$); overall appearance and appearance after surgery – 3.0 [1.8; 3.4] vs. 3.3 [3.1; 3.7] and 3.7 [0.8; 4.7] vs. 4.7 [4.3; 5.0] ($p < 0.001$); as well as overall and professional activity – 2.2 [1.0; 2.7] vs. 3.3 [2.7; 3.7] and 3.0 [1.0; 4.0] vs. 4.0 [3.4; 4.3] ($p < 0.001$); and satisfaction with the surgical outcome – 3.8 [1.3; 4.3] vs. 4.7 [4.0; 5.0] in the main group ($p < 0.001$).

More than two years after surgery (results from 36 patients, 7 of whom had less than 80 points), there were still statistically significant differences in total score, appearance, and satisfaction with the treatment outcome: 75.0 [73.0; 78.0] versus 91.5 [88.0; 96.5], 3.0 [3.0; 3.3] versus 4.7 [4.3; 5.0], and 3.7 [3.3; 3.83] versus 4.7 [4.3; 5.0] points ($p < 0.001$).

The differences in domains of pain and general appearance assessment 2 years after surgery were less pronounced – 3.1 [2.7; 3.6] vs. 4.0 [3.6; 4.3] ($p = 0.023$) and 3.0 [3.0; 3.2] vs. 3.3 [3.3; 3.7] points, respectively ($p = 0.022$).

Excellent outcomes were observed in 123 patients, good outcomes in 118 patients, including 42 (35.6%) with one or more significant negative factors, and satisfactory outcomes in 44 patients, including 35 (79.5%) with crucial negative factors; unsatisfactory outcomes were observed in three patients, including one case of persistent neurological deficit and two cases of instrumentation removal with complete loss of spinal deformity correction (Fig. 1).

Clinical cases

A female patient K. with idiopathic right-sided thoracic kyphoscoliosis (grade IV) and a lumbar countercurva-

ture. Satisfactory result (one crucial negative factor – scapular asymmetry of more than 5°; one significant negative factor – distance from the plumb line of more than 15 mm). The need for additional corrective surgery and the possibility of performing it (Fig. 2).

A female patient Z. with idiopathic right-sided thoracic scoliosis (grade IV) and a lumbar countercurvature. Good result (two acceptable negative factors – thoracic hypokyphosis of 16° and total SRS-24 score of 75 points; Fig. 3). SRS-24 score 2 years after surgery is 75 points (pain is 3 points and satisfaction with results is 3.5 points).

A female patient N. with idiopathic right-sided thoracic lordoscoliosis (grade IV) and a lumbar countercurvature. Excellent result: no negative factors (Fig. 4).

Discussion

Sometimes, when treating idiopathic scoliosis with surgery, there can be undesirable effects or complications resulting in changes to the surgical strategy and postoperative follow-up, and may require repeated surgery or procedures. These conditions are described and classified in the study by Guiss et al. [13].

We hypothesized that the negative changes in key parameters occurring and collectively affecting the surgical outcome cannot always be considered complications. Nevertheless, their varying trends may not only enable the standardization of treatment success assessment but also influence treatment strategy to eliminate undesirable effects.

There is a three-dimensional classification of surgical outcomes for idiopathic scoliosis using three-plane modeling of radiological data, as proposed by Pasha et al. [21]. The authors highlight three types of three-dimensional radiological outcomes after two years of follow-up. This classification was used for prediction of surgical outcomes; however, the outcome itself was assessed only using parameters from 3D-modeling of spinal radiographs.

The study objective was to identify the key parameters of surgical outcomes for

severe idiopathic thoracic scoliosis, their significance, and threshold values, deviations from which may indicate suboptimal clinical outcomes.

The basis was taken from the criteria for assessment of the surgical outcomes of idiopathic scoliosis, as presented in the study by M.V. Mikhaylovskiy [7].

The eight clinical and radiological indicators were the most relevant, as their change exceeding the threshold values had a negative impact on the surgical outcome.

Threshold values were set by exceeding the reference values of the physiological norm and statistically significant changes in indicators, based on previous studies [7, 14, 16, 18–20, 22].

According to data from V.V. Novikov [14], an absolute value of the residual primary scoliotic curve of more than 70° on the Cobb scale results in an increased risk of disruption of the integrity of the used corrective instrumentation, pseudoarthrosis of the artificial bone block, and complete or partial loss of the achieved spinal deformity correction.

We did not find a statistically significant difference in the incidence of the listed complications in patients with this negative factor; nevertheless, a residual scoliotic curve of more than 70° was combined with significant changes in nine clinical and radiological parameters, which caused its crucial impact on the treatment outcome. A final thoracic hyperkyphosis greater than 60° was considered crucial, as it was associated with statistically significant changes in six other clinical and radiological parameters.

Inadequate primary correction of the main scoliotic curve was considered a negative factor. If its degree is less than 50% of the initial deformity, the surgical outcome cannot be considered optimal [14, 19]. Despite the statistically significant influence of this factor on four other clinical and radiological parameters, the mean absolute values of the residual primary scoliotic curve and thoracic kyphosis at the end of the follow-up period did not exceed the threshold values determined by us as negative factors for the surgical outcome. Therefore, we judged this indicator to be significant but not crucial.

Table 1

Comparison of the parameters of patients with a residual scoliotic curve greater than 70° (Group 1) with the parameters of patients in the main group

Parameter MED [Q1; Q3] M ± SD (MIN–MAX)	Main group (n = 256)		patients	Group 1 (n = 32)		Comparison	
	patients	values		patients	values	difference pMED [95% CI] SMD [95% CI]	
Lumbar countercurvature, degrees	190 (74.0 %)	30.5 [22.0; 38.0] 31.1 ± 12.4 (2.0–68.0)		20 (62.0 %)	52.5 [42.5; 59.8] 52.7 ± 14.5 (32.0–86.0)	21.0 [15.0; 27.0]; –1.71 [–2.20; –1.23]	<0.001*
Upper thoracic countercurvature (if any), degrees	56 (22.0 %)	26.0 [20.0; 30.0] 26.4 ± 8.5 (7.0–54.0)		6 (19.0 %)	40.0 [33.8; 47.0] 41.0 ± 8.6 (32.0–53.0)	15.0 [7.0; 23.0] –1.8 [–2.6; –0.9]	0.001*
Thoracic kyphosis at the end of follow-up, degrees	256 (88.9 %)	27.0 [19.0; 37.0] 29.6 ± 15.0 (1.0–91.0)		32 (11.0 %)	52.5 [41.0; 62.5] 54.0 ± 20.7 (19.0–114.0)	24.0 [18.0; 30.0] –1.5 [–1.9; –1.2]	<0.001*
Lumbar lordosis at the end of follow-up, degrees	252 (98.0 %)	53.0 [46.0; 61.0] 53.3 ± 12.3 (11.0–110.0)		31 (97.0 %)	60.0 [55.5; 68.5] 61.5 ± 12.6 (33.0–87.0)	8.0 [3.0; 13.0] –0.7 [–1.0; –0.3]	<0.001*
Sullivan rotation at the end of follow-up, degrees	256 (88.9 %)	15.3 [11.7; 19.9] 16.4 ± 7.1 (or –0.8 to –36.6)		32 (11.0 %)	33.8 [31.0; 39.4] 35.5 ± 7.0 (26.0–56.2)	18.9 [16.7; 21.3] –2.7 [–3.1; –2.3]	<0.001*
Sitting height at the end of follow-up, cm	227 (89.0 %)	85.0 [82.5; 87.5] 84.6 ± 4.5 (64.0–96.0)		30 (94.0 %)	80.0 [77.6; 84.6] 8.8 ± 5.0 (69.5–89.0)	–4.0 [–5.5; –2.0] 0.84 [0.5; 1.2]	<0.001*
Vital capacity of the lungs, ml	90 (34.0 %)	1500.0 [1100.0; 1700.0] 952.0 ± 776.2 (700.0–1808.0)		11 (46.0 %)	1100.0 [1050.0; 1200.0] 1145.5 ± 220.7 (900.0–1700.0)	–300.0 [–500.0; –0.0] 0.1 [–0.5; 0.7]	0.021*
Postoperative posterior rib hump height, mm	233 (88.0 %)	30.0 [20.0; 35.0] 30.1 ± 11.5 (1.0–70.0)		22 (92.0 %)	45.0 [30.0; 50.0] 41.4 ± 13.2 (15.0–60.0)	15.0 [10.0; 20.0] –1.1 [–1.5; –0.6]	<0.001*
Anterior and posterior plumb lines at the end of follow-up, mm	44 (17.0 %)	10.0 [10.0; 15.0] 11.3 ± 5.4 (1.0–25.0)		7 (22.0 %)	20.0 [17.0; 20.0] 18.6 ± 4.8 (10.0–25.0)	10.0 [5.0; 10.0] –1.4 [–2.2; –0.5]	0.003*

* Statistically significant differences; SMD — standardized mean difference; pMED — pseudomedian of paired differences; M ± SD — mean ± standard deviation.

Table 2

Comparison of the parameters of patients with a thoracic kyphosis greater than 60° at the end of follow-up (Group 2) with the parameters of patients in the main group

Parameter MED [Q1; Q3] M ± SD (MIN–MAX)	Main group (n = 266)		patients	Group (n = 22)		Comparison	
	patients	values		patients	values	difference pMED [95% CI] SMD [95% CI]	p value
Sullivan rotation at the end of follow-up, degrees	266 (100 %)	15.4 [12.0; 20.8] 17.0 ± 7.7 (or –0.8 to –41.2)		22 (100 %)	34.7 [32.4; 40.4] 37.4 ± 7.3 (29.0–56.2)	20.3 [17.4; 23.3] –2.7 [–3.2; –2.2]	<0.001*
Standing height at the end of follow-up, cm	260 (98 %)	163.0 [157.5; 168.5] 163.0 ± 8.7 (133.0–189.0)		22 (100 %)	159.5 [148.0; 163.50] 156.8 ± 10.6 (137.5–176.0)	–6.0 [–11.0; –1.5] 0.7 [0.3; 1.2]	0.013*
Sitting height at the end of follow-up, cm	237 (89 %)	85.0 [82.5; 87.5] 84.5 ± 4.4 (64.0–96.0)		20 (90 %)	79.3 [76.3; 84.3] 79.7 ± 5.7 (69.5–90.0)	–5.0 [–7.5; –2.0] 1.1 [0.6; 1.5]	<0.001*
Anterior and posterior plumb lines at the end of follow-up, mm	236 (89 %)	30.0 [20.0; 35.0] 29.4 ± 11.7 (1.0–0.0)		19 (86 %)	40.0 [27.5; 50.0] 38.4 ± 13.7 (15.0–60.0)	10.0 [5.0; 15.0] –0.8 [–1.2; –0.3]	0.007*
Scapular asymmetry at the end of follow-up, mm	229 (86 %)	7.0 [5.0; 10.00] 7.6 ± 3.6 (2.0–20.0)		22 (100 %)	10.0 [7.0; 12.0] 10.3 ± 4.0 (5.0–20.0)	2.0 [1.0; 5.0] –0.8 [–1.2; –0.3]	0.002*

* Statistically significant differences; SMD — standardized mean difference; pMED — pseudomedian of paired differences; M ± SD — mean ± standard deviation.

Equally important are the clinical parameters of frontal imbalance as a manifestation of visible trunk asymmetries [5, 20].

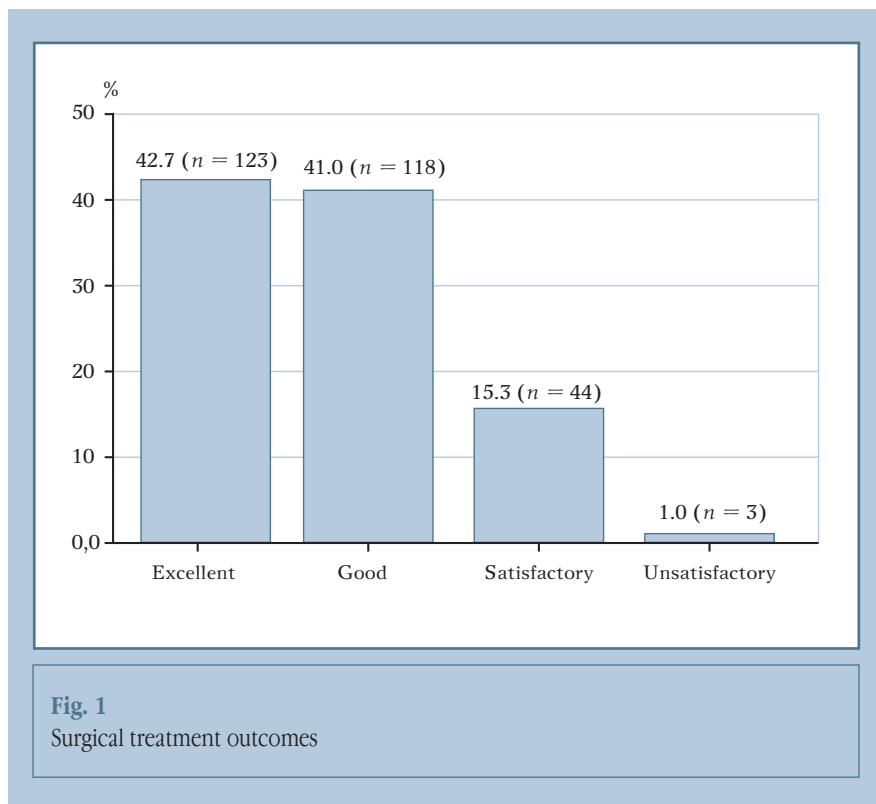
We identified shoulder imbalance of more than 5° as a crucial parameter, as only this group of patients showed significant differences in the questionnaire results (pain, overall appearance, and total score). The development or progression of a thoracic countercurvature (in double thoracic curves, Lenke type 2) [18] was not assessed separately, as these changes do not always lead to significant shoulder imbalance or necessitate repeated surgery. We did not assess the phenomenon of adding-on [22], since selective fusion was not used in the study group of patients; the lumbar spine area was instrumented in all cases.

Clinical frontal imbalance (distance from the plumb line anteriorly and posteriorly greater than 15 mm) was evaluated as a significant negative factor associated with residual thoracic scoliosis and rotation of the apical vertebra.

Thoracic hypokyphosis and lumbar hypolordosis were considered negative yet acceptable parameters, as the maintenance of physiological sagittal curves is crucial for sustaining overall sagittal balance and prevention of the onset of early degenerative processes in the lumbar spine [7]. However, no statistically significant differences were observed in these patients compared to the main group regarding other parameters.

We did not specifically evaluate the changes in the parameters of the spinopelvic sagittal balance, as most of our patients were adolescents at the time of surgery, and the main goal was to correct the visual aspect by eliminating a severe cosmetic defect [23].

According to V.V. Belozarov et al. [23], the main factors influencing the risk of postoperative imbalance in patients with idiopathic scoliosis (i.e. severe residual scoliotic curve, thoracic hyperkyphosis, and lumbar hypolordosis, as well as pronounced spinal imbalance in the long-term postoperative period) do



not diminish the quality of life; however, they concurrently increase the risk of mechanical postoperative complications by as much as 50%.

We classified a threshold value of less than 80 points based on the results of patient questionnaires using the SRS-24 questionnaire as acceptable, since no significant differences were found in this group of patients for any of the other studied parameters. The Russian-language questionnaire helps to assess the surgical outcome from the patient's perspective, thus complementing clinical and radiological examination techniques [4]. The decision to use the total score as a threshold, rather than analyzing individual domains, was based on the understanding that questionnaire results are influenced by numerous factors unrelated to spinal pathology or its treatment. Furthermore, the impact of the severity and type of spinal deformity on quality of life is a complex and compound issue [24]. For this reason, the overall assessment of quality of life seems to be the simplest way for attempting to standardize results. Similar to the CDS classification [13], we attempted to assess the surgical outcomes in terms of possible deviations

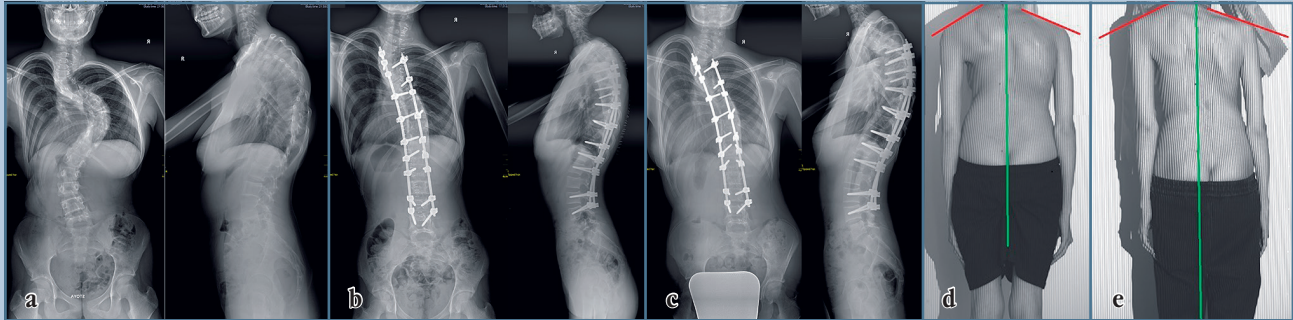
from routine postoperative follow-up and the need for additional unplanned surgeries, depending on the identification of various numbers and combinations of crucial, significant, and acceptable negative factors. No further unplanned clinical or radiological examinations or surgical treatment were required in the absence of crucial and significant negative factors. If isolated significant and acceptable negative factors are identified, additional examination and conservative treatment may be required, as well as an extended follow-up period. If crucial negative factors are identified, additional planned surgery may be appropriate in some cases.

We considered cases with complications that could not be completely resolved as unsatisfactory outcomes [13].

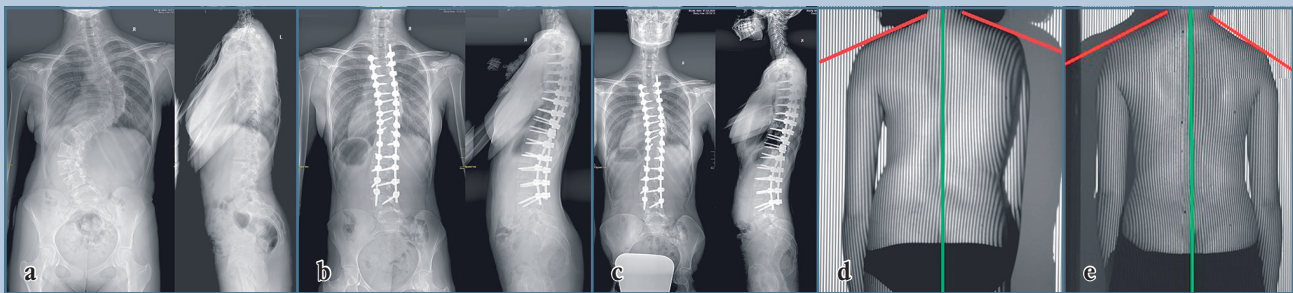
The proposed graded results determine the postoperative follow-up and treatment strategy for patients in the analyzed sample.

Conclusion

The assessment of clinical and radiological indicators of surgical outcomes in severe thoracic scoliosis, including the determination of their threshold

**Fig. 2**

Female patient K: **a** – right-sided thoracic scoliotic curve of 103°, lumbar countercurvature of 55°, thoracic kyphosis of 81°; **b** – after surgery: right-sided thoracic scoliotic curve of 30°, no lumbar countercurvature, upper thoracic scoliotic curve of 58°, thoracic kyphosis of 35°; **c** – 2 years after surgery: right-sided thoracic scoliotic curve of 37°, no lumbar countercurvature, upper thoracic scoliotic curve of 71°, thoracic kyphosis of 56°; **d** – clinically before surgery: shoulder imbalance of 15° to the right, plumb line along the left edge of the intergluteal cleft; **e** – 2 years after surgery: shoulder imbalance of 20° to the right, plumb line is 40 mm to the right of the intergluteal cleft

**Fig. 3**

Female patient Z: **a** – right-sided thoracic scoliotic curve of 87°, lumbar countercurvature of 79°, thoracic hypokyphosis of 14°; lumbar lordosis of 42°; **b** – after surgery: right-sided thoracic scoliotic curve of 27°, lumbar countercurvature of 16°, thoracic hypokyphosis of 13°, lumbar lordosis of 40°; **c** – at the end of follow-up: right-sided thoracic scoliotic curve of 29°, lumbar countercurvature of 22°, thoracic hypokyphosis of 16°, lumbar lordosis of 42°; **d** – before surgery: no frontal imbalance and no shoulder imbalance of more than 5°; **e** – 2 years after surgery: no frontal imbalance and no shoulder imbalance of more than 5°

values, revealed eight negative factors influencing treatment outcomes. The importance of their negative impact was established by identifying statistically significant differences across 398 studied parameters. Three crucial negative factors were identified that have the greatest impact on the surgical outcome. This is a

residual thoracic scoliotic curve of more than 70° (significant differences in nine parameters), thoracic hyperkyphosis of more than 60° (significant differences in six parameters), and shoulder imbalance of more than 5° (the only negative factor affecting the results of SRS-24 patient questionnaires).

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.

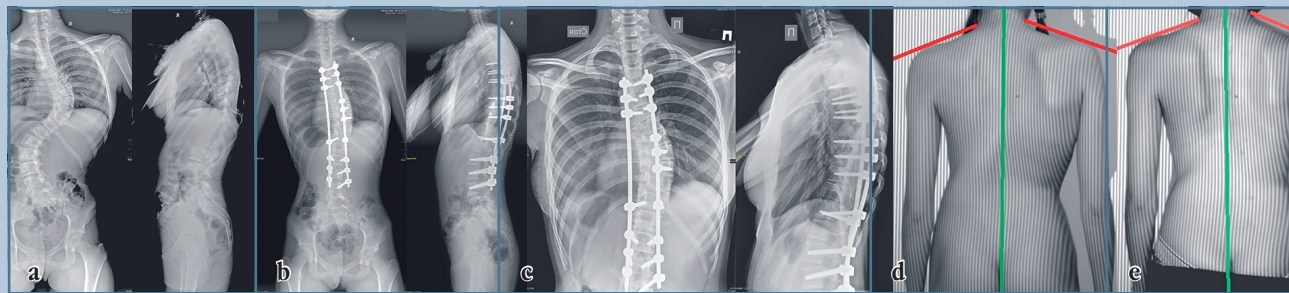


Fig. 4

Female patient N: **a** – right-sided thoracic scoliotic curve of 83°, lumbar countercurvature of 59°, thoracic kyphosis of 42°; **b** – after surgery: right-sided thoracic scoliotic curve of 37°, lumbar countercurvature of 15°, thoracic kyphosis of 22°; **c** – 2 years after surgery: right-sided thoracic scoliotic curve of 38°, lumbar countercurvature of 18°, thoracic kyphosis of 34°; **d** – before surgery: scapular asymmetry of 7° to the left; **e** – 2 years after surgery: scapular asymmetry of less than 5°, plumb line to the right of the intergluteal cleft

References

- De Giorgi G, Stella G, Becchetti S, Martucci G, Miscioscia D. Cotrel–Dubousset instrumentation for the treatment of severe scoliosis. *Eu. Spine J.* 1999;8:8–15. DOI: 10.1007/s005860050120
- Luhmann SJ, Lenke LG, Kim YJ, Bridwell KH, Schootman M. Thoracic adolescent idiopathic scoliosis curves between 70 degrees and 100 degrees: is anterior release necessary? *Spine (Phila Pa 1976)*. 2005;30:2061–2067. DOI: 10.1097/01.brs.0000179299.78791.96
- Dobbs MB, Lenke LG, Kim YJ, Luhmann SJ, Bridwell KH. Anterior/posterior spinal instrumentation versus posterior instrumentation alone for the treatment of adolescent idiopathic scoliotic curves more than 90 degrees. *Spine (Phila Pa 1976)*. 2006;31:2386–2391. DOI: 10.1097/01.brs.0000238965.81013.c5
- Mikhailovsky MV, Fomichev NG. *Surgery of Spinal Deformities*. Novosibirsk, 2002. ISBN: 978-5-91475-010-43
- Kubat O, Ovadia D. Frontal and sagittal imbalance in patients with adolescent idiopathic deformity. *Ann Transl Med.* 2020;8:29. DOI: 10.21037/atm.2019.10.49
- Banno T, Yamato Y, Hasegawa T, Yoshida G, Arima H, Oe S, Ide K, Yamada T, Kurosu K, Matsuyama Y. Evaluation of the changes in waistline asymmetry using digital photography in adolescents with idiopathic thoracolumbar/lumbar scoliosis after corrective surgery. *Spine Deform.* 2024;12:1079–1088. DOI: 10.1007/s43390-024-00850-x
- Mikhaylovskiy MV, ed. *Surgery for Idiopathic Scoliosis: Immediate and Long-Term Results*. Novosibirsk, 2007. ISBN: 978-5-91475-005-0
- Vissarionov SV, Kokushin DN, Belyanchikov SM, Murashko VV, Kartavenko KA, Nadirov NN. Surgical treatment of children with idiopathic scoliosis of Lenke type I with the use of total transpedicular fixation. *Pediatric Traumatology, Orthopaedics and Reconstructive Surgery*. 2014;2(2):3–8. DOI: 10.17816/PTORS223-8 EDN: ORTWLB
- Kim HJ, Chang DG, Lenke LG, Pizones J, Castelein R, Trobisch PD, Watanabe K, Yang JH, Suh SW, Suk SI. Rotational changes following use of direct vertebral rotation in adolescent idiopathic scoliosis: a long-term radiographic and computed tomography evaluation. *Spine (Phila Pa 1976)*. 2024;49:1059–1068. DOI: 10.1097/BRS.0000000000004869
- Chang DG, Suk SI, Kim JH, Song KS, Suh SW, Kim SY, Kim GU, Yang JH, Lee JH. Long-term outcome of selective thoracic fusion using rod derotation and direct vertebral rotation in the treatment of thoracic adolescent idiopathic scoliosis: more than 10-year follow-up data. *Clin Spine Surg.* 2020;33:50–57. DOI: 10.1097/BSD.0000000000000833
- Zhang H, Yang G, Guo C, Deng A, Xiao L. Preoperative halo-femoral traction with posterior surgical correction for the treatment of extremely severe rigid congenital scoliosis (Cobb angle >120°). *J Am Acad Orthop Surg.* 2022;30:421–427. DOI: 10.5435/JAOS-D-21-01095
- Buchanan R, Birch JG, Morton AA, Browne RH. Do you see what I see? Looking at scoliosis surgical outcomes through orthopedists' eyes. *Spine (Phila Pa 1976)*. 2003;28:2700–2704; discussion 2705. DOI: 10.1097/01.BRS.0000103383.81904.5A
- Guissé NF, Stone JD, Keil LG, Bastrom TP, Erickson MA, Yaszay B, Cahill PJ, Parent S, Gabos PG, Newton PO, Glotzbecker MP, Kelly MP, Pahys JM, Fletcher ND. Modified Clavien-Dindo-sink classification system for adolescent idiopathic scoliosis. *Spine Deform.* 2022;10:87–95. DOI: 10.1007/s43390-021-00394-4
- Novikov VV. *Surgical Tactics and Provision of Specialized Care to Patients with Severe Scoliosis*. Moscow, 2022. EDN: CXADPV
- Zhang Z, Wang L, Li JC, Liu LM, Song YM, Yang X. Characteristics of sagittal alignment in patients with severe and rigid scoliosis. *Orthop Surg.* 2023;15:1607–1616. DOI: 10.1111/os.13749
- Roaf R. Vertebral growth and its mechanical control. *J Bone Joint Surg Br.* 1960;42-B:40–59. DOI: 10.1302/0301-620X.42B1.40
- Sullivan TB, Bastrom T, Reighard F, Jeffords M, Newton PO. A novel method for estimating three-dimensional apical vertebral rotation using two-dimensional coronal Cobb angle and thoracic kyphosis. *Spine Deform.* 2017;5:244–249. DOI: 10.1016/j.jspsd.2017.01.012
- Gotfryd AO, Silber Caffaro MF, Meves R, Avanzi O. Predictors for postoperative shoulder balance in Lenke 1 adolescent idiopathic scoliosis: a prospective cohort study. *Spine Deform.* 2017;5:66–71. DOI: 10.1016/j.jspsd.2016.09.046

19. **Min K, Szalay C, Farshad M.** Posterior correction of thoracic adolescent idiopathic scoliosis with pedicle screw instrumentation: results of 48 patients with minimal 10-year follow-up. *Eur Spine J.* 2012;22:345–354. DOI: 10.1007/s00586-012-2533-3
20. **Gardner A, Berryman F, Pynsent P.** The use of statistical modelling to identify important parameters for the shape of the torso following surgery for adolescent idiopathic scoliosis. *J Anat.* 2021;239:602–610. DOI: 10.1111/joa.13454
21. **Pasha S, Shah S, Newton P.** Machine learning predicts the 3D outcomes of adolescent idiopathic scoliosis surgery using patient-surgeon specific parameters. *Spine (Phila Pa 1976).* 2021;46:579–587. DOI: 10.1097/BRS.0000000000003795
22. **Li Z, Yang H, Zhou C, Xiu P, Yang X, Wang L, Feng G, Liu L, Song Y.** Nomogram for predicting the distal adding-on phenomenon in severe and rigid scoliosis. *Front Surg.* 2023;9:1065189. DOI: 10.3389/fsurg.2022.1065189
23. **Belozerov VV, Peleganchuk AV, Mikhaylovskiy MV.** The effect of surgical correction of Lenke types I and III scoliotic deformities on the spinal balance in patients aged 15–35 years. *Russian Journal of Spine Surgery (Khirurgiya Pozvonochnika).* 2023;20(3):16–25. DOI: 10.14531/ss2023.3.16-25 EDN: ZCBTGE
24. **Molotkov YuV, Evsyukov AV, Ryabykh SO, Savin DM.** Impact of non-surgical factors on treatment results of patients with idiopathic scoliosis according to SRS-22 data (systematic review). *Genij Ortopedii.* 2024;30(4):608–619. DOI: 10.18019/1028-4427-2024-30-4-608-619 EDN: VYNEQF

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