EFFICACY OF ANTERIOR AND POSTERIOR MULTILEVEL VERTEBROTOMY IN ADOLESCENTS WITH LENKE TYPE 1 AND 2 IDIOPATHIC SCOLIOSIS OPERATED ON USING PEDICLE SCREW FIXATION WITH VARIOUS IMPLANT DENSITY

A.S. Vasyura, E.V. Gubina, M.V. Mikhaylovskiy
Novosibirsk Research Institute of Traumatology and Orthopaedics n.a. Ya.L. Tsivyan, Novosibirsk, Russia

Objective. To analyze the efficacy of posterior and anterior multilevel vertebrotomy in adolescents with Lenke type 1 and 2 idiopathic scoliosis operated on using pedicle screw and hybrid instrumentation with varying implant density (ID).

Material and Methods. The immediate and long-term results of surgical treatment of 271 adolescents with Lenke type 1 or 2 idiopathic scoliosis (with primary thoracic curve) operated on using one of three surgical techniques: instrumental correction and posterior fusion (n = 212), the same technique supplemented with discectomy and interbody fusion (n = 30), and that with posterior vertebrotomy (n = 29). In all three groups, the relationship between age, initial Cobb angle, mobility, ID, and treatment outcomes assessed using X-ray data and SRS-24 questionnaire was studied, including the construction of linear regression models.

Results. In all groups, significant predictors of deformity correction were initial Cobb angle and ID, while the indicators of mobility and age did not demonstrate significance. The study showed no effect of anterior and posterior vertebrotomy on the magnitude of correction and its maintenance in the long-term period, as well as on the patient-reported outcomes (SRS-24). The combination of all indicators in the model explains 51 % to 74 % of the achieved correction variability. The explanatory power of the ID for the achieved correction is at least three times less than the explanatory power of the initial Cobb angle.

Conclusion. Anterior discectomy with interbody fusion and posterior vertebrotomy as methods of spine release in surgery for adolescent idiopathic scoliosis do not provide additional correction of the thoracic scoliosis. Herein, the number of anchoring elements used for polysegmental fixation (implant density) does not play a role in maintaining the corrective effect.

Key Words: adolescent idiopathic scoliosis, pedicle screw fixation, anterior release, posterior release.

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Pedicle and hybrid instrumentation, due to a high efficacy for the amount of correction and its maintenance for a prolonged period, has almost replaced hook fixation in surgery for adolescent idiopathic scoliosis in recent years [1–3]. In this case, the opinion about the optimal number of anchoring elements varies from the sufficient minimum to bilateral application on each segment of the instrumental fixation area.

However, only a few reports have addressed mobilization (anterior and posterior) surgery [4, 5]. The aim of an anterior release (discectomy at several levels at the scoliotic curve apex and interbody fusion) is dual: to increase the flexibility of the most rigid part of a deformed spine and prevent the crankshaft phenomenon by forming an anterior block [6, 7] in incomplete skeletal growth [8]. A posterior release (in most cases, in the amount of Ponte or Schwab II osteotomy in various modifications) is used for severe rigid deformities to achieve the maximum corrective effect [9]. Like any other surgical manipulation, mobilization surgery is associated with a certain risk of complications, lengthens the duration of surgery, and increases blood loss.

During planning this study, we put forward a working hypothesis: anterior and posterior mobilization surgery (vertebrotomy) using pedicle and hybrid (combination of pedicle screws and hooks) instrumentation does not provide significant advantages for deformity correction and maintaining the achieved effect in adolescent thoracic idiopathic scoliosis.

The aim of this study was to analyze the efficacy of anterior and posterior multilevel vertebrotomy in adolescents with Lenke type 1 and 2 idiopathic scoliosis operated on using pedicle and hybrid instrumentation with different implant density (ID).

Study design: monocentric retrospective study.

Material and Methods

In the clinic, 1,262 patients with idiopathic scoliosis of various localization were operated on using hybrid instrumentation (hooks and pedicle screws) or pedicle screws alone in 2007–2017. Of these, the study enrolled 271 (231 girls and 40 boys; mean age, 14.3 years) patients who met the following inclusion criteria:

– Lenke type 1 and 2 adolescent idiopathic scoliosis with the thoracic primary curve;

– age of 10 to 18 years at the time of surgery;

– no spinal surgery before admission to the clinic;

– all interventions are performed by three surgeons with at least 25 years of work experience in a specialized clinic;

– use of transpedicular or hybrid instrumentation with pedicle screw and hook fixation for posterior instrumentation of the spine;

– same-day surgery, i.e. within a single operation, to perform the entire intervention, including mobilization manipulations and instrumented fixation;

– no implant-associated complications;

– postoperative follow-up for at least two years.

Preoperative examination included upright plain X-ray of the thoracic and lumbar spine, involving the pelvis in frontal and lateral projections, as well as spine X-rays performed in the lying position with an active trunk inclination towards the deformity's convexity. Spine X-rays were used to assess the following parameters:

– Cobb angle (in degrees) of the primary deformity curve, thoracic kyphosis, and lumbar lordosis;

– trunk balance in the frontal plane (in mm) based on the distance between the T1 centroid and the central sacral line;

– apical vertebral rotation of the primary curve according to the formula by Sullivan et al. [10]: 3D AVR (deg.) = 0.26 × (T5–T12 kyphosis) + 0.34 × (primary curve Cobb angle) - 5.38.

For each case, we determined implant density (ID) that was assessed as a ratio of the number of anchoring elements to the number of vertebrae involved in the instrumented fusion area.

The postoperative life quality was assessed based on the patient-reported SRS-24 scores [11].

Surgical technique features. All patients were operated on using modern segmental instrumentation. The lumbar spine and thoracolumbar junction were instrumented with screws, and the thoracic spine was instrumented using either screws or hooks alone. Hooks were placed in the apical, intermediate, and terminal vertebrae with the formation of pedicular transverse anchors. In 212 cases, the intervention included instrumented correction and posterior fusion using autologous bone; in another 59 cases, this intervention was combined with anterior or posterior release. Indications were determined based on the primary curve flexibility, need to prevent the crankshaft phenomenon (in patients with incomplete skeletal growth), and personal preferences of the operating surgeon. Anterior release included discectomy at 3–5 apical levels, followed by anterior fusion with autologous bone grafts. Posterior release involved posterior transverse wedge vertebrotomy at three apical levels, with the wedge base facing the scoliotic curve convexity, including resection of the superior and inferior articular processes, part of the laminae and spinous process roots of adjacent vertebrae, and ligamentum flavum with the formation of transverse defects of the posterior portions (actually, the intervention was an intermediate variant between Ponte and Smith-Petersen osteotomy). Therefore, three clinical groups were retrospectively formed based on the surgical intervention type: A – instrumented correction and posterior fusion (n = 212); B – discectomy, interbody fusion, instrumented correction, and posterior fusion (n = 30); C – posterior vertebrotomy, correction, and posterior fusion (n = 29).

Statistical analysis. Descriptive parameters are presented as median [first quartile; third quartile] and arithmetic mean ± standard deviation. The distributions of numerical parameters in the groups were compared using the unpaired Mann – Whitney U-test with calculation of a distribution bias and a 95 % confidence interval for the bias. Pairwise relationships between continuous parameters were studied by calculating Spearman's correlation coefficients with the achieved level of significance, p. Statistical hypotheses were tested at a critical level of significance $p = 0.05$, i.e. the difference was considered statistically significant if $p < 0.05$.

All statistical calculations were performed using the RStudio software (version 1.2.5001) in the R language (version 3.6.1).

Results

All information related to the pre- and postoperative changes in radiographic parameters is presented in Table 1. The groups are comparable in age of operated patients, postoperative follow-up duration, and length of the fusion area. The baseline Cobb angle of the primary curve is significantly lower in Group A (posterior surgery) and highest in Group B (anterior release). Furthermore, the curve flexibility in all three groups varies within relatively small limits.

Therefore, according to most of the assessed parameters (the flexibility of deformity and the relative magnitude of its correction and loss of correction, the magnitude of thoracic kyphosis and lumbar lordosis, apical vertebral rotation, its correction, and correction stability, etc.), the groups are fully comparable. There are differences only in the number of cases and in the ID parameter (only in the lower ID limit). These factors required application of specialized statistical tools that are discussed below.

To quantify the effect of age, baseline angle of deformity, flexibility of deformity, and ID on the amount of correction, linear regression models were generated for all three groups. The calculation results for the models are given in Table 2.

In all groups, significant predictors of deformity correction are the primary curve magnitude and ID. The flexibility of deformity and the age of patients were not significant in the studied patient samples.

To correctly investigate the release effect on the magnitude of achieved correction, the baseline Cobb angle and ID parameters should be comparable between groups. Table 2 shows that the baseline Cobb angle and ID are statistically significantly different, which leads to a difference in the magnitude of achieved correction and complicates analysis of the effect of anterior and posterior releases on the correction magnitude.

A rough estimate of the effect of significant predictors reveals that Group B (anterior release) differs from Group A (no release) by +23° in the baseline Cobb angle and by -0.12 in ID, on average. According to the linear regression model for Group B, this is equivalent to a contribution of $23 \times 0.54 - 0.12 \times 28.08 \approx 9.05$, which accounts for 75 % of the difference in achieved correction between groups B and A, which is 12°, on average.

Group C (posterior release) differs from Group A by +13° in the baseline Cobb angle and by +0.15 in ID, on average. According to the linear regression model for Group C, this is equivalent to a contribution of $13 \times 0.51 + 0.15 \times 9.98 \approx 8.13$, which accounts for 72 % of the difference in achieved correction between groups C and A, which is 11°, on average.

These calculations indicate either no effect of anterior and posterior releases on the magnitude of achieved correction or a negligible effect.

On the other hand, to study the effect of mobilization surgery on the magnitude of achieved correction, Propensity Score Matching (PSM) can be used to align the baseline Cobb angle, ID, flexibility, and age in pairs for groups B and A, C and A [12]. The results of comparison of parameters after alignment are shown in Tables 3 and 4.

The mean difference in achieved correction among groups B, C, and A after PSM is not significant and is equal to 4°, which once again confirms the conclusion about no or minimal effect of mobilization surgery on the magnitude of achieved correction.

As seen from the tables, the achieved correction in all groups is maintained and does not depend on the use of mobilization surgery.

In Table 5, determination coefficients R^2 for the generated linear models of achieved correction indicate that the set of all parameters in a model accounts for 51 to 74 % of the variability (variance) in the magnitude of achieved correction. The LMG method [13] was used to assess the contribution of each parameter to R^2. The contribution of ID relative to the baseline angle is 32% in release models and 13% in the model without release, i.e. the explanatory power of ID for achieved correction is at least three-fold less than that of the baseline Cobb angle.

SRS-24 questionnaire results. In this study, it was of interest to answer the following question: whether the obtained result is associated with using of the mobilization maneuver during surgery? Given that not all patients filled out the questionnaires, and there were only 7 patients in Group B, we considered it possible to combine patients of groups B and C into one Group (Study Group 2) for analysis, comparing their data with those of patients in Group 1 (Group A of the main study).

The results of SRS-24 questionnaire using 7 domains and a 5-point score system (1 – the lowest score; 5 – the highest score) are shown in Table 6.

Therefore, patients who underwent surgery without additional mobilization manipulations evaluated the general self-image and function after surgery somewhat higher. In turn, the domains "back pain", "self-image after surgery", "general function", "function-activity", and "satisfaction with surgery" were more preferable in the case of releases. In this case, the differences were not statistically significant for any parameter.

Under the same conditions, 82.7 % of patients in Group 1 and 80.8 % of patients in Group 2 were ready to agree to surgery.

The obtained data indicate no fundamental differences in assessment of the life quality in patients operated with and without an anterior or posterior release.

Discussion

The capabilities of transpedicular fixation (TPF) have been studied thoroughly and comprehensively over the past two decades. The use of TPF in comparison with the use of systems with hook anchoring in surgery for spinal deformities, primarily in adolescent idiopathic scoliosis, is associated with the following: TPF increases the amount of achieved correction [1, 14] and the degree of apical vertebral derotation [3, 15], reduces the rate of revision surgeries [16], decreases postoperative progression of deformity (loss of correction) [3], promotes better self-correction of lumbar countercurve [1, 17], reduces the length of the fusion area [17], improves the frontal balance of the trunk [1], promotes better restoration of respiratory function [14], and reduces blood loss and the duration of surgery [15, 17, 18] without increasing the rate of complications associated with malposition of anchoring elements [18–22] and failure of implants [16]. The disadvantages of TPF include a tendency to flatten the physiological curves of the spine [14, 23] and increase the cost of surgery and treatment in general [3, 24, 25].

Almost in parallel with investigation of the TPF capabilities in comparison with other anchoring elements, features of various configurations of the method were studied.

Li et al. [26] were the first who compared the outcomes of correction of adolescent idiopathic scoliosis (Lenke 1) with placement of pedicle screws fixed to a correcting rod (on the concave side of deformity) at every level or every other vertebra (in groups, every second or every third vertebra was instrumented, respectively, on the convex side of deformity). In two groups of 15 patients each, the same values of correction in the frontal plane and changes in thoracic kyphosis were obtained in the absence of neurological complications and differences for a follow-up period of 2 to 4.1 years. The authors emphasized a lower cost of surgery and a larger area of the bone bed in bone grafting using interval screw placement.

In 2009, Clements et al. [27] published a study on the dependence of the amount of adolescent idiopathic scoliosis correction on the number and type of anchoring elements of spinal instrumentation. They were probably the first who

Table 1

Clinical and radiographic characteristics of the study patients

Parameter	Group A	Group B	Group C
Number of patients, n	212	30	29
Mean age, years	15.5 (10–18)	14.0 (11–18)	13.3 (11–17)
Postoperative follow-up period, years	3.6 (2.1–7.9)	4.5 (2.1–10.4)	3.0 (2.1–4.4)
Cobb angle (thoracic curve), deg.			
before surgery	57.4 (33–106)	79.5 (45–112)	69.9 (46–96)
in lateral tilt position	35.3 (3–97)	56.4 (12–95)	46.1 (11–83)
after surgery	20.5 (6–43)	27.1 (8–64)	20.5 (7–93)
at the end of follow-up period	22.3 (8–56)	29.3 (8–74)	22.3 (8–45)
Deformity flexibility, %	37.9 (11–86)	32.1 (11–86)	39.3 (8–82)
Deformity correction, deg./%	36.9/64.2	50.4/63.4	49.4/70.7
Correction loss, deg./%	1.8/4.8	2.2/4.2	1.8/3.6
Thoracic kyphosis, deg.			
before surgery	29.4 (4–79)	33.6 (5–64)	32.5 (8–74)
after surgery	22.7 (5–53)	22.0 (9–43)	23.2 (11–51)
at the end of follow-up period	23.4 (2–57)	21.8 (2–42)	22.3 (9–36)
Lumbar lordosis, deg.			
before surgery	57.4 (10–83)	60.0 (39–81)	59.4 (40–79)
after surgery	50.5 (21–78)	48.3 (30–69)	52.6 (30–76)
at the end of follow-up period	51.6 (20–86)	50.0 (33–60)	56.3 (37–78)
Apical vertebral rotation, deg.			
before surgery	21.9 (12–72)	27.5 (11–63)	15.5 (10–33)
after surgery	7.8 (3–28)	7.5 (2–30)	6.4 (1–16)
at the end of follow-up period	6.9 (3–30)	7.3 (3–31)	6.6 (1–15)
Surgical correction of apical vertebral rotation, deg./%	14.1/64.3	20.0/72.7	9.1/8.7
Frontal imbalance, mm			
before surgery	13.6 (2–32)	15.6 (2–34)	16.5 (1–85)
after surgery	18.2 (2–63)	20.7 (3–50)	18.8 (2–70)
at the end of follow-up period	12.8 (8–56)	13.9 (2–32)	12.4 (2–33)
Length of the fusion area	12.8 (11–17)	12.97 (11–14)	13.07 (11–15)
Implant Density	1.34 (0.58–2.00)	1.2 (0.72–2.00)	1.57 (1.15–2.00)

Minimum and maximum values of the parameter are shown in brackets.

Table 2

Linear regression models of achieved correction for all study groups

Parameters	Group A (n = 212)		Group B (n = 30)		Group C (n = 29)	
	C	p	C	p	C	p
Cobb angle before surgery	0.55	<0.001*	0.54	<0.001*	0.51	<0.001*
Implant Density	13.84	<0.001*	28.08	0.007*	9.98	0.036*
Curve flexibility	-0.02	0.326	0.09	0.372	0.01	0.884
Age	-0.05	0.858	-0.88	0.323	-1.18	0.197
Free term	-11.28	0.112	-16.79	0.397	13.31	0.493

C – coefficient; *significant predictors.

coined the term Implant Density (ID) that is the ratio of the number of anchoring elements to the number of available fixation points.

In a group of 292 patients, including 250 patients with thoracic deformities, a clear correlation between ID and achieved correction was revealed, which was largely true for the rod on the concave side of the curve (corrective) than on the convex (stabilizing) side. The greatest correction (78 %) was achieved with the use of screws and ID of 2.0 (two screws per each instrumented vertebra); in this case, the higher the ID index, the more the thoracic kyphosis is flattened.

Table 3

Comparison of parameters after PSM in groups A and B

Parameters	Group A (n = 25)	Group B (n = 25)	Mann – Whitney U-test	
	Me [IQR] M ± SD		difference [95 % CI]	p-level
Age, years	15 [14; 16] 14.96 ± 1.70	14 [13; 16] 14.20 ± 2.35	1 [-1; 2]	0.288
Flexibility, deg.	26.38 [4.76; 43.48] 29.79 ± 24.77	28.125 [15.31; 48.21] 31.13 ± 19.96	-2.67 [-15.54; 12.22]	0.528
Cobb angle, deg.				
baseline	71 [65; 88] 73.60 ± 15.67	77 [70; 88] 78.92 ± 17.06	-6 [-15; 5]	0.233
after surgery	25 [17; 39] 28.24 ± 13.44	26 [21; 35] 28.16 ± 14.68	-1 [-8; 8]	0.861
at the end of follow-up	25 [20; 38] 30.52 ± 14.69	30 [21; 35] 30.24 ± 14.72	0 [-8; 8]	0.923
Implant Density	1.25 [1.15; 1.39] 1.25 ± 0.17	1.24 [1.16; 1.31] 1.22 ± 0.23	0.03 [-0.07; 0.15]	0.371
Achieved correction, deg.	43 [37; 52] 45.36 ± 10.44	51 [40; 56] 50.76 ± 11.88	-4 [-12; 1]	0.127
Loss of correction, deg.	1 [-1; 3] 2.28 ± 6.44	2 [-1; 5] 2.08 ± 6.03	0 [-3; 3]	0.770

Me – median; IQR – interquartile range; M – mean; SD – standard deviation; 95 % CI – 95 % confidence interval.

Quan and Gibson [28], who used TPF alone in 49 adolescents with idiopathic scoliosis (Lenke 1), achieved a decrease in the scoliotic deformity from 60.0 to 17.4° and noted flattening of the thoracic kyphosis from 20.0 to 11.6°. With a mean ID of 1.6 (1.2–2.0), the authors found no relationship between ID and deformity correction in the frontal and horizontal planes.

Sanders et al. [29], who used various variants of fixation elements (hooks, pedicle screws, wires, and their combinations) in 171 adolescents with idiopathic scoliosis (Lenke 1), noted that the number of anchoring elements was more important than the type of fixation and revealed a direct relationship between the corrective effect and preoperative deformity flexibility.

Yang et al. [30] operated 58 adolescents with idiopathic scoliosis (Lenke 1) and reporoted the possibility of correcting the scoliotic curve by 59 %; in their opinion, an increase in the number of anchoring elements does not improve the cosmetic and radiographic effects.

Bharucha et al. [31] used constructs with low (less than 1.3) and high (more than 1.3) ID in 91 patients with similar deformity (Lenke 1) and revealed no correlation between the ID value and the percentage of primary curve correction, angle of trunk rotation, and changes in the thoracic kyphosis. In addition, no correlation was found between two groups in the curve flexibility and the percentage of correction, changes in kyphosis and rotation. According to the results of SRS-22 questionnaire, there was also no difference between the groups. The only difference was the cost of implants in the high ID group, which turned out to be significantly higher: 13,272 versus 10,819 dollars.

Similar data were reported by Gotfryd et al. [32]: in two groups (23 patients each) of operated adolescents with idiopathic scoliosis (45–70°), the magnitude of correction and its loss after 2 years were identical regardless of the ID parameter, as were the results of questionnaire. In this case, the higher ID group was characterized by better correction of the rib hump but a higher cost of treatment.

In the only systematic review, Larson et al. [33] analyzed material from 10 publications (929 patients). In these papers, ID ranged from 1.06 to 2.00. Two studies analyzed the effect of various anhoring elements and demonstrated the superiority of pedicle constructs with high ID over hook and hybrid constructs. Comparison of the effect of pedicle constructs with different IDs showed that an increase in ID was not associated with an increase in achieved correction. The review's authors decided that the analyzed papers were not significant enough to reveal the sought differences; therefore, the effect of ID remains unclear.

Gebhart et al. [34] reported the results of surgical treatment in 119 adolescents with idiopathic scoliosis and identified two groups of factors: factors under surgeon control (ID and pedicle coefficient (PC): ID percentage of pedicle screws among all anchoring elements) and those not under surgeon control (deformity magnitude, length of fusion, curve flexibility). The rate of complica-

Table 4
Comparison of parametes after PSM in groups A and C

Variables	Group A (n = 28)	Group C (n = 28)	Mann – Whitney U-test	
	Me [IQR] M ± SD		difference [95 % CI]	p-level
Age, years	14 [13.00; 15.00] 13.96 ± 1.86	13 [12.00; 14.25] 13.21 ± 1.75	1 [0; 2]	0.130
Flexibility, deg.	44.32 [33.95; 55.16] 46.49 ± 19.21	39.28 [13.96; 54.51] 39.25 ± 28.88	6.41 [-6.90; 22.73]	0.385
Cobb angle, deg.				
baseline	66 [59.75; 77.75] 70.04 ± 16.04	67 [60.75; 78.25] 69.89 ± 13.25	0 [-9; 7]	0.922
immediately after surgery	22 [14.75; 29.50] 25.29 ± 13.41	18.5 [14.25; 24.75] 20.35 ± 8.27	3 [-2; 9]	0.294
at the end of follow-up	22.5 [17.75; 32.00] 26.61 ± 13.31	22 [15.25; 27.25] 22.23 ± 8.23	3 [-2; 8]	0.311
Implant Density	1.405 [1.29; 1.93] 1.52 ± 0.35	1.43 [1.36; 1.81] 1.55 ± 0.29	-0.01 [-0.18; 0.08]	0.530
Achieved correction, degree	45 [38.25; 50.00] 44.75 ± 9.75	48.5 [39.50; 56.50] 49.19 ± 10.75	-4 [-10; 1]	0.143
Loss of correction, deg.	0 [-1.00; 3.25] 1.32 ± 5.56	2 [0.00; 3.00] 1.56 ± 3.56	-1 [-3; 1]	0.457

Me – median; IQR – interquartile range; M – mean; SD – standard deviation; 95 % CI – 95 % confidence interval.

Table 5
Assessment of the contribution of parameters in linear regression models of achieved correction using LMG, %

Parameters	Group A (n = 212)	Group B (n = 30)	Group C (n = 29)
Coefficient of model determination R^2	0.60	0.51	0.74
Baseline angle	84 [71–94]	71 [21–90]	57 [30–67]
Implant Density	11 [4–22]	23 [3–64]	18 [4–39]
Age	2 [0.3–8.0]	2 [0.7–23.0]	24 [11.0–42.0]
Flexibility	0.4 [0.1–4.0]	4 [0.5–28.0]	0.7 [0.4–12.0]

Table 6
Assessment of the life quality of patients using the SRS-24 questionnaire (M ± SD), score

Analyzed parameter (SRS-24 domain)	Group 1 (A) 52 questionnaires	Group 2 (B + C) 47 questionnaires
Pain	3.73 ± 0.85	3.81 ± 0.79
General self-image	3.22 ± 0.72	3.86 ± 0.68
Self-image after surgery	4.29 ± 0.86	4.11 ± 0.82
Function after surgery	1.60 ± 0.92	1.52 ± 0.86
General function	2.90 ± 0.82	3.22 ± 0.79
Function-activity	3.99 ± 0.99	4.05 ± 0.86
Satisfaction with surgery	4.09 ± 0.55	4.33 ± 0.45

tions and re-operations did not correlate with any of the groups of factors. Primary curve correction correlated with the flexibility of deformity, and the length of fusion area correlated with the duration of surgery, hospital stay duration, cost of treatment, and blood loss; ID correlated directly with the cost of implants and inversely with the duration of hospital stay. PC had no correlation with any of the factors.

The effect of mobilization surgery on the result of adolescent idiopathic scoliosis correction using TPF is much less studied. We can only mention a study by Clements et al. [27] who noted that

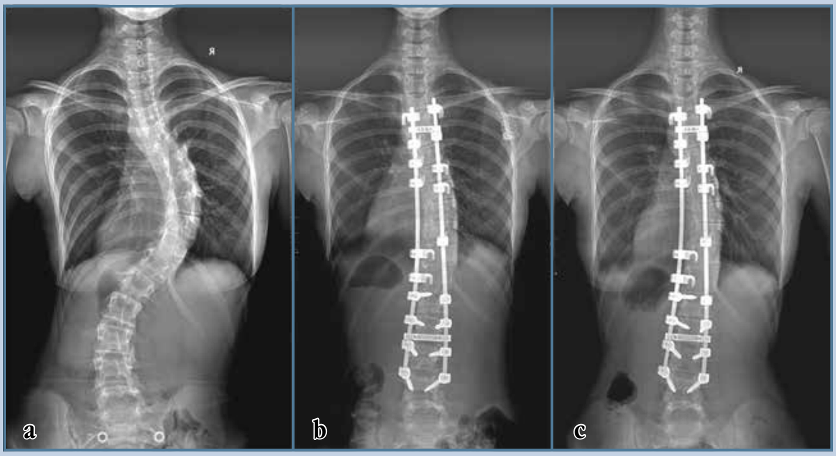

Fig.
Spine X-rays of a 13-year-old female patient A. with right-sided progressive thoracic idiopathic scoliosis and a lumbar countercurve (Lenke type 2CN): **a** – at upright position, the T4–T12 and L1–L4 Cobb angle is 75° and 43°, respectively; **b** – 7 days after surgery (posterior vertebrotomy, correction using hybrid instrumentation, posterior spinal fusion with autologous bone), the T4–T12 curve is 24°, and the L1–L4 curve is 8°; **c** – 26 months after surgery, the T4–T12 curve is 24°, and the L1–L4 curve is 9°

they did not investigate the effect of a number of factors on the amount of achieved correction, including a posterior release, because this effect was difficult to assess accurately. The effect of an anterior release on the corrective effect when using TPF has been addressed in a few studies. Luhmann et al. [4] used total TPF in 84 patients with deformities from 70 to 100° and showed no advantages of posterior correction with preceding anterior mobilization of the most deformed part of the scoliotic curve in the immediate and long-term (4.5 years) postoperative periods. Nearly the same results were obtained by Dobbs et al. [5]. In both studies, groups were identical in key preoperative parameters.

In our clinic, the use of generation III instrumentation (CDI) has started in 1996; and initially, we used exclusively hook systems as anchoring elements. Combining posterior fusion with an anterior or posterior release in order to achieve more significant correction and prevent the crankshaft phenomenon (discectomy and interbody fusion) seemed quite reasonable, and an analysis of the obtained results, in our opinion, completely confirmed this [8]. The introduction of TPF in our clinic consistently increased the quality of outcomes and just as consistently raised the question of reasonability of additional manipulations that increase the flexibility of the apical zone of a deformed spine (Fig.). As our experience has grown, we have come to the opinion that anterior and posterior releases can be avoided in the treatment of adolescent idiopathic scoliosis, regardless of the initial value of spinal deformity. This study is one of the few devoted to the efficacy of mobilization surgery in relation to posterior vertebrotomy. We can only mention a study by Halansky and Cassidy [35] who emphasized not only the absence of an increase in the amount of correction but also an increase in blood loss and the duration of surgery in the case of Ponte osteotomy. International consensus on the optimal surgical management of idiopathic scoliosis has shown that routine use of an anterior release is not considered optimal [36]. A thorough statistical analysis showed that these manipulations in TPF do not provide additional advantages both in deformity correction in all three planes and in its maintenance during long-term postoperative follow-up (up to 10 years). Similar results were obtained upon analysis of SRS-24 questionnaires.

Our findings confirmed data of many authors [24, 26, 28, 29, 31, 37] about the absence of dependence of the obtained results on the number of used anchoring elements (ID). It should be noted that some surgeons [25, 30] have the opposite opinion on this issue.

The main disadvantage of our study was a small number of patients in two of the three groups, which required the use of additional methods of statistical analysis. At the same time, the quantitative heterogeneity of these groups is quite understandable because surgical mobilization of the spine is indicated for the most severe deformities that are always not abundant. In any case, we consider this study as a small piece of the big picture that emerges when evaluating the results of surgical treatment of adolescent idiopathic scoliosis reported in the orthopedic literature.

Conclusion

The widespread use of TPF in surgery for adolescent idiopathic scoliosis raises doubts about the reasonability of combining spine mobilization procedures with corrective surgery. The study has demonstrated that anterior (discectomy and interbody fusion) and posterior (modified Ponte vertebrotomy) releases do not provide additional correction of thoracic scoliosis (Lenke 1, 2). In this case, the number of anchoring elements (ID) does not play a significant role in achieving a corrective effect and maintaining it for a long postoperative period.

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References

1. **Dobbs VB, Lenke LG, Kim YJ, Kamath G, Peelle MW, Bridwell KH.** Selective posterior thoracic fusions for adolescent idiopathic scoliosis: comparison of hooks versus pedicle screws. Spine. 2006;31:2400–2404. DOI: 10.1097/01.brs.0000240212.31241.8e.
2. **Min K, Sdzuy 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. 2013;22:345–354. DOI: 10.1007/s00586-012-2533-3.
3. **Suk SI, Lee CK, Kim WJ, Chung YJ, Park YB.** Segmental pedicle screw fixation in the treatment of thoracic idiopathic scoliosis. Spine. 1995;20:1399–1405.
4. **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. 2005;30:2061–2067. DOI: 10.1097/01.brs.0000179299.78791.96.
5. **Dobbs M, Lenke L, Kim Y, Luhmann SJ, Bridwell KH.** Anterior/posterior instrumentation versus posterior instrumentation alone for the treatment of adolescent idiopathic scoliosis curves more than 90 degrees. Spine. 2006;31:2386–2391. DOI: 10.1097/01.brs.0000238965.81013.c5
6. **Dubousset J, Herring G, Shufflebarger H.** The crankshaft phenomenon. J Pediatr Orthop. 1989;9:541–550. DOI: 10.1097/01241398-198909010-00008.
7. **Shufflebarger HL, Clark CE.** Prevention of the crankshaft phenomenon. Spine. 1991;16(8 Suppl):S409–S411.
8. Surgery for Idiopathic Scoliosis: Immediate and Long-Term Results, ed. by M.V. Mikhaylovskiy. Novosibirsk, 2007. In Russian.
9. **Ponte A.** What is a true Ponte osteotomy? 48th Annual Meeting & Course. Half-day Course, Lion, France, 2013:63–65.
10. **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.jspd.2017.01.012.
11. **Haher TR, Gorup JM, Shin TM, Homel P, Merola AA, Grogan DP, Pugh L, Lowe TG, Muray M.** Results of Scoliosis Research Society instrument for evaluation of surgical outcome in adolescent idiopathic scoliosis. A multicenter study of 244 patients. Spine. 1999;24:1435–1440. DOI: 10.1097/00007632-199907150-00008.
12. **Patorno E, Grotta A, Bellocco R, Schneeweiss S.** Propensity score methodology for confounding control in health care utilization databases. Epidemiol Biostat Public Health. 2013:10:e8940. DOI: 10.2427/8940.
13. **Lindeman RH, Merenda PF, Gold RZ.** Introduction to Bivariate and Multivariate Analysis, Glenview IL: Scott, Foresman and Co., 1980.
14. **Kim YJ, Lenke LG, Kim J, Bridwell KH, Cho SK, Cheh G, Sides B.** Comparative analysis of pedicle screw versus hybrid instrumentation in posterior spinal fusion of adolescent idiopathic scoliosis. Spine. 2006;31;291–298. DOI: 10.1097/01.brs.0000197865.20803.d4.
15. **Hwang CJ, Lee CK, Chang BS, Kim MS, Yeom JS, Choi JM.** Minimum 5-year follow-up results of skipped pedicle screw for flexible idiopathic scoliosis. J Neurosurg Spine. 2011;15:146–150. DOI: 10.3171/2011.4.SPINE10321.
16. **Kuklo TR, Potter BK, Lenke LG, Polly DW Jr, Sides B, Bridwell KH.** Surgical revision rates of hooks versus hybrid versus screw versus combined anteroposterior fusion for adolescent idiopathic scoliosis. Spine. 2007;32:2258–2264. DOI: 10.1097/BRS.0b013e31814b1ba6.
17. **Liljenqvist U, Lepsien U, Hackenberg L, Niemeyer T, Halm H.** Comparative analysis of pedicle screw and hook instrumentation in posterior correction and fusion of idiopathic thoracic scoliosis. Eur Spine J. 2002;11:336–343. DOI: 10.1007/s00586-002-0415-9.
18. **Cheng I, Kim Y, Gupta MC, Bridwell KH, Hurford RK, Lee SS, Theerajunyaporn T, Lenke LG.** Apical sublaminar wires versus pedicle screws – which provides better results for surgical correction of adolescent idiopathic scoliosis? Spine. 2005;30:2104–2112. DOI: 10.1097/01.brs.0000179261.70845.b7.
19. **Suk SI, Lee SM, Chung E-, Kim JH, Kim SS.** Selective thoracic fusion with segmental pedicle screw fixation in the treatment of thoracic idiopathic scoliosis: more than 5-year follow up. Spine. 2005;30:1602–1609. DOI: 10.1097/01.brs.0000169452.50705.61.
20. **Abul-Kasim K, Ohlin A.** The rate of screw misplacement in segmental pedicle screw fixation in adolescent idiopathic scoliosis. Acta Orthop. 2011;82:50–55. DOI: 10.3109/17453674.2010.548032.
21. **Hicks JM, Singla A, Shen FH, Arlet V.** Complications of pedicle screw fixation in scoliosis surgery: a systematic review. Spine. 2010;35:E465–E470. DOI: 10.1097/BRS.0b013e3181d1021a.
22. **Diab M, Smith AR, Kuklo TR.** Neural complications in the surgical treatment of adolescent idiopathic scoliosis. Spine. 2007;32:2759–2763. DOI: 10.1097/BRS.0b013e31815a5970.
23. **Vora V, Crawford A, Babekhir N, Boachie-Adjei O, Lenke L, Peskin M, Charles G, Kim Y.** A pedicle screw constructs giver an enhanced posterior correction of adolescent idiopathic scoliosis when compared with other constructs: myth or reality. Spine. 2007;32:1869–1874. DOI: 10.1097/BRS.0b013e318108b912.
24. **Storer SK, Vitale MG, Hyman JE, Lee FY, Choe JC, Roye DP Jr.** Correction of adolescent idiopathic scoliosis using thoracic pedicle screw fixation versus hook construct. J Pediatr Orthop. 2005;25:415–419. DOI: 10.1097/01.mph.0000165134.38120.87.
25. **Roach JW, Mehlman CT, Sanders JO.** Does the outcome of adolescent idiopathic scoliosis surgery justify the rising cost of the procedures? J Pediatr Orthop. 2011;31(1 Suppl):S77–S80. DOI: 10.1097/BPO.0b013e3181f73bfd.
26. **Li M, Shen Y, Fang X, Ni J, Gu S, Zhu X, Zhang Z.** Coronal and sagittal plane correction in patients with Lenke I adolescent idiopathic scoliosis: a comparison of consecutive versus interval pedicle screw placement. J Spinal Disord Tech. 2009;22:251–256. DOI: 10.1097/BSD.0b013e3181884940.
27. **Clements DH, Betz RR, Newton PO, Rohmiller M, Marks MC, Bastrom T.** Correlation of scoliosis curve correction with the number and type of fixation anchors. Spine. 2009;34:2147–2150. DOI: 10.1097/BRS.0b013e3181adb35d.
28. **Quan GM, Gibson MJ.** Correction of main thoracic adolescent idiopathic scoliosis using pedicle screw instrumentation: does higher implant density improve correction? Spine. 2010;35:562–567. DOI: 10.1097/BRS.0b013e3181b4af34.
29. **Sanders JO, Diab M, Richards SB, Lenke LG, Johnston CE, Emans JB, Sucato DJ, Erickson MA, Bridwell KH, McCarthy RE, Sarwark JF, Dormans JP.** Fixation points within the main thoracic curve: does more instrumentation produce greater curve correction and improved results? Spine. 2011;36:E1402–E1406. DOI: 10.1097/BRS.0b013e31822815ff.
30. **Yang S, Jones-Quaidoo SM, Eager M, Griffin JW, Reddi V, Novicoff W, Shilt J, Bersusky E, Defino H, Ouellet J, Arlet V.** Right adolescent idiopathic thoracic curve (Lenke I A and B): does cost of instrumentation and implant density improve radiographic and cosmetic parameters? Eur Spine J. 2011;20:1039–1047. DOI: 10.1007/s00586-011-1808-4.
31. **Bharucha NJ, Lonner BS, Auerbach JD, Kean KE, Trobisch PD.** Low-density versus high-density thoracic pedicle screw constructs in adolescent idiopathic scoliosis: do more screw lead to a better outcome? Spine J. 2013;13:375–381. DOI: 10.1016/j.spinee.2012.05.029.
32. **Gotfryd AO, Avanzi O.** Randomized clinical study on surgical techniques with different pedicle screw densities in the treatment of adolescent idiopathic scoliosis types Lenke 1A and 1B. Spine Deform. 2013;1:272–279. DOI: 10.1016/j.jspd.2013.05.004.

33. **Larson AN, Aubin CE, Polly DW Jr, Ledonio CG, Lonner BS, Shah SA, Richards BS 3rd, Erickson MA, Emans JB, Weinstein SL.** Are more screws better? A systematic review of anchor density and curve correction in adolescent idiopathic scoliosis. Spine Deform. 2013;1:237–247. DOI: 10.1016/j.jspd.2013.05.009.
34. **Gebhart S, Alton TB, Bompadre V, Krengel WF.** Do anchor density or pedicle screw density correlate with short-term outcome measures in adolescent idiopathic scoliosis surgery? Spine. 2014;39:E104–E110. DOI: 10.1097/BRS.0000000000000075.
35. **Halanski MA, Cassidy JA.** Do multilevel Ponte osteotomies in thoracic idiopathic scoliosis surgery improve curve correction and restore thoracic kyphosis? J Spinal Disord Tech. 2013;26:252–255. DOI: 10.1097/BSD.0b013e318241e3cf.
36. **de Kleuver M, Lewis SJ, Germscheid NM, Kamper SJ, Alanay A, Berven SH, Cheung KM, Ito M, Lenke LG, Polly DW, Qiu Y, van Tulder M, Shaffrey C.** Optimal surgical care for adolescent idiopathic scoliosis: an international consensus. Eur Spine J. 2014;23:2603–2618. DOI: 10.1007/s00586-014-3356-1.
37. **Rushton PR, Elmalky M, Tikoo A, Basu S, Cole AA, Grevitt MP.** The effect of metal density in thoracic adolescent idiopathic scoliosis. Eur Spine J. 2016;25:3324–3330. DOI: 10.1007/s00586-015-4335-x.

Address correspondence to:
Mikhaylovskiy Mikhail Vitalyevich
Novosibirsk Research Institute of Traumatology and Orthopaeducs n.a. Ya.L. Tsivyan,
17 Frunze str., Novosibirsk, 630091, Russia,
MMihailovsky@niito.ru

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Alexandr Sergeyevich Vasyura, MD, PhD, senior researcher of Department of Children Orthopaedics, 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;
Elena Vladimirovna Gubina, PhD, senior researcher of Department of Children Orthopaedics, Novosibirsk Research Institute of Traumatology and Orthopaedics n.a. Ya.L. Tsivyan, 17 Frunze str., Novosibirsk, 630091, Russia, ORCID: 0000-0002-2278-1421, EGubina@niito.ru;
Mikhail Vitalyevich Mikhaylovskiy, DMSc, Prof., chief researcher of Department of Children Orthopaedics, Novosibirsk Research Institute of Traumatology and Orthopaedics n.a. Ya.L. Tsivyan, 17 Frunze str., Novosibirsk, 630091, Russia, ORCID: 0000-0002-4847-100X, MMihailovsky@niito.ru.