



RADIOLOGICAL ASSESSMENT OF SPINAL RANGE OF MOTION AFTER SELECTIVE THORACIC SCOLIOSIS CORRECTION USING RIGID AND DYNAMIC SYSTEMS

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Objective. To perform comparative analysis of postural and functional radiographs of patients after correction of thoracic scoliosis using dynamic versus rigid fixation systems.

Material and Methods. This retrospective study included 105 patients (mean age 27 years) with idiopathic thoracic scoliosis (Lenke type 1). Selective fixation was performed using an anterior dynamic or posterior rigid system. Standard and functional radiographs (lateral flexion, flexion/extension) were compared two years after surgery.

Results. Both techniques ensured correction of the main curve by 73–75% and the lumbar counter-curve by 62–64% ($p \leq 0.005$). In the dynamic fixation group, 92% of sagittal functional range of motion (17.1° out of 17.6°) and 51.4% of coronal range of motion (22.1° out of 39.0°) were preserved in the instrumented area ($p \leq 0.005$). Asymmetry was observed: 88.6% (19.6° out of 20.1°) of motion was preserved when bending toward the convex side, versus 27% (35.2° out of 42.1°) when bending toward the concave side. In the rigid fixation group, no motion remained in the fusion area. The total functional range of motion of the entire spine was higher with dynamic fixation than with rigid fixation: in the coronal plane 71.2° vs. 45.1° and in the sagittal plane 78.7° vs. 58.6° ($p \leq 0.005$).

Conclusion. The dynamic fixation system provides stable deformity correction comparable to a rigid one but allows preserving up to 92% of sagittal and 51% of coronal mobility in the operated area with characteristic asymmetry. Rigid fixation leads to a complete motion loss in the fusion area and significantly lower total functional range of motion of the spine.

Key Words: spine; spine surgery; thoracic scoliosis; rigid system; dynamic system.

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Idiopathic scoliosis is one of the most common orthopedic spinal deformities, affecting 2% to 4% of the population [1]. However, only 0.2–0.3% of patients require surgical correction [2]. The disease exerts a significant negative impact on young patients, manifesting as reduced quality of life, chronic pain, psychosocial consequences, and functional limitations [3–5].

For Lenke type 1 thoracic scoliosis, which is the most common type, an anterior correction approach can be utilized [4–10]. However, rigid spinal instrumentation inevitably leads to a loss of mobility in the instrumented zone, as well as to adjacent segment degeneration [11]. The need for effective and safe treatment of scoliosis stimulates the improvement of modern technologies [12]. Dynamic stabilizing systems, originally developed for growth modulation, are considered a next-generation tool for patients with

completed or nearing completion skeletal growth [10]. A review of the literature indicates that existing studies primarily focus on the outcomes of surgical deformity correction, whereas the aspect of preserving spinal mobility remains under-investigated [15].

This study aims to evaluate postural and functional radiographs in patients with thoracic idiopathic scoliosis prior to and following the use of dynamic versus rigid fixation systems.

Material and Methods

The study included 105 patients (92 females, 13 males) with a median age of 27 (range 16–35) years.

Inclusion criteria: idiopathic right-sided thoracic scoliosis with a preoperative primary curve of 35–70° of Cobb; primary curve mobility of $\geq 30\%$ on functional radiographs (traction or bending tests);

absence of a structural lumbar counter-curve ($>25^\circ$) and hyperkyphosis ($>40^\circ$); patient age between 16 and 45 years with a Risser sign of ≥ 4 at the time of surgery; surgical intervention limited to selective thoracic fixation using either a dynamic correction system without anticipated growth modulation or a posterior rigid system; availability of complete radiographic data taken preoperatively and at follow-up visits for at least two years; and no loss of correction during long-term follow-up.

Exclusion criteria: severe comorbidity, implant-related complications during the follow-up period (revision surgery, cord breakage, rod fracture, periscrew bone resorption, loss of correction, etc.), and back pain at the time of follow-up examinations.

The number of fixed levels and the fusion length were taken into account. Patients were followed up during out-

patient visits, with control radiographic examinations at 3, 6, 12, and 24 months postoperatively.

The range of motion was evaluated based on spine radiographs obtained in the neutral position, as well as functional flexion-extension and lateral bending radiographs at 2 years postoperatively (Fig. 1–3).

Ethical review

The study was approved by the Bio-medical Ethics Council of the N.N. Pri- orov National Medical Research Center of Traumatology and Orthopedics of the Russian Ministry of Health (Minutes No. 1/23 dated 28.12.2023). Informed consent for publication of clinical data was obtained from the patients or their parents.

Radiological data assessment

All patients underwent a standard preoperative evaluation, including standing anteroposterior (frontal) and lateral (sagittal) spine radiographs, as well as functional bending radiographs (lateral bending to the left and right in the frontal plane) and radiographs in position of maximal flexion/extension in the sagittal plane (Fig. 4).

In the early postoperative period, standing radiographs were obtained in standard views to evaluate the initial correction and implant position (Fig. 5).

To assess sagittal plane motion, the difference between the flexion and extension angles was calculated. The range of motion in the frontal plane within the fixation zone was evaluated as the sum of data from functional radiographs at extreme positions minus the Cobb angle of deformity; a similar approach was applied to the lumbar spine. To assess the functional range of motion (ROM) in each plane, data from the thoracic and lumbar spine departments were summed: $ROM = \text{thoracic ROM} + \text{lumbar ROM}$.

Statistical data analysis

Statistical analysis was performed using Statistica 13.3 software. Data were expressed as mean $\pm$ standard deviation ($M \pm SD$). The non-parametric Mann–Whitney and Kruskal–Wallis tests were used for group comparisons. Differences

were considered statistically significant at $p < 0.05$.

Results

This retrospective single-center study compared the effects of dynamic (anterior) and rigid (posterior) fixation systems on spinal range of motion (ROM). The mean preoperative Cobb angle of the primary curve was $57.2^\circ \pm 3.4^\circ$, while the mean side-bending angle in the frontal plane was $39.2^\circ \pm 5.5^\circ$. Following surgical correction using a dynamic stabilization system (most frequent fixation levels: T5–T12 and T6–T12, a median of instrumented vertebrae was 9; Table 1), the main curve angle decreased to $11.3^\circ \pm 8.6^\circ$, representing a 75.3% correction. At the two-year follow-up, a slight increase to $14.3^\circ \pm 10.3^\circ$ was observed (Table 2). In the rigid system group (predominant fixation levels T3–L1 and T3–T12, with a median of 11 vertebrae, Table 1), the postoperative angle was $10.2^\circ \pm 8.6^\circ$ (73.2% correction), which subsequently stabilized at

$11.4^\circ \pm 3.2^\circ$ at the 24-month follow-up. Furthermore, this group had a greater total number of instrumented levels, with the upper instrumented vertebra (UIV) being T3 in 100% of cases. In addition to correcting the primary curve, both systems demonstrated a positive effect on the lumbar countercurve: its angle decreased from a preoperative value of $14.3^\circ \pm 10.6^\circ$ to $9.5^\circ \pm 4.6^\circ$ in the dynamic fixation group, and to $5.2^\circ \pm 4.6^\circ$ in the rigid fixation group immediately postoperatively. During long-term follow-up, the correction remained stable, measuring $5.5^\circ \pm 2.6^\circ$ and $5.2^\circ \pm 4.3^\circ$, respectively ($p \leq 0.005$ compared to baseline values; Table 2). Sagittal balance was characterized by a significant increase in the thoracic kyphosis angle in the dynamic fixation group from $18.3^\circ \pm 9.8^\circ$ to $24.7^\circ \pm 9.2^\circ$ at the two-year follow-up ($p = 0.02$), whereas this parameter remained stable in the rigid fixation group ($22.1^\circ \pm 6.6^\circ$ immediately postoperatively and $22.3^\circ \pm 2.6^\circ$ at long-term follow-up). A qualitative analysis of mobility (Table 3) revealed

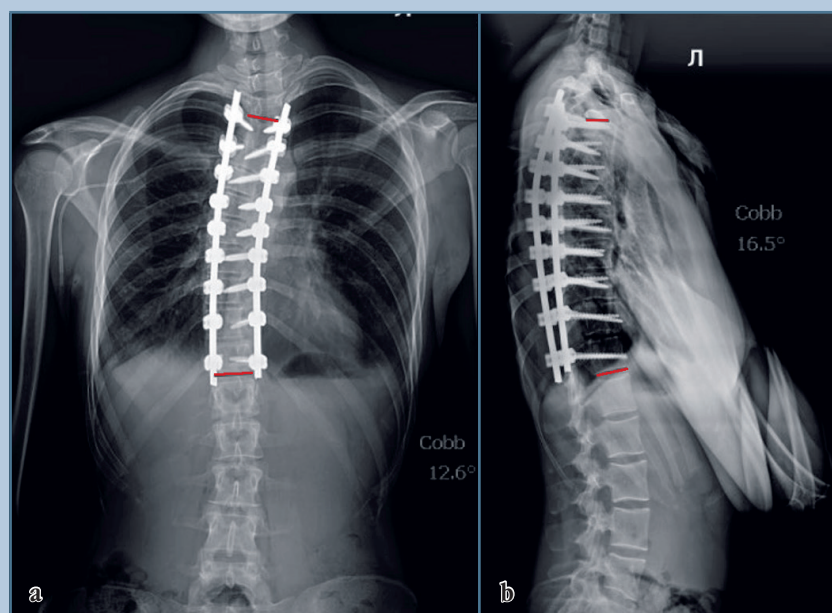


Fig. 1

Postural radiographs of a 22-year-old patient obtained 2 years after rigid fixation at the T4–T12 level in the frontal (a) and sagittal (b) projections: the angle within the instrumented zone is 12.6° , and the kyphosis angle is 16.5°

that at two years postoperatively, the dynamic system group retained 92% of the preoperative sagittal range of motion in the thoracic spine (17.1° vs. 17.6° preoperatively; $p \leq 0.005$) and 51.4% in the frontal plane (22.1° vs. 39° ; $p \leq 0.005$). Concurrently, a pronounced asymmetry was observed in the frontal plane, characterized by a reduced range of motion during lateral flexion toward the concave (left) side.

In the group with a rigid instrumentation system in the thoracic spine, motion in the frontal plane was absent (0°); however, partial mobility was preserved in the uninstrumented lumbar spine, where the frontal range of motion was 45.1° compared to 50.3° preoperatively ($p \leq 0.003$), and the sagittal range of motion was 58.6° compared to 69.6° ($p \leq 0.005$). In the frontal plane, the total range of motion (ROM) of the thoracic and

lumbar departments reached 71.2° with dynamic fixation and 45.1° with rigid fixation (compared to 89.3° preoperatively; $p \leq 0.005$). In the sagittal plane, the values were 78.7° and 58.6° , respectively (compared to 87.2° preoperatively; $p \leq 0.005$). Preserved motion within the fixation zone was observed with the use of the dynamic system, showing a sagittal flexion of $30.6^\circ \pm 14.6^\circ$ and extension of $13.6^\circ \pm 12.6^\circ$, whereas motion was absent within the instrumented segments in the posterior rigid stabilization group. Thus, when comparing the two fixation methods, ROM of the entire spine was significantly higher in the dynamic system group in both the frontal (71.2° vs. 45.1°) and sagittal (78.7° vs. 58.6°) planes. Statistical significance of all intergroup differences and changes over time was confirmed using the Mann–Whitney U test at a significance level of $p < 0.05$.

Discussion

According to White and Panjabi [16, 17], the thoracic spine is anatomically constrained in three-dimensional kinematic analysis due to the vertical orientation of the facets, the close proximity of the spinous processes, and the rib cage, which provide natural restriction. The total range of motion of the thoracic spine (T1–T12) varies from 34° to 90° for flexion/extension, from 94° to 164° for lateral flexion, and from 108° to 198° for axial rotation [18, 19]. A systematic review by Borkowski et al., which synthesized data from 33 cadaveric studies on thoracic spine mobility, reported lower mean values: 28° for flexion/extension, 38° for lateral flexion, and 45° for axial rotation.

Studies evaluating global ROM in patients with idiopathic thoracolumbar/lumbar scoliosis demonstrate that a high-

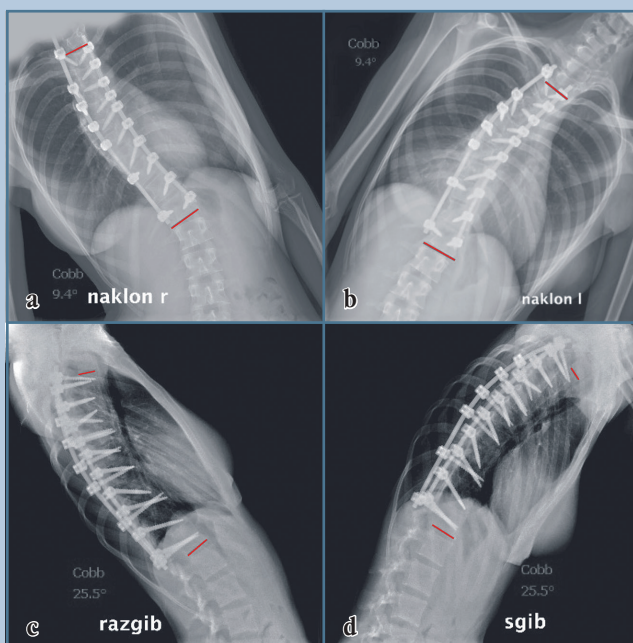


Fig. 2

Functional radiograph of a 26-year-old female patient: thoracic bending test: lateral bending toward the convexity – 9.4° (a), toward the concavity – 9.4° (b); range of motion (ROM) in the frontal plane – 0° . In extension – 25.5° (c), in flexion – 25.5° (d); range of motion (ROM) in the sagittal plane – 0°

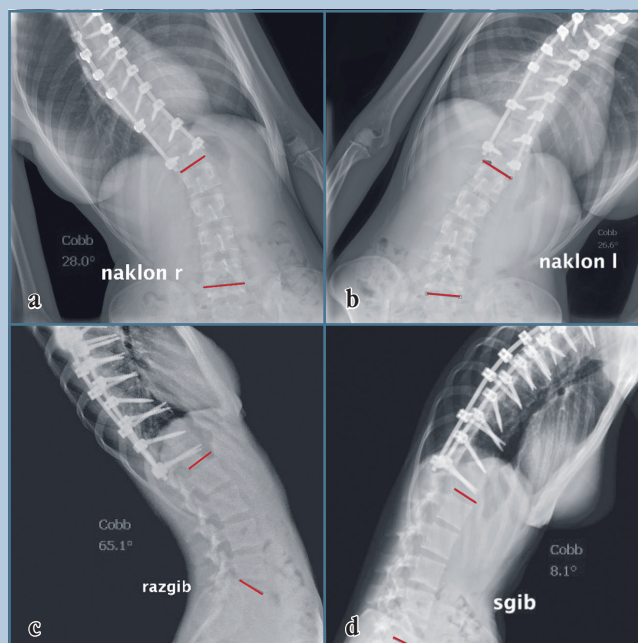
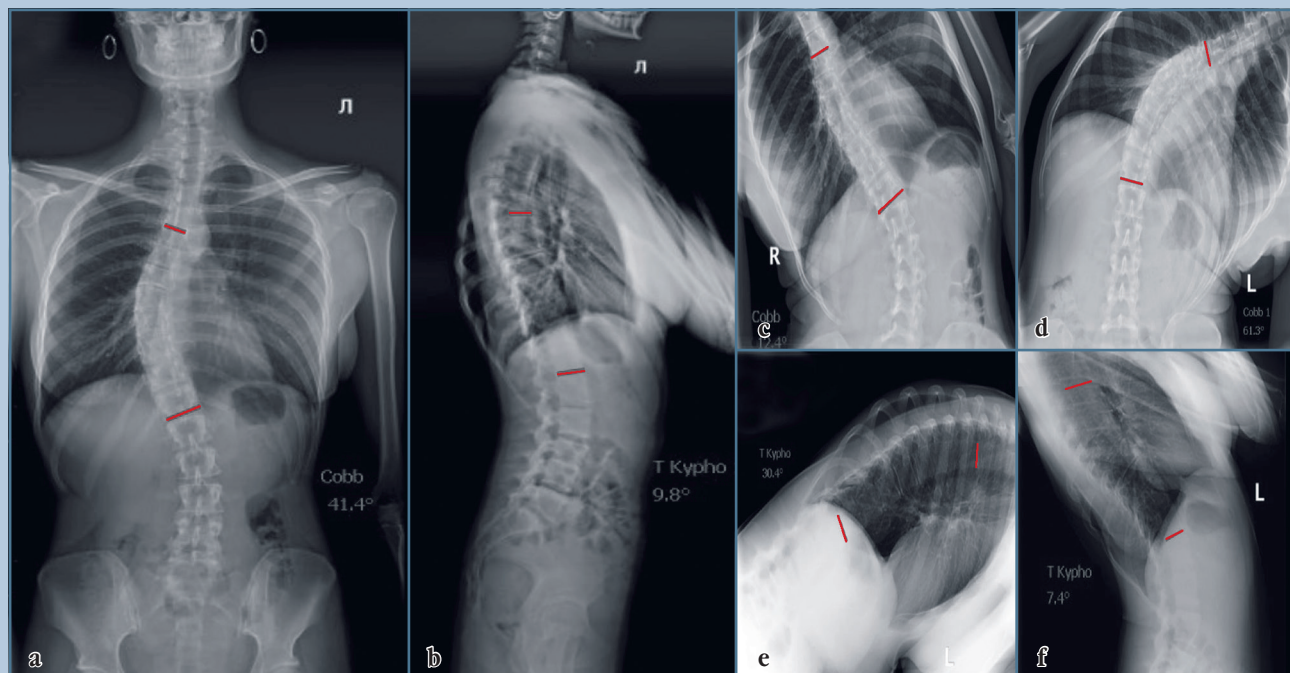


Fig. 3

Functional radiograph of a 26-year-old female patient: lumbar spine bending test: right lateral flexion was 28.0° (a) and left lateral flexion was 26.6° (b), with a total range of motion (ROM) in the frontal plane of 49.6° . In extension, the angle was 65.1° (c), and in flexion, 8.1° (d), with a total range of motion in the sagittal plane of 55.9°

**Fig. 4**

Postural radiographs of a 27-year-old female patient with Lenke type 1 thoracic scoliosis: Cobb angle of 41.4° and a kyphosis angle of 9.8° in the frontal (a) and sagittal (b) projections; bending tests showed a right-bending angle of 12.4° (c) and a left-bending angle of 61.3° (d) relative to the frontal plane, with a frontal range of motion of 39.9°; in flexion, the angle was 30.4° (e), and in extension, 7.4° (f), with a sagittal range of motion of 23°

er degree of curvature is associated with a more significant reduction in mobility [21]. Mobility analysis in unoperated patients confirms these functional limitations inherent to the deformity itself, with Sung et al. [23] concluding that the reduction is most pronounced in flexion and rotational movements.

Rigid fixation is known to eliminate motion at the fixation site with the formation of a bone block [24]. Similar results were reported by Engsborg et al. [25], who found that adult patients who had undergone spinal deformity surgery demonstrated a significant reduction in trunk mobility compared to preoperative patients.

Marks et al. [26, 27] sequentially evaluated the outcomes of spinal fusion in adolescent idiopathic scoliosis, demonstrating a significant increase in compensatory mobility within the unfused segments. This effect was particularly pronounced at the L2–L5 levels during

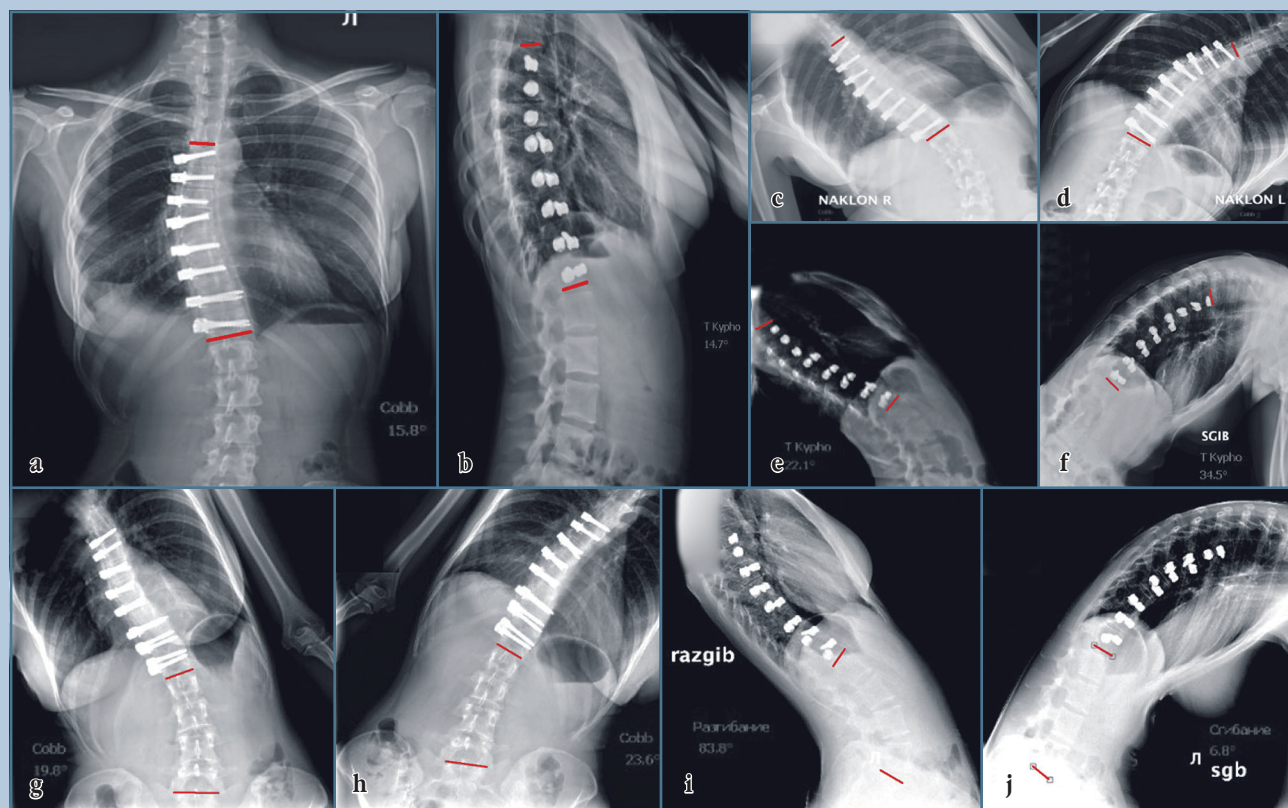
lateral bending, thereby imposing an increased mechanical load on these segments. Notably, hypermobility remains unchanged over time (based on a follow-up period of more than 10 years) and does not correlate with patients' subjective quality of life assessment. Patients return to daily activities takes an average of 5.5 years [28].

To address the limitations associated with rigid systems, growth-preserving and growth-modulating constructs were developed [29], which were subsequently adapted for the treatment of patients with nearing to complete or completed growth [30]. Early studies evaluating postoperative mobility are extremely limited [13]. Although radiographic imaging represents the standard approach for assessing surgical treatment [31], and dynamic radiographs are routinely performed prior to surgery to evaluate mobility [31, 32], there is a lack of sufficient data on the assessment of motion

using plain radiographs. Functional radiography for assessing lumbar spine mobility is described by S.H. Khadzhimuratova et al. [33].

In a prospective study, Buyuk et al. [34] evaluated spinal range of motion 1 year postoperatively following vertebral body tethering (dynamic correction of the growing spine) in 32 adolescent patients (aged 10 to 16 years) with idiopathic thoracic scoliosis. Utilizing functional radiography (lateral bending, flexion/extension), the authors demonstrated preserved spinal mobility. However, a more pronounced reduction in the frontal plane was observed during lateral bending, which decreased by 77% compared to preoperative values and exceeded 5° in 62.5% of patients. Range of motion in the sagittal plane was $21^\circ \pm 12^\circ$ ($33^\circ \pm 13^\circ$ during flexion and $11^\circ \pm 14^\circ$ during extension).

Another retrospective study utilizing 3D kinematic analysis demon-

**Fig. 5**

Postural and functional radiographs of a 27-year-old female patient 2 years after thoracic scoliosis correction using a dynamic fixation system: at the T5–T12 level in the frontal (a) and sagittal (b) postural projections: the Cobb angle within the instrumented zone is 15.8°, thoracic kyphosis is 14.7°; functional radiographs of the instrumented zone: lateral bending toward the convex side is 1.1° (c), lateral bending toward the concave side is 32.9°, the range of motion (ROM) in the frontal plane is 31.8° (d); extension is 22.1° (e), flexion is 34.5° (f), the ROM in the sagittal plane is 12.4°; functional radiographs of the lumbar spine below the instrumented zone: right lateral bending is 19.8° (g), left lateral bending is 23.6° (h), the ROM in the frontal plane is 3.8° (i); extension is 83.8°; flexion is 6.8° (j); the ROM in the sagittal plane is 77.4°; the total functional range of motion of the thoracic and lumbar spines in the frontal plane is 35.6°, and in the sagittal plane is 89.8% by 73% (from $42.1^\circ \pm 19.9^\circ$ to $35.2^\circ \pm 12^\circ$; $p \leq 0.003$), whereas during lateral bending toward the convex (right) side, it is only by 11.4% (from $20.1^\circ \pm 8.1^\circ$ to $19.6^\circ \pm 7.1^\circ$; $p \leq 0.005$)

Table 1

Characteristics of fixation levels in the study groups

Group	Proximal fixation level	Distal fixation level	Number of fixed levels (median)	Most common levels of fixation	The ratio of the most common fixation levels
Anterior dynamic stabilization system	T5 – 70% T6 – 30%	T12 – 20% L1 – 32% L2 – 43% L3 – 5%	9	T5–T12 T6–L1	70.0% 30.0%
Posterior rigid fixation system	T3 – 100%	T12 – 25% L1 – 41% L2 – 45% L3 – 5%	11	T3–T12 T3–L1 T3–L2 T3–L3	41.0% 9.5% 45.0% 5.5%

Table 2

Preoperative postural radiographic data of patients with idiopathic thoracic scoliosis postoperative and after two years

Indicator	Preoperative	Postoperative (dynamic system)	Postoperative (rigid system)	After 2 years (dynamic system)	After 2 years (rigid system)	p
Main curve Cobb angle, deg.	38.1 ± 20.5	11.3 ± 8.6	10.2 ± 8.6	14.3 ± 10.3	11.4 ± 3.2	0.005
Countercurve Cobb angle, deg.	14.3 ± 10.6	9.5 ± 4.6	5.2 ± 4.6	5.5 ± 2.6	5.2 ± 4.3	0.005
Kyphosis, deg.	18.3 ± 9.8	21.7 ± 9.6	22.1 ± 6.6	24.7 ± 9.2	22.3 ± 2.6	0.020

Table 3

Preoperative and two-year postoperative functional radiographic data of patients with idiopathic thoracic scoliosis

Indicator	Preoperative	At 2-year follow-up (anterior dynamic stabilization)	At 2-year follow-up (posterior rigid fixation system)	p
Tilt of the primary curve to the right, degrees	20.1 ± 8.1	19.6 ± 7.1	8.5 ± 5.1	≤0.005
Tilt of the primary curve to the left, degrees	42.1 ± 19.9	35.2 ± 12	8.5 ± 5.1	≤0.003
Right bending in the countercurve, degrees	30.1 ± 6.1	25.3 ± 15.1	15.5 ± 5.1	≤0.003
Left bending in the countercurve, degrees	30.2 ± 5.1	25.3 ± 16.1	15.1 ± 5.6	≤0.005
Frontal angle of motion of the primary curve, degrees	39.0	22.1	0.0	≤0.005
Frontal angle of motion of the lumbar curve, degrees	50.3	50.1	45.1	≤0.003
Total frontal angle of motion, degree	89.3	71.2	45.1	≤0.005
Flexion in the primary curve, degrees	32.8 ± 14.8	30.6 ± 14.6	19.5 ± 10.6	≤0.020
Extension in the primary curve, degrees	15.2 ± 14.2	13.6 ± 12.6	19.5 ± 10.6	≤0.020
Flexion in the countercurve, degrees	5.4 ± 5.2	6.2 ± 5.2	6.4 ± 5.2	≤0.003
Extension in the countercurve, degrees	75 ± 5.2	6.8 ± 5.2	65.0 ± 13.8	≤0.005
Sagittal angle of motion in the thoracic spine, degrees	17.6	17.1	0.0	≤0.005
Sagittal angle of motion in the lumbar spine, degrees	69.6	61.8	58.6	≤0.005
Total sagittal angle of motion, degrees	87.2	78.7	58.6	≤0.005

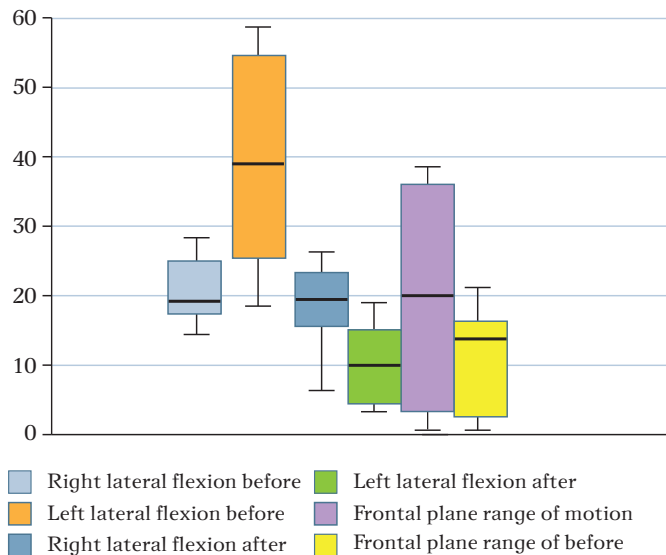
strated that at two years postoperative, patients with dynamic stabilization systems retained a significant amount of trunk mobility, particularly in extension and rotation, compared to those with rigid systems; furthermore, patients who underwent anterior vertebral body tethering experienced a loss of motion only during lateral bending [35]. The data obtained in our study provide quantitative radiological evidence of the preservation of sagittal range of motion at 92.0% of the baseline level. Frontal mobility decreased by 48.6%, with an asymmetry of 73.0% toward the concave side and 11.4% toward the convex side, demonstrating the long-term preservation of the dynamic cord. It is also worth noting that the achieved correction remains sta-

ble during long-term follow-up, and an increase in the kyphosis angle within the dynamic system fixation zone has a positive effect on restoring the spinal profile, which tends to develop hypokyphosis in this type of deformity [36].

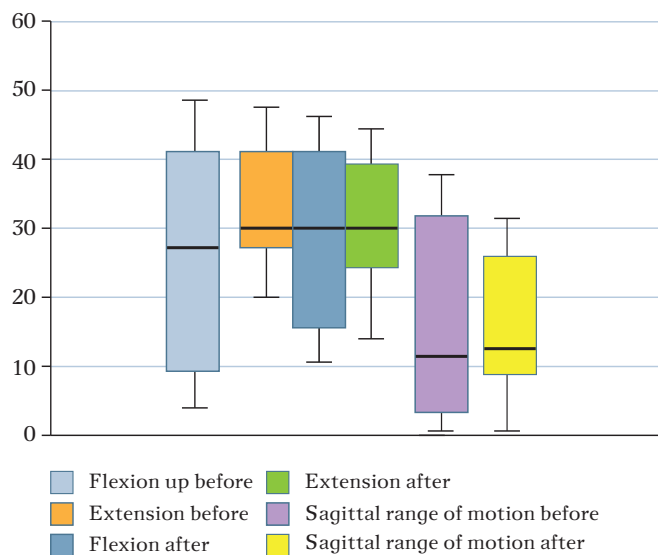
Conclusions regarding load redistribution in non-fixed segments complement the study by Marks et al., which demonstrated that the mobility of unoperated lumbar segments remains stable over the long term and does not change significantly during long-term follow-up. The analysis revealed that both surgical techniques led to a statistically significant ($p \leq 0.005$) reduction in the lumbar countercurve angle. In the dynamic system group, the angle decreased from $14.3^\circ \pm 10.6^\circ$ to $5.5^\circ \pm 2.6^\circ$ at the two-

year follow-up (approximately 62% correction), whereas in the rigid fixation group, it decreased to $5.2^\circ \pm 4.3^\circ$ (64%). This result is consistent with the study by Lenke et al. [37], which demonstrated that the anterior approach for selective thoracic fusion provides a high rate of correction for both thoracic and lumbar curves.

In a qualitative study using semi-structured interviews of 40 patients at three or more years post-operation, Royse et al. [38] found that patients three years after dynamic correction of a growing spine or posterior spinal fusion for idiopathic scoliosis reported pain relief, preserved function, and improved appearance following surgical treatment. Functional benefits reflecting quality of life are beyond the

**Fig. 6**

Data from functional frontal-view radiographs of the thoracic spine, pre- and post-application of a dynamic fixation system, demonstrating the range-of-motion advantages of the dynamic system in the frontal plane.

**Fig. 7**

Data from functional sagittal radiographs of the thoracic spine before and after the application of a dynamic fixation system: demonstrating the mobility advantages of the dynamic system in the sagittal plane.

scope of this study and warrant further investigation.

Conclusion

The obtained data demonstrate that both techniques provide comparable and temporally stable correction of both the primary thoracic curve (73–75% reduction in the Cobb angle) and the lumbar countercurve (reduction from 14.3° to 5.2–5.5°, representing approximately 62%). The dynamic system preserves up to 92% of sagittal and 51% of frontal range of motion in the instrumented segment. Concurrently, a characteristic asymmetry is observed due to the ongoing corrective effect of the cord: maintaining 88.6% of mobility during bending toward the convexity versus 27.0% during bending toward the concavity. Along with this, physiological thoracic kyphosis was restored, increasing from 18.3° to 24.7°. Rigid fixation results in a complete loss of mobility within the instrumented zone while maintaining an unaltered sagittal profile. Consequently, the total ROM of the entire spine (thoracic + lumbar segments) under rigid fixation is significantly lower than that under dynamic fixation: 45.1° vs. 71.2° in the frontal plane and 58.6° vs. 78.7° in the sagittal plane ($p \leq 0.005$). It is also necessary to evaluate the correlation between residual spinal mobility and quality of life in patients following selective thoracic scoliosis correction.

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Additional information

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