ULTRASOUND EXAMINATION OF *M. ERECTOR SPINAE* IN PATIENTS WITH THORACIC SCOLIOSIS AFTER DYNAMIC AND RIGID FIXATION

M.S. Raspopov, S.V. Kolesov, V.V. Shvets, N.A. Eskin, V.S. Pereverzev, A.I. Kazmin, E.D. Bogdashevskaya, N.S. Morozova, S.B. Bagirov, I.E. Domrachev
National Medical Research Center of Traumatology and Orthopedics n.a. N.N. Priorov, Moscow, Russia

Objective. To assess the condition and functional parameters of *m. erector spinae* in patients who underwent dynamic anterior and rigid posterior fixation for thoracic scoliosis, using ultrasound diagnostics (US) and a proprietary methodology.

Material and Methods. The comparative study involved 95 patients aged 15–55 years with idiopathic right-sided thoracic scoliosis (Cobb angle 35–60°): 33 of them after dynamic fixation, 32 after rigid fixation, and 30 patients awaiting surgery (control group). The follow-up period exceeded 12 months. Ultrasound examination included measuring of the fiber pennation angle, muscle thickness, contractility index, and relative asymmetry at the apex of the scoliotic curve. Measurements were performed in two patient positions: at rest and during maximum extension (30°, controlled by a goniometer).

Results. Statistically significant differences ($p \leq 0.05$) between the groups were found. At rest, the pennation angle after dynamic fixation (20.06° ± 0.15°) was 26.5% higher than after rigid fixation (15.85° ± 0.62°), but lower than control values (23.57° ± 0.93°). The thickness of *m. erector spinae* with dynamic fixation (1.23 cm ± 0.01 cm) was close to the control (1.35 cm ± 0.02 cm), whereas with rigid fixation a pronounced decrease in thickness was observed (0.89 cm ± 0.01 cm). During extension (30°), the pennation angle in patients operated on with the dynamic system sharply increased to 39.5° (close to the control value of 40.5°), which was 2.4 times higher than the indicator (16.2°) in the group with rigid fixation. The thickness of *m. erector spinae* (2.15 cm ± 0.05 cm) under load after dynamic fixation corresponded to the control (2.20 cm ± 0.03 cm), while rigid fixation showed thinning (1.21 cm ± 0.14 cm). The mean contractility index after dynamic fixation was significantly lower ($p < 0.05$) than that (84.65% ± 0.35%) after rigid fixation and close to the control value (53.9%), indicating preservation of muscle contractility. Relative asymmetry was minimal in the dynamic fixation group (1.6%) compared to that in the rigid fixation (2.24%) and control (2.96%) groups.

Conclusion. The ultrasound technique used in the study demonstrated high efficiency in assessing the condition of the paraspinal muscles. Anterior dynamic fixation for thoracic scoliosis provided the preservation of *m. erector spinae* functional activity, the maintenance of natural contraction and improved muscle symmetry, whereas posterior rigid fixation was accompanied by structural changes, including reduced elasticity and degeneration of muscle fibers.

Keywords: spine surgery; dynamic stabilization system; ultrasound diagnostics of muscles.

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Scoliosis is a three-dimensional deformity of the spine affecting its entire structure and influencing the biomechanics of the surrounding muscles [1].

As scoliosis progresses, changes occur in the tone and distribution of load on the back muscles, which can result in pain and dysfunction. As the deformity progresses, *m. erector spinae* undergo restructuring, the dynamic coefficients of which are one of the key predictors of scoliosis deformity and spinal stability [2, 3]. According to research, the condition and function of the paraspinal muscles have a direct impact on sagittal balance [4], therefore the role of the muscular factor is of great interest and is actively discussed [5].

Nowadays, the gold standard for surgical treatment of idiopathic thoracic scoliosis is deformity correction using rigid spinal instrumentation through a posterior approach [6, 7]. Recently, however, an anterior dynamic system has been used to correct scoliosis, the main advantage of which is the preservation of mobility in the fixation area with satisfactory deformity correction [8]. Furthermore, an anterolateral approach to the spine is performed; therefore, preservation of paravertebral muscles results in earlier recovery of patients compared to rigid fixation [9, 10].

There are few studies examining muscle characteristics in patients with scoliosis after surgical treatment using various assessment techniques [11–13].

For example, electromyography in a number of studies shows a decreased muscle tone in patients with scoliotic deformity after rigid fixation; the decreased muscle tone is associated with atrophy at the level of the operated segments [11, 14] that can be defined by direct visual ultrasound monitoring, which allows the size, structure, and location of muscle bundles to be evaluated for the study of the back muscles [15] without invasive techniques [16, 17]. We did not find any publications on the use of ultrasound and the characteristics of the postoperative pennation angle using dynamic fixation. The current article studies the influence of two types of systems (dynamic and rigid) on the deep muscles of the back, in particular *m. erector spinae*, using ultrasound diagnostics and a proprietary methodology.

The objective is to assess the condition and functional parameters of *m. erector spinae* in patients who underwent dynamic anterior and rigid posterior fixation for thoracic scoliosis, using ultrasound diagnostics.

Material and Methods

This study was performed as a comparative cohort analysis with a retrospective-prospective design. Patients aged 15 to 55 who underwent surgery for thoracic scoliosis using anterior dynamic and posterior rigid systems between 2018 and 2023 were included.

Inclusion criteria: idiopathic thoracic scoliosis, Cobb angle between 35° and 60° prior to surgery, completed growth, surgical treatment, selective fixation of the thoracic spine, and follow-up period of more than 12 months. Exclusion criteria: neurological conditions, previous spinal surgery, systemic pathologies.

According to the surgical fixation technique, patients were divided into three groups (Table 1). The first group consisted of 33 patients who underwent surgery using an anterior dynamic correction system (Fig. 1); the second group consisted of 32 patients who underwent surgery using rigid transpedicular fixation through a posterior approach (Fig. 2); and the third (control) group consisted of 30 patients before surgery.

All patients underwent ultrasound examination of the paravertebral muscles on a Canon Aplio700 performed by a single researcher with over 15 years of experience.

Ultrasound examination technique. Patient preparation involved positioning the patient comfortably in a prone position to relax the back muscles, which is important for obtaining a high-quality and informative image of *m. erector spinae*, the most powerful and longest back muscle selected for quantitative assessment [2]. The study was performed in two positions: a relaxed prone position to evaluate the baseline condition of *m. erector spinae* and maximum extension to analyze muscle function under load. For unification of the measurement of the lumbar extension angle, a goniometer was used with a target range of 25–35°, which corresponds to physiological capabilities and avoids compensatory movements [18]. The goniometer was positioned between the iliac crest (stationary arm) and the midaxillary line (movable arm) to monitor trunk tilt (Fig. 3).

Imaging methods. A linear ultrasonic probe with a frequency of 7.5–10.0 MHz was used for diagnosis. The sonograph was placed at an angle of 30–45° and shifted laterally 2 cm from the spinous processes in the area of the apex of the scoliotic curve, which provided clear imaging of *m. erector spinae*. Two images were captured in the apex of the deformity for each functional position, which allowed for a comparative analysis of muscle condition.

The pennation angle (ϑ) of muscle fibers was defined as the angle formed by the line between the direction of the muscle fibers and the line of the aponeurosis [19]. The contractility index was calculated as the ratio of thickness under load to thickness at rest, multiplied by 100. Asymmetry was calculated using the formula: | (left side – right side) | / mean value × 100.

Muscle thickness in ultrasound examination is defined as the distance between the superficial and deep fasciae of the muscle, as measured perpendicular to its length [15, 20] (Fig. 4).

The thickness ϑ of *m. erector spinae* fibers was measured at rest (passive state) and at maximum extension (active state). Ultrasound images of the structure of the muscles under study were obtained in each position (Fig. 5).

Statistical analysis. Ultrasound images were saved on the hard drive of the ultrasound system, and the results were analyzed using Statistica 6.1.2 software. During data analysis, the mean value and standard deviation (M ± SD) were calculated. The Mann–Whitney U test and Kruskal–Wallis test were used to compare the groups. Differences were considered statistically significant at $p < 0.05$.

Results

The study showed statistically significant differences ($p < 0.05$) in the functional parameters of *m. erector spinae* between groups after surgical correction of thoracic scoliosis. At rest, ϑ in the dynamic fixation group (20.06° ± 0.15°; L:19.91°/R:20.21°) exceeded the values by 26.5% in the rigid group (15.85° ± 0.62°; L:15.25°/R:6.48°), although it remained below the control values (23.57° ± 0.93°; L:2.64°/R:24.5°), as shown in Fig. 6. Similarly, muscle thickness at rest using the dynamic technique (1.23 ± 0.01 cm; L:1.24/R:1.22) was similar to that of the control group (1.35 ± 0.02 cm), in contrast to a pronounced decrease with rigid fixation (0.89 ± 0.01 cm; L:0.90/R:0.88), as shown in Fig. 7. During functional load (30° extension), the dynamic system provided a sharp increase to 39.5° (L:38°/R:41°), which was 2.4 times higher than in the rigid group (16.2°; L:16.2°/R:16.25°) and corresponded to the physiological norm (control: 40.5°; L:39°/R:42°), as shown in Fig. 8. The thickness of *m. erector spinae* under load in the dynamic group (2.15 ± 0.05 cm; L: 2.10/R: 2.20) did not differ significantly from the control (2.20 ± 0.03 cm), whereas rigid fixation showed critical muscle thinning (1.21 ± 0.14 cm; L: 1.35/R: 1.08), as shown in Fig. 9. The contractility index confirmed the retention of reduction with the dynamic technique (60.59 ± 0.14; L:60.73%/R:60.45 %) compared to its sharp decrease with rigid fixation (84.65 ± 0.35; L:85.0%/R:84.3%) and proximity to control values (53.9%), as shown in Fig. 10. The minimal relative asymmetry in the dynamic group (1.6% versus 2.24% in the rigid group and 2.96% in the control group) suggests a restoration of symmetry. All quantitative data, including angle increase under load (+19.44° with dynamic fixation vs. +0.4° with rigid fixation), are presented in Table 2,

Table 1

Demographic and clinical characteristics of patients in the study groups

Group	Age, years (mean ± standard deviation)	Gender (M/F), *n*	Fixation levels (more common)	Follow-up period, months (mean ± standard deviation)
1 (*n* = 33)	19.8 ± 4.7	10/23	T5–T12 (*n* = 22); T6–L1 (*n* = 11)	14.2 ± 3.5
2 (*n* = 32)	20.1 ± 5.0	12/20	T3–L1 (*n* = 18); T5–T12 (*n* = 14)	16.8 ± 4.2
Control (*n* = 30)	21.5 ± 5.2	8/22	–	–

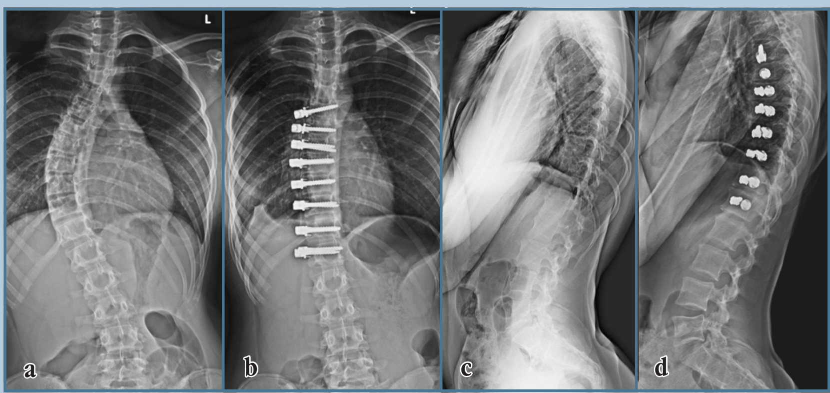

Fig. 1
Radiographs before **(a, c)** and after **(b, d)** surgical treatment using an anterior dynamic system with fixation at the T6–L1 level

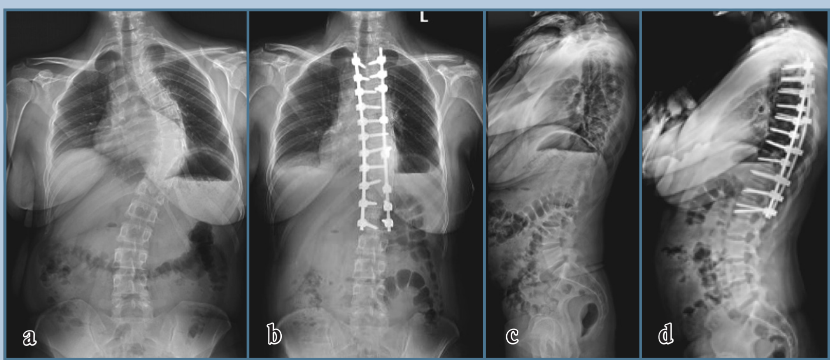

Fig. 2
Radiographs before **(a, c)** and after **(b, d)** surgical treatment using an posterior rigid system with fixation at the T3–L1 level

which also shows intergroup differences in thickness, contractility index, and standard deviations, confirming the advantage of the dynamic system in retaining the functionality of the paravertebral muscles.

Discussion

Nicolaus Steno was the first to describe ϑ (the angle between muscle fibers and aponeurosis) in the context of muscle physiology. In his treatise "Elementorum Mythologiae Specimen" (1667), he used geometric models of muscles and described the change in angles between fibers during contraction, stating "dum contrahitur musculus, anguli eius acuti fiunt ampliores" that means "during contraction, the muscle's angles increase." It was Steno who first focused on the connection between the architecture of muscle fibers and their function [21]. Later, in the 19th century, Ernst H. Weber (1846) formalized the mathematical correlation between muscle size and strength, and Haxton (1944) developed a method for calculating physiological cross-sectional area (PCSA) considering this angle, which he associated with the mechanical properties of muscles [22]. In recent studies using *in vivo* ultrasonography in six subjects, it was found that the ϑ of the triceps surae muscle increases during the transition from dorsiflexion (–15°) to plantar flexion (+30°): by 6–12° (39–67%) at rest and by 9–16° (29–43%) during maximum isometric contraction [23]. In a study by Franchi et al. [24], 10 weeks of concentric (CON) and eccentric (ECC) training caused different changes in ϑ in the muscles: CON increased it by 30 % due to fiber shortening and the addition of sarcomeres in parallel, while ECC resulted in a slight increase in PA (+5%) with a 12% fiber lengthening, associated with mechanical stimulus and activation of the mitogen-activated protein kinase system, confirming the role of the pennation angle in representing muscle characteristics under load. Sinha et al. [25] show that diffusion tensor imaging (DTI) can be used in vivo to track the orientation of muscle fibers in human gastrocnemius muscles. Using the EPI sequence

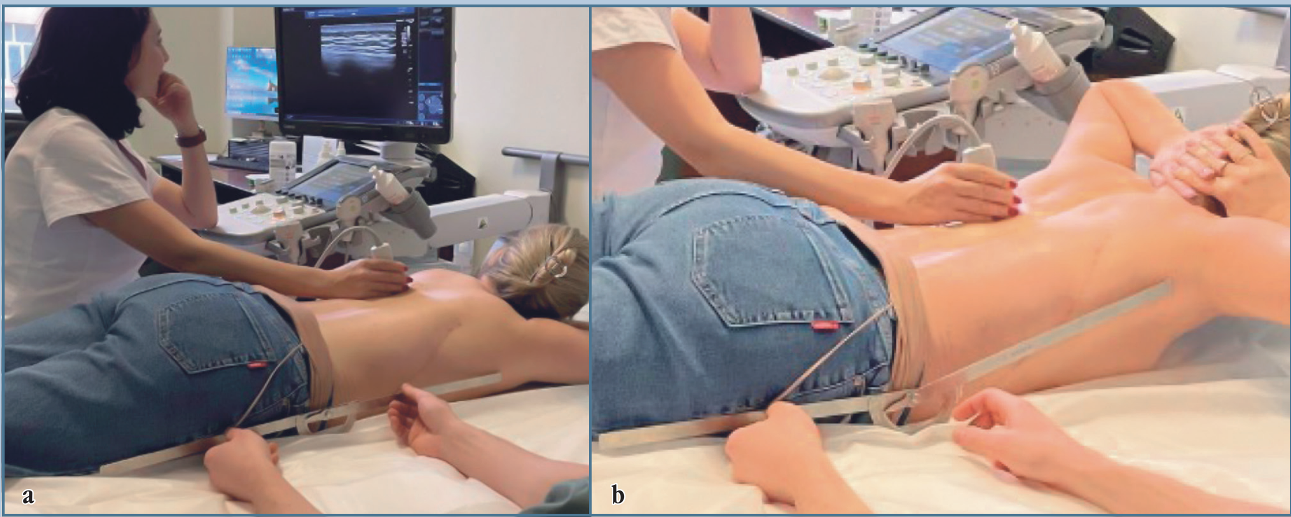

Fig. 3
Methodology of ultrasound examination of the structure of the spinal extensors in a relaxed **(a)** and tense **(b)** position using a goniometer

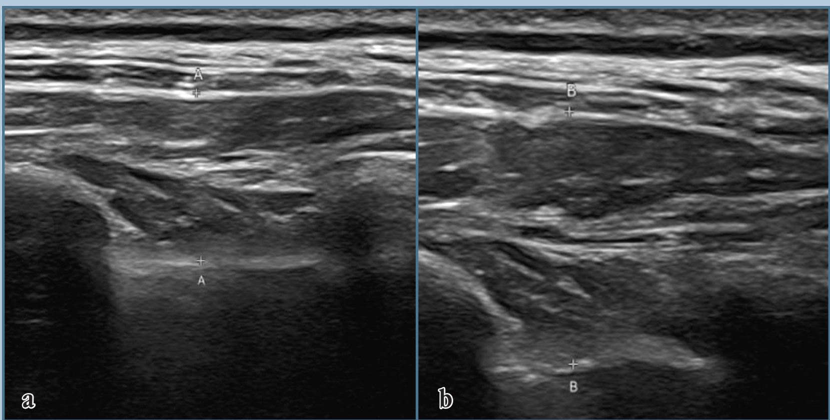

Fig. 4
Sonogram of *m. erector spinae*: **a** – relaxed position; **b** – maximum extension

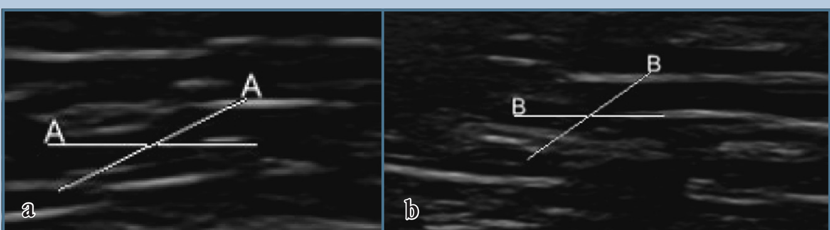

Fig. 5
Fiber pennation angle of *m. erector spinae* at rest (**a** – passive state) and at maximum extension (**b** – active state)

on MRI, the angles of fiber orientation relative to the magnet axis (SI axis) were recorded in five patients, reflecting muscle architecture. The angles ranged from 13.4° (lateral head of the gastrocnemius muscle) to 48.5° (medial head of the soleus muscle), which is consistent with the data obtained from spectroscopy and ultrasound studies. The role of paravertebral muscles in the pathogenesis of idiopathic scoliosis, and their connection with pain syndrome and functional limitations associated with muscle and fascia imbalance is being actively studied [26–29]. During ultrasound imaging, Pan et al. [16] observed the decrease in elasticity and asymmetry of the paravertebral muscles after surgery in patients with different types of scoliosis. Analyzing the electromyographic activity of the paraspinal muscles in 19 patients with idiopathic scoliosis before and after selective stabilization of the thoracic spine, which was recorded bilaterally on the thoracic and lumbar paraspinal muscles in various positions, Lu et al. [14] noted a decrease in asymmetry and activity, which is probably associated with atrophy. Kim et al. [30] analyzed CT data over 9.9 years in a long-term study involving 42 patients with scoliosis who underwent posterior

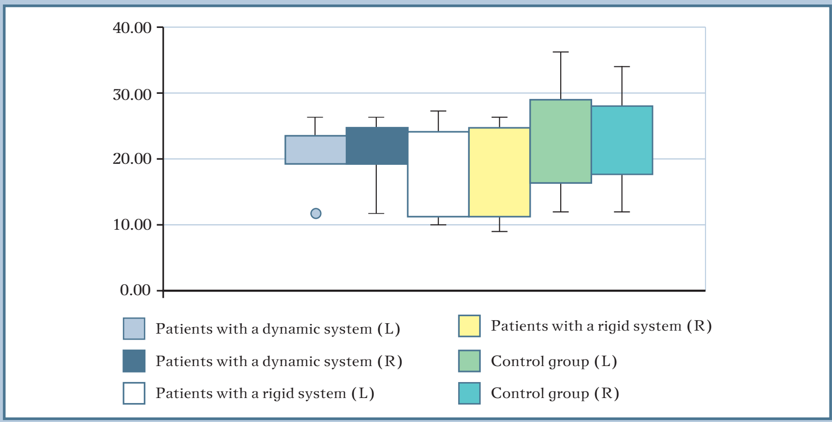

Fig. 6
Pennation angle at rest in the study groups: L – left side; R – right side

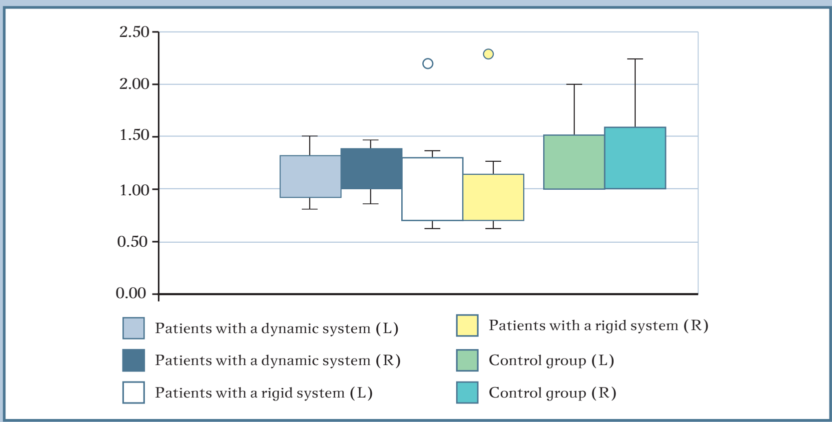

Fig. 7
Thickness of *m. erector spinae* at rest in the study groups: L – left side; R – right side

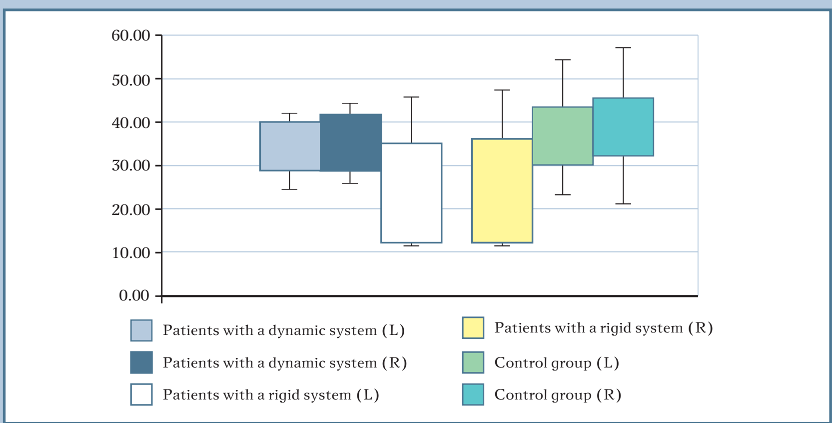

Fig. 8
Pennation angle at tension position in the study groups: L – left side; R – right side

spinal fusion. It was revealed that the cross-sectional area of most paravertebral muscles significantly decreased during the follow-up period. The only exception was the lumbar muscle, which, on the contrary, showed a tendency toward symmetrical development. These differences are associated with the surgical technique: the posterior approach results in injury to the spinal extensors and multifidus muscles, while the deeply placed lumbar muscle is almost unaffected. Furthermore, it adopts a compensatory load over time, ensuring the vertical position of the body, which explains its pronounced growth [31]. In this study, we used parasagittal ultrasound to evaluate the effect of rigid and dynamic fixation on the morphofunctional parameters of *m. erector spinae*: ϑ (indicator of functional activity), contractility index, and muscle thickness (marker of hyper-/atrophy) [12, 32]. The given approach provided an opportunity to study in detail the effect of correction techniques on the key muscle responsible for vertical stability, which is crucial for optimizing the treatment of idiopathic scoliosis.

Conclusion

The applied ultrasound technique demonstrated high efficiency in the assessment of the paravertebral muscle condition, providing an objective comparison of the results of rigid posterior and dynamic anterior fixation in the correction of thoracic scoliosis. Anterior dynamic fixation of thoracic scoliosis is advisable for preserving the functional activity of *m. erector spinae*, maintaining natural biomechanics, and improving muscle symmetry, whereas posterior rigid fixation is followed by structural changes, including decreased elasticity and degeneration of muscle fibers.

The study had no sponsors. The authors declare that they have no conflict of interest.
The study was approved by the local ethics committee of the institution.
All authors contributed significantly to the research and preparation of the article, read and approved the final version before publication.

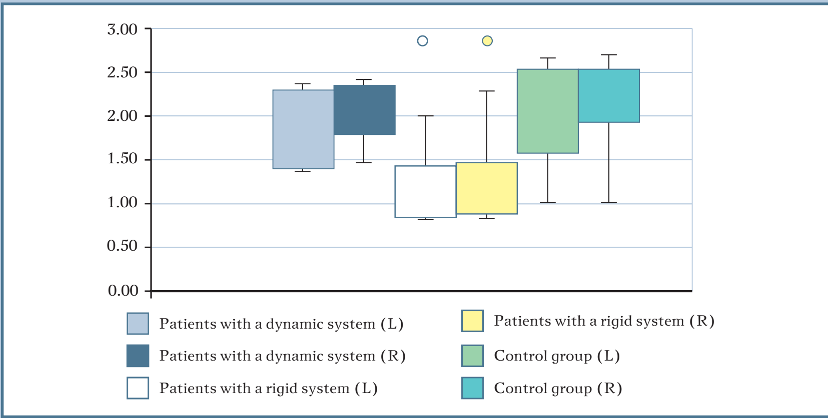

Fig. 9
Thickness of *m. erector spinae* at tension in the study groups: L – left side; R – right side

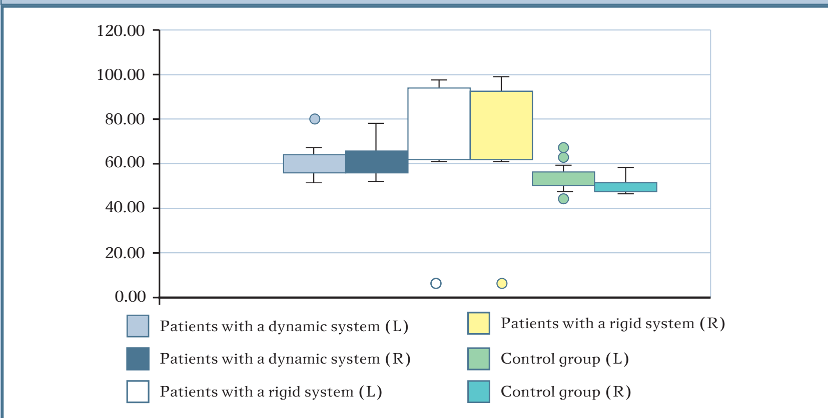

Fig. 10
Contractility index in the study groups: L – left side; R – right side

Table 2

Comparison of ultrasound parameters of *m. erector spinae* in patient groups

Parameter	Dynamic fixation ($n = 33$)	Rigid fixation ($n = 32$)	Control group ($n = 30$)	p value*
Pennation angle, degrees	20.06 (19.91L*/20.20R*)	15.85 (15.25L/16.48R)	23.57 (22.64L/24.5R)	0.009
Pennation angle at extension of 30°, degrees	39.5 (38L/41R)	16.2 (16.2L/16.25R)	40.5 (39L/42R)	0.001
Increase in pennation angle at extension of 30°, degrees	+19.44	+0.40	+19.50	0.001
Thickness at rest, cm	1.23°	0.89	1.35	0.05
Thickness under load, cm	2.15	1.21	2.20	0.001
Contractility Index (left side)	60.73	85.00	55.17	0.001
Contractility Index (right side)	60.45	84.30	52.63	0.001
Mean contractility index, %	60.59	84.65	53.90	0.001
Relative asymmetry, %	1.60	2.24	2.96	0.001

* Statistical significance indicator according to the Kruskal—Wallis test; L — left side; R — right side.

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Address correspondence to:
Raspopov Mikhail Sergeyevich
National Medical Research Center
of Traumatology and Orthopedics n.a. N.N. Priorov,
10 Priorova str., Moscow, 127299, Russia,
mihail.raspopov74@mail.ru

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Mikhail Sergeyevich Raspopov, MD, orthopedic surgeon, Spine Pathology Department, National Medical Research Center of Traumatology and Orthopedics n.a. N.N. Priorov, 10 Priorova str., Moscow, 127299, Russia, eLibrary SPIN: 1843-2864, ORCID: 0009-0005-9517-7347, mihail.raspopov74@mail.ru;
Sergey Vasilyevich Kolesov, DMSc, Prof., traumatologist-orthopedist, head of the Spine Pathology Department, National Medical Research Center of Traumatology and Orthopedics n.a. N.N. Priorov, 10 Priorova str., Moscow, 127299, Russia, eLibrary SPIN: 1989-6994, ORCID: 0000-0001-9657-8584, dr-kolesov@yandex.ru;
Vladimir Viktorovich Shvets, DMSc, orthopedic surgeon, leading researcher at the Spine Pathology Department, National Medical Research Center of Traumatology and Orthopedics n.a. N.N. Priorov, 10 Priorova str., Moscow, 127299, Russia, ORCID: 0000-0001-8884-2410, vshvetcv@yandex.ru;
Nikolay Aleksandrovich Eskin, DMSc, traumatologist-orthopedist, head of the Functional Diagnostics Department, National Medical Research Center of Traumatology and Orthopedics n.a. N.N. Priorov, 10 Priorova str., Moscow, 127299, Russia, eLibrary SPIN: 1215-9279, ORCID: 0000-0003-4738-7348, cito-uchsovet@mail.ru;
Vladimir Sergeyevich Pereverzev, MD, PhD, orthopedic surgeon, Spine Pathology Department, National Medical Research Center of Traumatology and Orthopedics n.a. N.N. Priorov, 10 Priorova str., Moscow, 127299, Russia, eLibrary SPIN: 8164-1389, ORCID: 0000-0002-6895-8288, vcpereverz@gmail.com;
Arkadii Ivanovich Kazmin, MD, PhD, orthopedic surgeon, Spine Pathology Department, National Medical Research Center of Traumatology and Orthopedics n.a. N.N. Priorov, 10 Priorova str., Moscow, 127299, Russia, eLibrary SPIN: 4944-4173, ORCID: 0000-0003-2330-0172, KazminAI@cito-priorov.ru;
Ekaterina Dmitryevna Bogdashevskaya, MD, ultrasound specialist, National Medical Research Center of Traumatology and Orthopedics n.a. N.N. Priorov, 10 Priorova str., Moscow, 127299, Russia, ORCID: 0009-0005-8217-0808, bogdashevskaya83@mail.ru;
Nataliia Sergeyevna Morozova, MD, PhD, orthopedic surgeon, Spine Pathology Department, National Medical Research Center of Traumatology and Orthopedics n.a. N.N. Priorov, 10 Priorova str., Moscow, 127299, Russia, eLibrary SPIN: 4593-3231, ORCID: 0000-0003-4504-6902, morozcito@gmail.com;
Samir Beyukishi oglu Bagirov, MD, orthopedic surgeon, Spine Pathology Department, National Medical Research Center of Traumatology and Orthopedics n.a. N.N. Priorov, 10 Priorova str., Moscow, 127299, Russia, eLibrary SPIN: 9620-7038, ORCID: 0000-0003-1038-1815, bagirov.samir22@gmail.com;
Ivan Evgenyevich Domrachev, MD, orthopedic surgeon, postgraduate student, Spine Pathology Department, National Medical Research Center of Traumatology and Orthopedics n.a. N.N. Priorov, 10 Priorova str., Moscow, 127299, Russia, eLibrary SPIN: 1367-3096, ORCID: 0009-0005-9014-3068, VaniaD97@yandex.ru.