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Comparison of long-term results of anterior surgical correction of Lenke type 5 idiopathic scoliosis using dynamic and rigid fixation in patients with complete or near-complete skeletal maturity

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1. Introduction

Approaches to surgical treatment of idiopathic scoliosis with a major lumbar/thoracolumbar curve (Lenke type 5) remain debatable[1] regarding choice of anterior or posterior approach,[2] optimal instrumentation levels,[3,4] and complication prevention.[5] Posterior correction and instrumentation have become the "gold standard" for surgical treatment of any type of idiopathic scoliosis ever since the introduction of the Harrington rod,[6] and its analogues.[7] Surgical correction of scoliosis went through a rapid development phase after the introduction of third-generation instrumentation into clinical practice.[8]

Simultaneously with the development of posterior spine surgery, improvements in the principles and techniques for anterior surgery took place. Dwyer proposed in 1974 an anterior correction system,[9] which was later modified[10–12] and widely used.[13,14]

According to the Lenke classification, types 1 and 5 are optimal for anterior correction.[1] Namely, rigid anterior scoliosis correction has a number of significant advantages compared to posterior interventions: it allows to reduce the number of instrumented segments,[15] allows for correction comparable to posterior instrumentation,[16–19] diminishes the risks of neurological complications,[20,21] as well as the rate of complications associated with wound healing.[19] Additionally, female patients experience less difficulties during pregnancy and childbirth (pregnancy proceeds as in healthy individuals)[22] and the long-term outcomes have proven to be excellent (more than 15 years follow-up).[23] In general, there is little difference in radiological or clinical outcomes in patients with Lenke type 5 scoliosis treated through anterior or posterior approaches.[24] Still, the risks and benefits of each approach are considered individually for each patient.[24]

More recently, dynamic scoliosis correction approaches have been gaining traction, primarily aiming at growth modulation in pediatric patients[25–28] and selectively as an option for skeletally mature patients.[5,29] Dynamic correction allows for preserved mobility in the instrumented region, which has been confirmed by biomechanical studies.[30] Furthermore, dynamic correction allows patients to return to their usual physical activity and sports within a relatively early timeframe.[31]

Despite the growing number of studies involving dynamic correction of spinal deformities in patients with idiopathic scoliosis, studies comparing various methods of anterior correction have not yet been published.

2. Purpose

The aim of this study is to compare the long-term clinical and radiological outcomes of anterior surgical correction using rigid and

Abbreviations: AP, anterior-posterior; UIV, upper instrumented vertebrae; LIV, lower instrumented vertebrae; VBT, vertebral body tethering; PJK, proximal junctional kyphosis; SRS 22, Scoliosis Research Society questionnaire; ASC, anterior scoliosis correction; ASF, anterior spinal fusion; GI, group 1; GII, group 2; Follow-up, FU.

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dynamic instrumentation in patients with Lenke 5 idiopathic scoliosis and complete or near-complete skeletal maturity.

3. Hypothesis

Dynamic anterior surgical treatment of thoracolumbar and lumbar scoliosis is associated with similar radiographic results in deformity correction compared to rigid instrumentation, but with superior functional results.

4. Materials and methods

A retrospective non-randomized comparative study was conducted based on treatment of patients with Lenke type 5 idiopathic scoliosis, who underwent anterior surgical deformity correction using rigid instrumentation (with spinal fusion) and a dynamic system.

Patients were divided into two groups based on the fixation method (Group I - anterior instrumentation and spinal fusion; Group II - anterior dynamic correction).

All surgical interventions were performed by the same surgeon: from 2008 to 2015 in Group I, and from 2019 to 2021 in Group II. In Lenke type 5 (1) deformity, the major structural curve is located between the T12 and the L4 vertebrae. The thoracic and upper thoracic curves are non-structural, meaning that they are smaller in size than the major curve, and correct to less than 25° on lateral bending radiographs. The type of deformity was assessed in accordance with the Lenke classification and only type 5 deformities were included in the analysis.

Group I included 26 patients with lumbar and thoracolumbar idiopathic scoliosis, 23 female, 3 male, aged 13–25 years. All patients underwent thoraco-phreno-lumbotomy, with resection of the 10th rib for grafting purposes, total discectomy, and dissection of the anterior longitudinal ligament at 4–6 levels at the apex of the deformity. Surgical access was performed on the convex side using a single surgical incision and thoracotomy. Correction was performed via anterior segmental instrumentation using a single- or double-rod arrangement (Fig. 1).

A single rod was used in 14 patients, a double rod in 8 patients, and additional interbody fusion using meshes – in 4 patients.

Group II consisted of 23 patients, 22 female, 1 male aged 14–44 years. A thoraco-phreno-lumbotomy was performed without rib resection. Two screws with anchor plates were placed at index levels and correction was carried out using two cords (Fig. 2).

Both groups only included patients who underwent single-stage interventions without the use of preoperative halo-traction. For both groups, the indications for surgical treatment were deformity angles of more than 40°.

Based on radiographic evaluation, the end vertebrae were included within the fixation zone. L3 was selected as the lower instrumented vertebra (LIV) if the L3 - L4 disc was parallel or open on the concave side, neutral on opposite side bending, and centered above the sacrum. In other cases, L4 was chosen as the LIV. In one case, L2 was chosen as the LIV. If the two lower vertebrae were parallel, then the more caudal one was selected as the LIV.

Preoperative and final follow-up AP and lateral radiographs of the spine in the standing position were analyzed using the Cobb method. To assess the flexibility of the spine, side-bending radiographs, traction test (axial traction with a load of 40% of the patient's weight, but not more than 30 kg), magnitude of lumbar lordosis and thoracic kyphosis, as well as vertebral rotation using the Nash-Moe method were measured before and after surgery (33). Due to the lack of availability of full-spine radiographs at the time of preoperative examination and surgery in patients with rigid instrumentation, the assessment of sagittal parameters in both groups was eliminated from the study. Radiographic parameters were measured as follows: thoracolumbar transitional kyphosis T10-L2; lumbar lordosis L1-S1; segmental instrumented angle (AP Cobb angle between the upper instrumented vertebra (UIV) and the LIV); Risser score. Radiographic evaluation was performed by a single specialist who was independent of the surgical team.

The duration of surgery, blood loss, hospital stay, and duration of opiate administration in the early postoperative period were assessed.

Functional outcomes were assessed at each follow-up using the Scoliosis Research Society (SRS-22) questionnaire. All clinical and radiological complications were recorded and evaluated in detail. Loss of correction was considered as an increase in the instrumented curve of more than 5° for all correction methods.

Statistical analysis was carried out using the SPSS statistics software. Descriptive statistics on the variables of interest were filled in to assess differences between groups at baseline and during two years of follow-up. Two-sample *t*-tests were used to compare dynamic and rigid correction groups with respect to baseline demographic and surgical characteristics.

The same approach was used to evaluate radiographic parameters of coronal and sagittal plane restoration. Estimated blood loss differences between the two groups were analyzed using the Mann–Whitney test for non-parametric data.

5. Results

In assessment of demographic parameters, patients in Group II were,

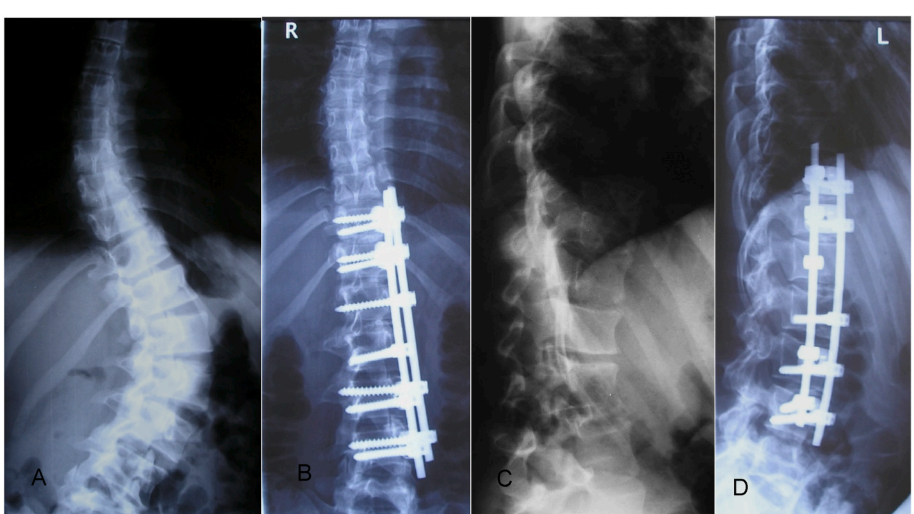

Fig. 1. Preoperative (A, C) and postoperative (B, D) radiographs of a 17 y.o. female patient, who underwent anterior scoliosis correction using rigid instrumentation.

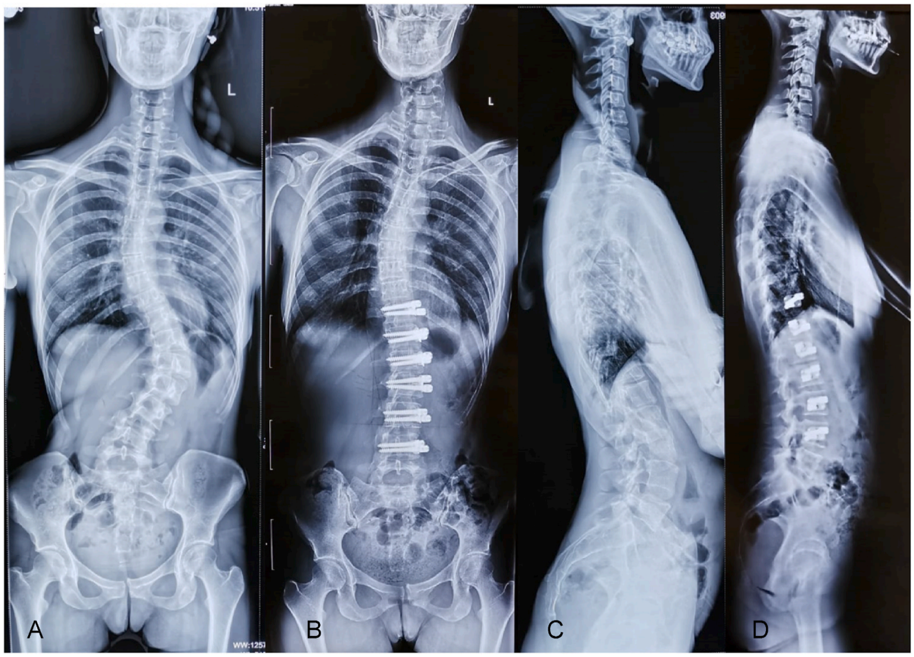

Fig. 2. Preoperative (A, C) and postoperative (B, D) radiographs of a 26 y.o. female patient who underwent anterior dynamic scoliosis correction.

on average, more than 8 years older (mean age 25.3 ± 10.9), compared with Group I (17.6 ± 12.8) $p = 0.023$.

In the rigid instrumentation group, the Risser score was 3 in five patients (19.23%), 4 in twelve (46.15%), and 5 in nine patients (34.61%).

The apical vertebra was T12 in four patients (15.38%), L1 in thirteen patients (50%), and L2 in nine patients (34.61 %). The UIV was T9 in two (7.69%), T10 in eight (30.76%), T11 in twelve (46.15%), and T12 in four patients (15.38%). The LIV was L2 in one case (3.84%), L3 in nine patients (34.61%), and L4 in fourteen patients (53.84%).

The main curve Cobb angle ranged from 45° to 87° (mean value: 64.4 ± 10.9°) before surgery, 25.8 ± 12.6° immediately after surgery, and 27.9 ± 5.3° at last follow-up. Transitional kyphosis T10-L2 before surgery averaged 8.1 ± 7.6°, 4.8 ± 3.2° immediately after surgery, and 5.2 ± 3.1° at last follow-up.

In the dynamic correction group, the Risser score was 3 in seven patients (30.43%), 4 in eleven (47.82%), and 5 in five patients (27.73%). The apical vertebra was T12 in four patients (17.39%), L1 in seven (30.43%), and L2 in twelve patients (52.17%). The UIV was T9 in five patients (27.73%), T10 in eleven (47.82%) and T11 in ten patients (43.47%). LIV was L3 in eleven patients (47.82%) and L4 in twelve patients (52.17%). The preoperative Cobb angle of the major curve averaged 52.4 ± 9.6° (52° to 83°) before surgery, 29.6 ± 9.2° after surgery, and 24.2 ± 12.3° at latest follow-up. Transitional kyphosis T10-L2 averaged 6.0 ± 7.5° before surgery, 3.8 ± 2.4° after surgery, and 3.2 ± 1.6° at final follow-up. Apical vertebral rotation estimated using the Nash-Moe method in Group I before surgery averaged 1.6 ± 0.58, 0.13 ± 0.54 immediately after surgery, and 0.18 ± 0.32 at final follow-up. In patients with dynamic correction, these values were 1.82 ± 0.35 before surgery, 0.84 ± 0.36 after surgery, and 0.81 ± 0.39 at final follow-up.

The average number of instrumented levels was 5.7 ± 0.8 in Group I and 6.4 ± 1 in the Group II ($p = 0.701$). In both groups, a comparable number of levels was instrumented. Preoperative mobility of the thoracolumbar/lumbar curve was statistically significantly higher in the dynamic correction group: 28.2 ± 9.1 compared to 36 ± 7.2 ($p = 0.008$) in patients with rigid constructs. The mean preoperative lumbar lordosis was 54.8° ± 12.0°, 51.7° ± 10.5° after surgery, and 52.2° ± 11.3° at final follow-up in the group with dynamic correction and in the group with rigid instrumentation it was 58.8° ± 11.9° before surgery, 52.1° ± 9.5° after surgery, and 49.4° ± 12.6° at final follow-up ($p = 0.183$).

The data on radiographic parameters that were used to compare the two groups are demonstrated in Table 2.

The duration of postoperative follow-up varied from three to five years (68.3 ± 3.25 months) for patients in Group I and from two to two years and eight months (mean: 25.08 ± 2.87 months) for patients in Group II. Patients in both groups did not experience significant loss of deformity correction during the follow-up period (rigid $p = 0.335$ and dynamic $p = 0.225$).

Average estimated blood loss was 280.5 ± 70.4 ml in Group I, and 155 ± 50.5 ml in Group II ($p < 0.05$).

Group II patients spent less time in the hospital after surgery, and were discharged on average before the 5th day (5.2 ± 1.5), compared with an average 7-day stay (7.3 ± 2.0) in Group I ($p < 0.05$). Decreased consumption of opioid analgesics for an average of 2.5 ± 1.9 days after surgery in Group II, compared to 3.1 ± 1.9 days in Group I was also

Table 1
Values of the parameters studied in the study groups: Risser score, levels of fixation and rotation of the apical vertebrae.

Parameter	Rigid instrumentation	Dynamic correction
Gender	23 female, 3 male	22 female, 1 male
Age	17.3 ± 12.8	25.3 ± 10.9
Risser score	3 - 5 (19.23%) 4 - 12 (46.15%) 5 - 9 (34.61%)	3 - 7 (30.43%) 4 - 11 (47.82%) 5 - 5 (27.73%)
Apical vertebra	T12- 4 (15.38%) L1 - 13 (50%) L2 - 9 (34.61%).	T12 - 4 (17.39%) L1 - 7 (30.43%) L2 -12 (52.17%).
UIV	T9 - 2 (7.69%) T10 - (30.76%) T11 - 12 (46.15%) T12 -4 (15.38%)	T9 - 5 (27.73%) T10 - 11 (47.82%) T11 - 10 (43.47%)
LIV	L2 - 1 (3.84%) L3 - 9 (34.61%) L4 - 14 (53.84%)	L3 -11 (47.82%), L4 - 12 (52.17%)
Apical vertebra rotation according to Nash and Moe	Before surgery 1.6 ± 0.58 After surgery 0.13 ± 0.54 Final follow-up 0.18 ± 0.32	Before surgery 1.82 ± 0.35 After surgery 0.84 ± 0.36 Final follow-up 0.81 ± 0.39

Table 2
Basic radiographic data for rigid and dynamic correction of Lenke type 5 thoracolumbar/lumbar deformities.

Observation period	Rigid instrumentation	Dynamic Correction
	Cobb angle before/after surgery/final follow-up	
before surgery	64.4 ± 10.9°	52.4 ± 9.6°
after surgery	25.8 ± 12.6°	29.6 ± 9.2°
final follow-up	27.9 ± 5.3°	27.9 ± 5.3°
	Major curve Cobb angle at preoperative traction test	
before surgery	36 ± 7.2°	28.2 ± 9.1°
	Transitional kyphosis T10-L2	
before surgery	6.0 ± 7.5°	8.1 ± 7.6°
after surgery	3.8 ± 2.4°	4.8 ± 3.2°
final follow-up	3.2 ± 1.6°	5.2 ± 3.1°
	Lumbar lordosis L1-S1	
before surgery	58.8° ± 11.9°	54.8° ± 12.0°
after surgery	52.1° ± 9.5°	51.7° ± 10.5°
final follow-up	49.4° ± 12.6°	52.2° ± 11.3°

observed ($p = 0.103$).

On assessment of early complications, postoperative pneumothorax was observed in 5 patients with rigid and 3 patients with dynamic correction, which required prolonged chest tube drainage. There was no significant loss of correction during the follow-up period among both groups. Complications, associated with cord breakage in dynamic correction, loosening of screws or fractures of implants in rigid instrumentation were not observed. Neuropathic pain syndrome was observed in 3 patients in Group I and in 4 patients in Group II, with a correlation with the age of the patients, as it usually developed in older patients. In majority of cases this problem was resolved with the use of gabapentin at a dosage of 300 mg 2 times a day for 2–3 months.

Analysis of SRS 22 questionnaire data demonstrated that patients with rigid instrumentation had a mean score of 4.1 ± 0.63 for function; 4.0 ± 0.71 for pain; 3.94 ± 0.78 for mental function; 4.32 ± 0.64 for satisfaction with the results of surgery and 4.4 ± 0.76 for self-image. In the dynamic correction group the mean scores were 4.8 ± 0.3 for function; 4.2 ± 0.66 for pain; 4.4 ± 0.35 for mental health; 4.3 ± 0.77 for surgical result satisfaction; and 4.6 ± 0.42 for self-image ($p < 0.05$ for all domains) (Table 3).

6. Discussion

Based on the review of available literature, there is still insufficient objective evidence for the benefits of dynamic correction in idiopathic scoliosis compared to standard fusion approaches. The indications for this novel scoliosis treatment approach – optimal deformity type, angle, major curve mobility, and age of patients, particularly in conditions of skeletal maturity – still remain to be clarified.[29] It is important to note that patients with complete skeletal maturity tend to have more rigid deformities, and, consequently, growth modulation is not possible.

Although dynamic correction has become an innovative strategy for the treatment of scoliosis without fusion for adolescent scoliosis with continued growth, the decision of whether to use dynamic or rigid instrumentation is also not well defined in this subset of patients.

It has been firmly established that anterior correction is highly effective, is associated with lower blood loss, fewer fusion segments, preserved mobility due to uninstrumented segments, and improves the overall functional state of the spinal column.[32] The peak publication activity regarding the topic of anterior Lenke type 5 scoliosis correction falls on the end of 2000s and beginning of 2010s, followed by gradually diminishing interest in the anterior approach for lumbar/thoracolumbar idiopathic scoliosis treatment. This loss of interest has been primarily dictated by a lack of significant differences between radiographic and functional results of anterior and posterior approaches.[2,24,32,33]

Latest literature data, however, suggests that dynamic correction of scoliosis in adults leads to superior radiographic results to those in younger patients undergoing vertebral body tethering, which is related to more aggressive surgical techniques aimed at satisfactory correction.[5] It is worth noting, that most studies evaluate the optimal LIV for anterior scoliosis correction[34,35] but very scarce data on the choice of UIV exists for dynamic correction surgery.

In our study, rigid instrumentation provided better correction than dynamic systems, but a longer surgery duration with a markedly increased intraoperative blood loss, which is associated with greater surgical morbidity due to interbody fusion, which requires a total discectomy and ligament resection. Dynamic correction, on the other hand, only requires nucleotomy at the apex of the deformity in more severe deformity cases. The average angle of correction in rigid instrumentation was from 64.4 ± 10.9° to 27.9 ± 5.3° at final follow-up, while in the dynamic correction it was 52.4 ± 9.6° to 24.2 ± 12.3° respectively. The deformities in the dynamic correction group before surgery were more mobile by about 10%. Trobisch et al published data in 2021 on a series of patients who underwent dynamic correction at the thoracolumbar/lumbar level with satisfactory results. In their study, however, the frequency of cord breaks was significantly higher than described in literature, supporting the hypothesis that lumbar VBT is associated with higher cord breakage rates than thoracic VBT.[36] This phenomenon is likely related to the use of a single cord and aggressive derotation maneuvers, as well as greater mobility of the lumbar region compared to the thoracic spine. In our dynamic correction group of 23 people, no cases of cord breakage were recorded, which is often the case in younger patients. These findings can be attributed to the routine use of double cords, which provide greater tensile strength and reduce fatigue. Unfortunately, there are no biomechanical studies providing evidence for greater strength of double cords, although such an assumption was made by Baroncini et al[37] A recent biomechanical study demonstrated that single or double cords did not significantly differ in restricting global and L1-L2 spinal range of motion in flexion or extension (<10%) and left or right axial rotation (<14%).[30] In addition, it was shown, that intervertebral discs and facet joints do not undergo degenerative changes after an average of 29 months of follow-up in dynamic correction surgery.[38]

Lumbar lordosis was one of the evaluated parameters that changed significantly after surgery in the rigid instrumentation group. Anterior correction has been shown to have a limited kyphogenic effect, however, it provides a harmonious sagittal profile, at the same time preserving the paraspinal muscles and posterior ligaments, which explains the low rate of PJK associated with this approach.[35,39,40] Furthermore, loss of correction is uncommon with modern anterior rigid instrumentation compared to the first generations of Dwyer and Zielke systems, which were associated with pseudarthrosis and implant failure.[41]

According to our study data, the use of a double cord in the lumbar spine did not have a kyphogenic effect on lumbar lordosis. These findings are consistent with the results of similar studies using single cords in the lumbar region.[36,42] At the same time, it provides inferior derotation as per assessment of apical vertebra rotation according to Nash-Moe method (Table 1). Improvements in T10-L2 transitional kyphosis parameters were achieved in both groups.

Regarding the functional outcomes of Lenke type 5 scoliosis correction, one study reported that all SRS-22 domains were significantly higher in the anterior scoliosis correction group compared to posterior correction,[43] although other studies suggest that there is no such difference.[32,44] Sudo et al (2013) reported that surgical treatment of Lenke

Table 3
SRS 22 questionnaire results at final follow-up for anterior correction using rigid and dynamic instrumentation.

Parameter	Rigid instrumentation	Dynamic correction	R
Function	4.1 ± 0.63	4.8 ± 0.3	0.034
Pain	4.0 ± 0.71	4.2 ± 0.66	0.022
Self-image	4.4 ± 0.76	4.6 ± 0.42	0.024
Mental health	3.94 ± 0.78	4.4 ± 0.35	0.046
Satisfaction with results	4.2 ± 0.64	4.5 ± 0.77	0.037

type 5 scoliosi via anterior approach resulted in satisfactory radiographic, clinical, and functional outcomes, including pulmonary function, at an average follow-up of 23 years.[45] Kelly et al (2010) reported that the anterior approach provided satisfactory long-term (follow-up of 17 years) SRS and Oswestry scores, as well as excellent functional outcomes in lumbar and thoracolumbar deformities.[41] In our study, dynamic correction provided the best functional SRS-22 outcomes. There were no significant differences between the two groups in terms of patient perceptions of function, pain, or self-image. Measures of satisfaction with surgery, and mental health were higher in the anterior dynamic correction group, however, indicating that this treatment fulfilled patient expectations (Table 3).

Our study has certain limitations, including sample power and retrospective nature of the analyzed data and lack of randomization. Outcome assessment tools were not used consistently to allow comparisons to be made at clear intervals before or after surgery. However, the fact that there are no similar comparative studies on rigid and dynamic anterior scoliosis correction approaches renders our study beneficial for further understanding of dynamic scoliosis correction. The obtained data demonstrates a clear advantage of the dynamic approach in terms of functional outcome.

7. Conclusion

Both rigid and dynamic approaches in Lenke type 5 anterior correction of idiopathic scoliosis can provide satisfactory correction in terms of radiographic outcomes in patients with complete or near-complete skeletal maturity and thoracolumbar deformities of similar magnitude. However, preliminary results suggest that patients undergoing dynamic scoliosis correction can expect a better quality of life in the long term. To further substantiate the data reported in this article, further studies with a higher level of evidence are required.

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Ethical compliance

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki Declaration and its later amendments.

Data access statement

Research data supporting this publication are available from the N. N. Priorov National Medical Research Center.

CRediT authorship contribution statement

Vladimir S. Pereverzev: Conceptualization, Data curation, Formal analysis, Investigation, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft. **Sergey V. Kolesov:** Conceptualization, Data curation, Methodology, Supervision, Validation. **Arkadii I. Kazmin:** Conceptualization, Data curation, Formal analysis, Investigation, Software, Visualization. **Andrey A. Panteleev:** Formal analysis, Validation, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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