COMPARATIVE ANALYSIS OF THE RESULTS OF SURGICAL CORRECTION OF IDIOPATHIC THORACIC SCOLIOSIS IN PATIENTS WITH ACTIVE BONE GROWTH

M.A. Chernyadjeva, A.S. Vasyura, V.L. Lukinov, V.V. Novikov
Novosibirsk Research Institute of Traumatology and Orthopaedics n.a. Ya.L. Tsivyan, Novosibirsk, Russia

Objective. To conduct a comparative analysis of surgical treatment results for idiopathic thoracic scoliosis in patients during active bone growth and to identify the most effective methods of scoliosis correction for the considered age group.
Material and Methods. The results of surgical treatment of 343 patients aged 10–14 years with continued active growth and progressive idiopathic thoracic scoliosis were analyzed. The patients were operated on in 1998–2018 using five surgical techniques: hybrid fixation with and without anterior stage, transpedicular fixation, and laminar fixation with and without anterior stage.
Results. Statistically significant deformity progression was observed in patients operated on using laminar (Group IV) and hybrid (Group I) fixation. An additional anterior stage (discectomy and interbody fusion) in combination with laminar fixation (Group V) does not prevent deformity progression after surgery. In patients who underwent hybrid fixation in combination with the anterior stage (Group II) or total transpedicular fixation (Group III), no statistically significant progression of scoliotic deformity was observed in the postoperative period. Patients operated on with total transpedicular fixation (Group III) show improvement in all domains of the SRS-24 questionnaire: no increase in pain throughout the entire follow-up period, higher assessment of appearance after surgery and satisfaction with the treatment result. In groups II and III, there was no negative dynamics of topographic parameters in the long-term period after treatment; the initial correction of the deformity was maintained throughout the entire postoperative follow-up.
Conclusion. Total transpedicular fixation provides the best correction of scoliosis in the absence of progression in the long-term postoperative follow-up in children during the period of active bone growth (age 10–14 years). According to the survey data, patients operated on with total transpedicular fixation demonstrate improvement in the following domains: the absence of pain syndrome throughout the entire postoperative follow-up period, the highest assessment of appearance after surgery and satisfaction with the result of surgical treatment. Hybrid fixation in combination with the anterior stage and total transpedicular fixation ensure the absence of negative dynamics of topographic parameters in the long term after surgery with maintenance of the initial surgical correction of spinal deformity.
Key Words: idiopathic scoliosis, progressive idiopathic scoliosis, incomplete growth, surgical treatment, anterior fusion, anterior release.
Please cite this paper as: *Chernyadjeva MA, Vasyura AS, Lukinov VL, Novikov VV. Comparative analysis of the results of surgical correction of idiopathic thoracic scoliosis in patients with active bone growth. Hir. Pozvonoc. 2022;19(1):22–30.*
DOI: http://dx.doi.org/10.14531/ss2022.1.22-30.

The effectiveness of surgical treatment of idiopathic scoliosis provides, first of all, the planning of the treatment process: technique, surgical stages, and the choice of a particular type of hardware to achieve the maximum result of deformity correction. Most surgical techniques for idiopathic scoliosis treatment are of only historical interest to modern researchers. Others are actively used nowadays [1, 2].

To date, there is no single universal technique and approach to the correction of scoliotic deformity that could be applied in rapidly growing patients [3]. This is confirmed by a vast number of domestic and foreign papers devoted to the issue [4–7].

The relevance of the topic is out of the question since idiopathic scoliosis is the most common form of spinal deformity. Meanwhile, the issue of anterior interventions in patients of the considered age group remains open due to the onset of modern posterior instrumentation [7].

Today, our clinic has a considerable experience in the treatment of spinal deformities, including different techniques and approaches to the correction of scoliotic deformities of various etiologies. This allows for an objective analysis of their effectiveness.

The objective is to conduct a comparative analysis of surgical treatment results for idiopathic thoracic scoliosis in patients during active bone growth and to identify the most effective methods of scoliosis correction for the considered age group.

Material and Methods

The study is a single-center cohort nonrandomized controlled with a retro- and prospective collection of material. The level of evidence is 3A.

Patients

The results of the surgical treatment of 343 patients included in the study were assessed by the following criteria:

– the presence of idiopathic thoracic scoliosis;
– age – from 10 to 14;
– incomplete bone growth (Risser test at the time of surgery – 0–3);
– the scoliotic deformity magnitude is 40° or more;
– the period of postoperative follow-up is at least 24 months;
– no neurological deficit at the time of surgery;
– patients operated on for the first time for the underlying disease.

Patients were divided into the following groups depending on the surgical option used:
– Group I (n = 55) – hybrid spine fixation without anterior stage;
– Group II (n = 16) – hybrid fixation in combination with the anterior stage;
– Group III (n = 98) – total transpedicular fixation without anterior stage;
– Group IV (n = 43) – laminar fixation without anterior stage;
– Group V (n = 131) – laminar fixation in combination with the anterior stage.

Patients in groups I, II, and III were operated on from 2009 to 2018; IV and V – from 1998 to 2009.

Techniques

Before surgery, patients underwent a standard preoperative examination: an X-ray of C7–S1 in the standing position in frontal and lateral projections, as well as functional spondylograms in the position of lateral inclination towards curvature; MSCT and MRI to exclude congenital anomalies of the development of bone structures and spinal cord.

Apical vertebral rotation of the main scoliotic curve was assessed in all patients according to the Sullivan et al. formula [8]:

AVR (apical vertebral rotation)/ Sullivan torsion = 0.26 (kyphosis of T5–T12) + 0.34 (Cobb angle) – 5.38.

The postoperative examination included an X-ray of the C7–S1 vertebrae in the patient's standing position in frontal and lateral projections to evaluate the correction of the main curve and the counter curve, the degree of postoperative progression of deformities, and the dynamics of changes in the sagittal contour. The time of surgery, the blood loss volume, and the number of spinal motion segments included in the instrumentation zone were considered. All patients in the pre- and postoperative periods were examined by a neurologist to identify possible neurological complications.

The postoperative control program also includes a questionnaire method using the Russian-language version of the SRS-24 questionnaire [9, 10]; 333 questionnaires filled at 6, 12, 24, and more months after surgery were analyzed.

Back surface topotraphy (BST) using the the COTM (computer optical topographic method) [11] was done before and after a surgery at the stages of outpatient control. This was done to evaluate the main topographic parameters describing the trunk's position in space, as well as the relative position of individual regions of the back, including the shoulder girdles, pelvis, and spine. A total of 338 topograms were analyzed.

Statistical analysis

Before statistical processing of the data, a preliminary verification was made to ensure completeness and the presence of input errors; an exploratory data analysis was carried out to identify abnormal values (outliers). Some patients with abnormal values were excluded from the study for these reasons. Due to this, it was possible to form a final sample of 343 patients.

The incomplete volume of the collected data of the COTM in the study groups should be attributed to the statistical study limitation.

A statistical analysis is an exploratory analysis, descriptive statistics, correlation analysis, and regression analysis.

Results

Table 1 presents cumulative general statistical data on operated patients.

The groups are fully compatible in terms of gender and age structure, which enabled an analysis of the parameters characterizing the corrective effect of the surgeries.

According to the received data (Table 2), it can be concluded that statistically significant postoperative progression was noted in the groups where laminar fixation was used (groups IV and V). Meanwhile, additional anterior intervention could not prevent the deformity from progressing in the postoperative period. No statistically significant progression of the main scoliotic curve in the postoperative period was noted in groups II and III.

According to the study results, the best outcome of the correction of the apical vertebral rotation as one of the elements of idiopathic scoliosis formation, as well as the absence of correction loss of this parameter after 2 years from the moment of surgical treatment were found in Group III (transpedicular fixation).

The comparative analysis of the blood loss volume and surgery duration between these groups is given in our previous publications [12].

There were no neurological complications in the early and long-term postoperative periods.

The study of questionnaire data in dynamics in all groups as a whole extracted the following trend. The back pain indicators were favorable during the entire period of postoperative follow-up (Table 3).

The general appearance indicators were stable throughout the entire period of postoperative follow-up with a slight decrease in Group V from 4.42 ± 5.18 points to 3.81 ± 0.48 points.

The highest evaluation rate of appearance after surgical treatment was observed in Group III: an increase from 4.23 ± 0.45 points to 4.66 ± 0.39 points, while in the other groups this indicator had the opposite trend.

The indicators of spinal function and general activity steadily improved after surgery in all groups. Only in Group IV, by the year from the moment of surgery, there was an increase in spinal functions. Within 2 years the patients returned to the level corresponding to the indicators of 6 months after surgery (Table 4).

A consistent strong performance was noted in the domain corresponding to satisfaction with the conducted surgical treatment (Table 4).

Patients of Group III operated on using total transpedicular fixation showed improvement in all domains. They did not have an increase in pain during the entire postoperative period; the highest indicators of appearance evaluation after surgery and satisfaction with the result of treatment were observed (Table 4).

There was no comparison of the questionnaire data depending on the gender of patients due to the small number of men in the study sample.

The study of COTM data in dynamics in all groups showed the following outcomes. A positive trend of the trunk decompensation parameter in the frontal plane was found throughout the entire period of postoperative follow-up in groups II and III. An increase in this parameter in the long-term period was found in groups I, IV, and V (Table 5).

The evaluation of the dynamics of distortions (inclination) of the shoulder and pelvic girdles in the frontal plane showed an improvement in these parameters after surgery in all groups:

– shoulder distortion trend: Group I – correction of 3.13°; Group II – 3.43°; Group III – 1.45°; Group IV – 2.12°; and Group V – 2.46°;

– pelvic distortion trend: Group I – correction of 0.95°; Group II – 0.23°; Group III – 1.25°; Group IV – 0.48°; and Group V – 0.36°.

After surgery and at the follow-up stages, patients of groups I, II, and III have a stable positive trend of reducing the parameters of shoulder and pelvic distortions in the frontal plane. Shoulder girdle: Group I – from 1.84° ± 1.23° to 1.59° ± 1.42°; Group II – from 1.90° ± 1.76° to 1.80° ± 1.75°; and Group III – from 2.58° ± 2.43° to 1.24° ± 1.26°. Pelvic girdle: Group I – from 2.06° ± 1.79° to 1.98° ± 1.10°; Group II – from 1.93° ± 1.40° to 0.96° ± 1.17°; and Group III – from 1.48° ± 1.71° to 0.97° ± 1.21°.

The reverse trend was observed in groups IV and V. There was an increase in the parameters of the shoulder distortion 2 years after surgery in comparison with the postoperative data in the groups from 1.62° ± 1.35° to 2.30° ± 1.74° and from 2.01° ± 1.54° to 2.68° ± 1.99°, respectively. The change in pelvic distortion parameters in these groups also had negative trends: in Group IV – from 1.57° ± 1.43° to 1.89° ± 1.36°; in Group V – from 2.39° ± 2.19° to 2.45° ± 1.78°.

In addition to the main clinical and topographic indicators, the dynamics of additional topographic parameters of the frontal plane, which have no clinical analogs, were assessed. These include the lateral asymmetry angle of the primary curve, which is similar to the Cobb angle, and the lateral deviation of the primary curve. There was a pronounced decrease in the lateral asymmetry angle after surgery in all groups (Table 6). By the end of the postoperative period, an increase in this parameter was found in groups I, IV, and V. This corresponds to the analysis of X-ray photographs at the observation stages, indicating the progression of the main scoliotic curve with partial loss of correction. A similar trend was observed regarding the dynamics of the lateral deviation parameter of the main curve (Table 6).

The change in the trunk balance, assessed by the slope parameter in the sagittal plane, shows similar trends of changes in the sagittal and frontal profiles of patients in the long-term postoperative period (Table 7).

Composite indices are one of the most essential indicators of general changes in topographic parameters. All composite indices of back shape disorders (general, as well as in the frontal and horizontal planes) are considerably decreased (improved) due to surgical treatment with preservation of postoperative follow-up in all groups (Table 8).

Discussion

Until recently, two-stage surgical treatment was preferred in actively growing patients. In this case, anterior mobilization and interbody fusion with autologous bone grafting were initially performed throughout the main scoliotic curve. After that, deformity correction with posterior segmental instrumentation and posterior fusion with autologous bone grafting was carried out. This enabled the formation of a bone block to prevent the development of the crankshaft phenomenon. Moreover, this approach provided additional mobilization of the spine before the corrective stage [13]. Smith-Petersen osteotomy is used as an alternative to anterior mobilization for the treatment of patients with severe and rigid deformities of the spine [13, 14].

It has been shown to achieve mobility of spinal deformity, which is required for correction with dorsal instruments, it is sufficient to perform intraoperative mobilization of soft tissues in most patients [15]. Meanwhile, according to Cheng et al. [4], even in adolescents aged 10-14, the use of only posterior segmental hybrid instrumentation can ensure the same correction of rigid idiopathic scoliosis with a magnitude of more than 75°, as well as performing a two-stage operation with a mobilizing discectomy. Some authors [5, 16] suggest the use of intraoperative or preoperative traction, which, together with posterior instrumentation using transpedicular fixation, eliminates anterior surgery without affecting the treatment outcome of gross and rigid idiopathic scoliosis.

Table 1

General description of operated patients, M ± m

Groups	Age at the time of surgery, y.o.	Follow-up period after surgery, months	Gender distribution (w: m), n
I	12.60 ± 0.70	46.50 ± 25.70	55f
II	76.50 ± 34.50	76.50 ± 34.50	15f : 1m
III	12.90 ± 1.10	28.20 ± 16.60	91f : 7m
IV	13.10 ± 0.80	154.90 ± 77.10	41f : 2m
V	12.40 ± 1.04	99.60 ± 29.30	113f : 18 m

Table 2

The trend of X-ray parameters in the study groups at the postoperative follow-up stages, M ± m

Groups	1. Before surgery, deg.	2. After surgery, deg.	3. The last control in 2 years, deg.	1–2. Correction, deg. (%)	2–3. Loss of correction, deg. (%)	Wilcoxon rank sum test, p-level
I	MSC: 61.00 ± 13.60	MSC: 18.50 ± 10.40	MSC: 24.40 ± 10.10	MSC: 42.50 ± 9.10 (70.70 ± 12.10)	MSC: 5.90 ± 3.10 (14.20 ± 8.30)	1–2: <0.001* 2–3: <0.001*
	AVR: 22.70 ± 6.41	AVR: 6.90 ± 4.40	AVR: 9.40 ± 4.50	AVR: 15.80 ± 4.70 (70.80 ± 13.90)	AVR: 2.50 ± 1.60 (16.90 ± 12.10)	1–2: <0.001* 2–3: <0.001*
II	MSC: 78.80 ± 19.50	MSC: 25.10 ± 12.70	MSC: 27.00 ± 12.30	MSC: 53.70 ± 13.10 (68.60 ± 10.01)	MSC: 1.90 ± 1.12 (3.70 ± 2.20)	1–2: <0.001* 2–3: <0.001*
	AVR: 32.10 ± 9.60	AVR: 9.60 ± 6.10	AVR: 9.70 ± 6.10	AVR: 22.50 ± 5.80 (71.10 ± 9.60)	AVR: 0.10 ± 0.20 (0.60 ± 1.01)	1–2: <0.001* 2–3: 0.036*
III	MSC: 68.90 ± 20.26	MSC: 16.10 ± 11.50	MSC: 16.30 ± 11.60	MSC: 52.76 ± 12.44 (78.20 ± 10.10)	MSC: 0.10 ± 0.50 (0.20 ± 0.70)	1–2: <0.001* 2–3: 0.008
	AVR: 25.30 ± 9.10	AVR: 6.20 ± 4.60	AVR: 6.30 ± 4.60	AVR: 19.10 ± 6.31 (77.20 ± 11.40)	AVR: 0.16 ± 0.31 (0.80 ± 1.70)	1–2: <0.001* 2–3: <0.001*
IV	MSC: 59.40 ± 15.00	MSC: 17.30 ± 8.20	MSC: 30.60 ± 10.80	MSC: 42.07 ± 10.20 (71.30 ± 9.20)	MSC: 13.30 ± 7.42 (32.10 ± 16.60)	1–2: <0.001* 2–3: <0.001*
	AVR: 22.00 ± 6.90	AVR: 5.70 ± 3.60	AVR: 12.00 ± 4.50	AVR: 16.30 ± 5.00 (74.90 ± 13.20)	AVR: 6.30 ± 2.70 (40.50 ± 17.70)	1–2: <0.001* 2–3: <0.001*
V	MSC: 82.80 ± 22.60	MSC: 31.20 ± 18.50	MSC: 38.30 ± 20.80	MSC: 51.60 ± 13.60 (64.30 ± 14.60)	MSC: 7.20 ± 7.50 (15.00 ± 16.50)	1–2: <0.001* 2–3: <0.001*
	AVR: 35.00 ± 13.20	AVR: 15.60 ± 10.10	AVR: 16.90 ± 10.70	AVR: 19.40 ± 7.00 (57.40 ± 16.40)	AVR: 1.30 ± 1.60 (11.10 ± 41.00)	1–2: <0.001* 2–3: <0.001*

* Statistically significantly different measurement parameters; correction of multiple comparisons was performed by the Benjamini-Hochberg procedure.
M ± m — mean value ± standard deviation; MSC — the main scoliotic curve; AVR (apical vertebral rotation)/torsion by Sullivan.

Table 3

Trends in pain in patients of the studied groups according to the SRS-24 questionnaire, depending on the surgical technique, 6, 12, and 24 months after surgery, scores (M ± m)

Groups	6 months	12 months	24 months	Wilcoxon rank sum test, p-level
I	4.10 ± 0.40	4.20 ± 0.40	3.90 ± 0.40	6–12 months: 0.152; 12–24 months: 0.044*
II	3.90 ± 0.40	3.80 ± 0.30	4.10 ± 0.30	6–12 months: 0.797; 12–24 months: 0.009*
III	4.00 ± 0.60	3.90 ± 0.36	3.90 ± 0.40	6–12 months: 0.933; 12–24 months: 0.625
IV	4.00 ± 0.40	4.10 ± 0.40	4.00 ± 0.50	6–12 months: 0.776; 12–24 months: >0.999
V	4.00 ± 0.50	3.90 ± 0.50	3.80 ± 0.40	6–12 months: 0.101; 12–24 months: 0.979

* Statistically significantly different parameters.

Nowadays, there is no universal technique and approach to the correction of scoliotic deformity to be applied in actively growing patients. This is proved by a huge number of domestic and foreign publications devoted to this subject.

In the early stages of of the development of scoliosis surgery, the widespread use of anterior interventions, including discectomy and anterior fusion, was quite justified. This is due to the lack of hardware at that time to prevent the postoperative progression of the scoliotic deformity in growing patients.

Simultaneously, there are situations when it is not possible to install transpedicular screws on each vertebra of the main scoliotic curve due to patients' anatomical features. In these cases, additional anterior mobilization and stabilization will allow for achieving optimal surgical correction [17].

The results of our study demonstrate the presence of a positive contribution of anterior interventions in achieving the optimal surgical outcome of idiopathic scoliosis correction. In the group of patients with incomplete growth, the greatest stabilizing effect of anterior interventions was found in laminar and hybrid fixation. In these cases, the inter-

Table 4

The survey results of patients according to the SRS-24 questionnaire, depending on the surgical technique, 6, 12, and 24 months after surgery, scores (M ± m)

Parameters	Group I	Group II	Group III	Group IV	Group V
Function after surgery					
6 months	1.67 ± 0.92	1.20 ± 0.63	1.24 ± 0.56	1.74 ± 0.90	2.12 ± 1.23
12 months	2.87 ± 1.52	2.50 ± 1.18	1.44 ± 0.53	1.96 ± 1.07	2.10 ± 1.31
24 months	2.64 ± 1.43	2.70 ± 1.34	1.75 ± 1.50	2.11 ± 1.24	2.46 ± 1.31
Wilcoxon rank sum test, p-level	6–12 months: 0.023*; 12–24 months: 0.521	6–12 months: 0.053; 12–24 months: 0.809	6–12 months: 0.072; 12–24 months: >0.999	6–12 months: 0.352; 12–24 months: 0.544	6–12 months: 0.909; 12–24 months: 0.280
General activity					
6 months	3.31 ± 0.87	2.46 ± 0.42	3.00 ± 0.98	3.15 ± 0.71	3.05 ± 0.81
12 months	3.16 ± 0.57	2.87 ± 0.70	3.15 ± 0.60	3.13 ± 0.69	3.19 ± 0.84
24 months	3.54 ± 0.59	3.50 ± 0.53	3.33 ± 0.94	3.19 ± 0.69	3.25 ± 0.71
Wilcoxon rank sum test, p-level	6–12 months: 0.944; 12–24 months: 0.002*	6–12 months: 0.053; 12–24 months: 0.090	6–12 months: 0.028*; 12–24 months: 0.773	6–12 months: 0.968; 12–24 months: 0.062	6–12 months: 0.158; 12–24 months: 0.391
Satisfaction with the surgical outcomes					
6 months	4.39 ± 0.49	3.90 ± 0.45	4.35 ± 0.46	4.26 ± 0.66	4.26 ± 0.65
12 months	4.28 ± 0.48	4.36 ± 0.29	4.48 ± 0.41	4.28 ± 0.50	4.28 ± 0.62
24 months	4.09 ± 0.55	4.27 ± 0.52	4.67 ± 0.47	4.07 ± 0.62	4.25 ± 0.61
Wilcoxon rank sum test, p-level	6–12 months: 0.109; 12–24 months: 0.136	6–12 months: 0.058; 12–24 months: 0.723	6–12 months: 0.628; 12–24 months: 0.789	6–12 months: 0.726; 12–24 months: 0.269	6–12 months: 0.133; 12–24 months: 0.957

* Statistically significantly different parameters.

Table 5

Trends in the change of trunk decompensation in the frontal plane in the study groups at the treatment stages, deg. (M ± m)

Groups	Before surgery	After surgery	6 months	12 months	24 months	Wilcoxon rank sum test, p-level
I	10.19 ± 8.02	3.75 ± 6.02	5.96 ± 6.37	8.07 ± 7.08	9.86 ± 14.34	Before/after: <0.05*; after/24 months: <0.05*
II	18.92 ± 22.95	12.90 ± 14.22	8.33 ± 10.28	8.56 ± 11.25	7.04 ± 9.33	Before/after: <0.05*; after/24 months: <0.05*
III	22.00 ± 16.57	20.02 ± 11.07	16.95 ± 10.54	14.48 ± 14.11	10.71 ± 8.00	Before/after: <0.05*; after/24 months:<0.001*
IV	16.75 ± 2.91	5.69 ± 8.41	6.84 ± 8.74	10.47 ± 9.88	13.49 ± 11.15	Before/after: <0.05*; after/24 months: <0.05*
V	10.80 ± 14.87	2.19 ± 5.66	2.73 ± 5.88	3.33 ± 7.03	6.25 ± 11.65	Before/after: <0.05; after/24 months: <0.05*

* Statistically significantly different parameters.

vention was practically non-competitive to exclude postoperative progression and the development of the crankshaft phenomenon. Under other conditions, the use of anterior corrective systems is associated with the need for extended approaches (thoraco-phreno-lumbotomy). This is fraught with damage to the truncus sympaticus and an increase in blood loss volume and surgery duration. As for the volume of correction, it has no advantages over posterior transpedicular systems.

Conclusions

A comparison of various instrumental correction techniques for idiopathic scoliosis in patients with incomplete bone growth showed the following results. Firstly, total transpedicular fixation provides correction of the main thoracic curve and the counter curve in the absence of scoliotic deformity progression in the long-term postoperative follow-up. Secondly, it reduces the loss of rotation correction of the apical vertebra. Patients operated on with total transpedicular fixation demonstrate improvement in all

Table 6

Trends in the change of additional indicators of the frontal plane in patients of the study groups at the treatment stages, deg. (M ± m)

Parameters	Before surgery	After surgery	6 months	12 months	24 months	Wilcoxon rank sum test, p-level
Lateral asymmetry angle of the curve						
Group I	59.9 ± 10.9	8.4 ± 5.2	12.7 ± 3.0	9.3 ± 6.7	12.6 ± 4.4	Before/after: <0.001*; after/24 months: 0.250
Group II	66.1 ± 21.9	18.3 ±15.0	25.5 ± 16.7	21.3 ± 15.5	16.5 ± 10.8	Before/after: <0.001*; after/24 months: 0.742
Group III	45.9 ± 20.2	20.3 ± 12.10	17.7 ± 8.7	19.9 ± 11.8	18.9 ± 11.6	Before/after: <0.001*; after/24 months: 0.304
Group IV	56.1 ± 18.2	7.0 ± 5.6	19.03 ± 20.7	15.2 ± 12.2	15.6 ± 10.7	Before/after: <0.001*; after/24 months: 0.007*
Group V	82.5 ± 23.1	13.9 ± 11.8	19.9 ± 21.0	22.6 ± 22.6	20.3 ± 21.0	Before/after: <0.001*; after/24 months: 0.057
Lateral deviation of the main curve						
Group I	25.4 ± 4.6	3.8 ± 2.5	4.4 ± 3.7	5.9 ± 2.0	6.5 ± 2.0	Before/after: <0.001*; after/24 months: 0.250
Group II	29.1 ± 10.3	7.2 ±4.2	9.8 ±5.9	10.3 ± 7.8	7.7 ± 5.5	Before/after: <0.001*; after/24 months: 0.742
Group III	20.1 ± 11.3	7.4 ± 3.5	8.5 ± 6.6	8.6 ± 6.3	8.7 ± 6.6	Before/after: <0.001*; after/24 months: 0.304
Group IV	24.8 ± 7.5	3.4 ± 2.9	6.7 ± 3.9	6.8 ± 5.0	8.7 ± 8.0	Before/after: <0.001*; after/24 months: 0.007*
Group V	32.0 ± 8.1	5.5 ± 4.2	9.9 ± 11.5	8.6 ± 9.1	9.1 ± 8.0	Before/after: <0.001*; after/24 months: 0.057

* Statistically significantly different parameters.

Table 7

Trends of the changes in the trunk inclination in the sagittal plane in patients of the study groups at the treatment stages, deg. (M ± m)

Groups	Before surgery	After surgery	6 months	12 months	24 months	Wilcoxon rank sum test, p-level
I	3.5 ± 2.2	3.0 ± 1.6	12.1 ± 2.2	1.2 ± 1.2	1.5 ± 1.7	Before/after: 0.091; after/24 months: : >0.999
II	2.7 ± 1.8	2.8 ± 1.8	2.8 ± 2.2	1.9 ± 1.3	1.9 ± 2.0	Before/after: 0.465; after/24 months: : 0.250
III	4.4 ± 2.6	3.6 ± 2.6	2.8 ± 1.8	2.4 ± 1.8	1.8 ± 1.7	Before/after: 0.256; after/24 months: : 0.055
IV	2.9 ± 2.2	4.3 ± 2.9	2.3 ± 1.6	1.7 ± 1.3	1.9 ± 1.6	Before/after: 0.008*; after/24 months: : 0.003*
V	3.1 ± 2.2	3.7 ± 2.0	2.1 ± 1.7	1.7 ± 1.3	1.9 ± 1.5	Before/after: 0.091; after/24 months: : 0.015*

* Statistically significantly different parameters.

Table 8

Trends of the changes in the composite indices of back shape disorders in patients of the study groups at the treatment stages (M ± m)

Groups	Before surgery	After surgery	6 months	12 months	24 months	Wilcoxon rank sum test, p-level
I	2.64 ± 0.52	1.59 ± 0.35	1.67 ± 0.33	1.71 ± 0.45	1.78 ± 0.56	Before/after: 0.002*; after/24 months: : >0.999
II	3.15 ± 0.85	2.75 ± 3.88	3.52 ± 1.35	2.27 ± 1.07	1.97 ± 1.25	Before/after: 0.206; after/24 months: : 0.008*
III	3.19 ± 0.97	2.32 ± 0.61	2.25 ± 0.76	2.18 ± 0.78	2.00 ± 0.61	Before/after: <0.001*; after/24 months: : 0.128
IV	2.65 ± 0.73	1.84 ± 0.41	1.79 ± 0.79	1.85 ± 0.70	1.98 ± 0.66	Before/after: <0.001*; after/24 months: : 0.610
V	3.34 ± 0.82	2.52 ± 0.34	2.25 ± 1.28	1.50 ± 0.38	1.63 ± 5.04	Before/after: <0.001*; after/24 months: :>0.999

*Statistically significantly different parameters.

questionnaire domains: the absence of pain throughout the entire postoperative follow-up period, the highest assessment of appearance after surgery, and satisfaction with the result of surgical treatment.

Hybrid fixation in combination with the anterior stage and total transpedicular fixation ensures the absence of negative dynamics of topographic parameters in the long term after surgery with the maintenance of the initial surgical correction of spinal deformity.

In patients with incomplete growth operated on using laminar and hybrid fixation, an anterior intervention was practically non-competitive to exclude postoperative progression and prevent the development of the crankshaft phenomenon. Nevertheless, it could not prevent the deformity from progressing in the postoperative period.

In the case of the use of transpedicular instrumentation in patients with idiopathic scoliosis and incomplete bone growth, anterior interventions are necessary if complete segmental instrumentation of the main scoliotic curve is not possible. This is due to the individual anatomical features of the patient's spine, which do not allow the main scoliotic curve apex to be included in the area of instrumental spinal fusion. In such cases, hybrid fixation in combination with the anterior stage is the procedure of choice. This is the main difference in the surgical approach in children aged 10–14 from the one used in patients with completed bone growth.

The study had no sponsors. The authors declare that they have no conflict of interest.

References

1. **Pehlivanoglu T, Oltulu I, Ofluoglu E, Sarioglu E, Altun G, Korkmaz M, Yildirim K, Aydogan M.** Thoracoscopic vertebral body tethering for adolescent idiopathic scoliosis: a minimum of 2 years' results of 21 patients. J Pediatr Orthop. 2020;40:575–580. DOI: 10.1097/BPO.0000000000001590.
2. **Serarslan U, Alici E, Akcali O, Kosay C, Unal M, Gultekin A.** There is no remarkable difference between pedicle screw and hybrid construct in the correction of Lenke type-1 curves. Turk Neurosurg. 2018;28:799–804. DOI: 10.5137/1019-5149.JTN.20522-17.1.
3. **Miller DJ, Cahill PJ, Vitale MG, Shah SA.** Posterior correction techniques for adolescent idiopathic scoliosis. J Am Acad Orthop Surg. 2020;28:e363-e373. DOI: 10.5435/JAAOS-D-18-00399.
4. **Cheng MF, Ma HL, Lin HH, Chou PH, Wang ST, Liu CL, Chang MC.** Anterior release may not be necessary for idiopathic scoliosis with a large curve of more than 75° and a flexibility of less than 25. Spine J. 2018;18:769–775. DOI: 10.1016/j.spinee.2017.09.001.
5. **Zhang H, Wang Y, Guo C, Tang M, Chen L, Liu S, Wang Y, Chen J.** Posterior-only surgery with strong halo-femoral traction for the treatment of adolescent idiopathic scoliotic curves more than 100°. Int Orthop. 2011;35:1037–1042. DOI: 10.1007/s00264-010-1111-8.
6. **Sanchez-Marquez JM, Sanchez Perez-Grueso FJ, Perez Mart n-Buitrago M, Fernandez-Baillo N, Garcia-Fernandez A, Quintans-Rodriguez J.** Severe idiopathic scoliosis. Does the approach and the instruments used modify the results? Rev Esp Cir Ortop Traumatol. 2014;58:144–151. DOI: 10.1016/j.recote.2014.03.006.
7. **Mikhaylovskiy MV, Sadovoy MA, Novikov VV, Vasyura AS, Suzdalov VA.** Idiopathic scoliosis: a 20-year retrospective analysis of the surgical activity in a highly specialized clinic. Hir. Pozvonoc. 2017;14(1):8–13. DOI: http://dx.doi.org/10.14531/ss2017.1.8-13.
8. **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/jjspd.2017.01.012.
9. **Zusman NL, Somogyi RD, Barney NA, Yang S, Halsey MF.** Adolescents with spondylolysis have lower SRS-22 scores than controls and peers with pre-operative idiopathic scoliosis. Spine Deform. 2021;9:135–140. DOI: 10.1007/s43390-020-00201-6.
10. **Gubina EV.** Clinical application of Russian version questionnaire of Scoliosis Research Society outcomes instrument-24 (SRS-24). Hir. Pozvonoc. 2004;(2):34–39.
11. **Sarnadsky VN.** Computer optical topography: variability of results in patients with scoliosis examined in a natural pose. Hir. Pozvonoc. 2010;(4):74–85. DOI: 10.14531/ss2010.4.74-85.
12. **Chernyadjeva MA, Vasyura AS, Novikov VV.** Evaluation of the role of ventral interventions in the surgery of idiopathic scoliosis in patients with active bone growth. Pediatric Traumatology, Orthopaedics and Reconstructive Surgery. 2021;9(1):17–28. DOI: 10.17816/PTORS52706.
13. **Uribe JS, Schwab F, Mundis GM, Xu DS, Januszewski J, Kanter AS, Okonkwo DO, Hu SS, Vedat D, Eastlack R, Berjano P, Mummaneni PV.** The comprehensive anatomical spinal osteotomy and anterior column realignment classification. J Neurosurg Spine. 2018;29:565–575. DOI: 10.3171/2018.4.SPINE171206.
14. **Gokcen B, Yilgor C, Alanay A.** Osteotomies/spinal column resection in paediatric deformity. Eur J Orthop Surg Traumatol. 2014;24 Suppl:S59–S68. DOI: 10.1007/s00590-014-1477-1.
15. **Mikhailovsky MV.** Stages of spine surgery development: historical excursus. Hir. Pozvonoc. 2004;(1):10–24.
16. **LaMothe JM, Al Sayegh S, Parsons DL, Ferri-de-Barros F.** The use of intraoperative traction in pediatric scoliosis surgery: a systematic review. Spine Deform. 2015;3:45–51. DOI: 10.1016/j.jspd.2014.06.007.
17. **Qiu Y, Wang WJ, Zhu F, Zhu ZZ, Wang B, Yu Y.** [Anterior endoscopic release/posterior spinal instrumentation for severe and rigid thoracic adolescent idiopathic scoliosis]. Zhonghua Wai Ke Za Zhi. 2011;49:1071–1075.

Address correspondence to:
Chernyadjeva Marija Aleksandrovna
Novosibirsk Research Institute of Traumatology
and Orthopaedics n.a. Ya.L. Tsivyan,
17 Frunze str., Novosibirsk, 630091, Russia,
MChernyadjeva@yandex.ru

Received 08.11.2021
Review completed 15.03.2022
Passed for printing 17.03.2022

Marija Aleksandrovna Chernyadjeva, postgraduate student, traumatologist-orthopaedist in the Department of pediatric orthopedic surgery, Novosibirsk Research Institute of Traumatology and Orthopaedics n.a. Ya.L. Tsivyan, Russia, 17 Frunze str., Novosibirsk, 630091, Russia, ORCID: 0000-0002-5034-6515, MChernyadjeva@yandex.ru;
Aleksandr Sergeyevich Vasyura, MD, PhD, senior researcher in Department of pediatric orthopedic surgery, Novosibirsk Research Institute of Traumatology and Orthopaedics n.a. Ya.L. Tsivyan, 17 Frunze str., Novosibirsk, 630091, Russia, ORCID: 0000-0002-2473-3140, niito@niito.ru;
Vitaly Leonidovich Lukinov, PhD in Physics and Mathematics, senior researcher, Department of research organization, Novosibirsk Research Institute of Traumatology and Orthopaedics n.a. Ya.L. Tsivyan, 17 Frunze str., Novosibirsk, 630091, Russia, ORCID: 0000-0002-3411-508X, vitaliy.lukinov@gmail.com;
Vyacheslav Viktorovich Novikov, DMSc, senior researcher in the Department of pediatric orthopedic surgery, Novosibirsk Research Institute of Traumatology and Orthopaedics n.a. Ya.L. Tsivyan, 17 Frunze str., Novosibirsk, 630091, Russia, ORCID: 0000-0002-9130-1081, VNovikov@niito.ru.