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Original Study Article

Study of reactions of the sensorimotor system in adolescents during and after surgical correction of spinal deformity

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BACKGROUND: Little attention has been paid to the study of delayed sensory and motor reactions in adolescents with spinal deformities after surgical treatment.

AIM: To study the reactions of the sensorimotor system of adolescents after surgical correction of spinal deformity.

MATERIALS AND METHODS: The state of the sensory and motor spheres was analyzed in the immediate postoperative period in 21 adolescents with idiopathic scoliosis and in 13 with congenital deformities of the spine. A complex of methods involving global and stimulation electroneuromyography was used. The amplitude of motor, reflex potentials and interference electromyogram was evaluated at the maximum arbitrary tension of the lower limb muscles. Using an esthesiometer, thermal pain sensitivity in Th1–S2 dermatomes was explored. In the process of surgical correction, intraoperative neuromonitoring was performed with registration of motor evoked potentials of the lower limb muscles.

RESULTS: At the beginning of surgical intervention, high-amplitude, well-reproducible motor evoked potentials were obtained in all patients. In the group of patients with idiopathic scoliosis, compared with those with congenital deformities, smooth flow of surgery prevailed ($p > 0.05$) without significant changes in motor potentials relative to the baseline ($p > 0.05$). The number of observations of motor potentials decreased in the both groups and did not exceed 10%; the differences were not significant ($p > 0.05$). The study of the reactions of the sensorimotor system in the immediate postoperative period triggered an increase in the amplitude of M-responses of *m. rectus femoris, m. flexor digitorum brevis, m. gastrocnemius*, and a decrease in the amplitude of the total EMG of *m. rectus femoris*. Values of H-reflexes remained at the preoperative level. The analysis of thermal pain sensitivity demonstrated the presence of a more pronounced reaction than that of the motor component. Changes in indicators of this type of sensitivity in groups of adolescents with idiopathic and congenital scoliosis were opposite. In idiopathic scoliosis, negative dynamics of the values prevailed, while in adolescents with congenital deformities of the spine, positive dynamics prevailed. This was because the amount of correction of the main and compensatory curves of the deformity in the group with idiopathic scoliosis was 48% greater ($p = 0.0004$) and 51% greater ($p = 0.011$), respectively.

CONCLUSIONS: After surgical correction of spinal deformities in adolescents, the reactions of the sensory system of thermal pain sensitivity were more pronounced than those of the motor sphere.

Keywords: idiopathic scoliosis; congenital deformities of the spine; adolescents; surgical correction of the deformity; motor evoked potentials; M-responses; H-responses; EMG; thermal pain sensitivity; intraoperative monitoring.

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Оригинальное исследование

Исследование реакций сенсомоторной системы подростков в процессе и после хирургической коррекции деформации позвоночника

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Обоснование. В литературе мало внимания уделено исследованию отсроченных реакций чувствительной и двигательной сфер подростков с деформациями позвоночника после оперативного лечения.

Цель — исследовать реакции сенсомоторной системы подростков после хирургической коррекции деформации позвоночника.

Материалы и методы. Проанализирована динамика состояния чувствительной и двигательных сфер в ближайший период после оперативного лечения деформации позвоночника у 21 подростка с идиопатическим сколиозом и у 13 с врожденными деформациями позвоночника. В работе использован комплекс методов глобальной и стимуляционной электронейромиографии. Оценивали амплитуду моторных, рефлекторных потенциалов и интерференционной электромиограммы при максимальном произвольном напряжении мышц нижних конечностей. С помощью эстезиометра исследовали температурно-болевую чувствительность в дерматомах Th_1–S_2. В процессе хирургической коррекции выполнен интраоперационный нейромониторинг с регистрацией моторных вызванных потенциалов мышц нижних конечностей.

Результаты. В начале операционного вмешательства у всех пациентов получены высокоамплитудные хорошо воспроизводимые моторные вызванные потенциалы. В группе пациентов с идиопатическим сколиозом по сравнению с группой с врожденными деформациями преобладало ($p > 0{,}05$) спокойное течение оперативного вмешательства без существенных изменений моторных вызванных потенциалов относительно базового уровня ($p > 0{,}05$). Количество наблюдений опасного снижения показателей моторных вызванных потенциалов в обеих группах сравнения не превышало 10 %, различия статистически не значимы ($p > 0{,}05$). При изучении реакций сенсомоторной системы в ближайшем послеоперационном периоде выявлено увеличение амплитуды М-ответов *m. rectus femoris*, *m. flexsor digitorum brevis*, *m. gastrocnemius*, снижение амплитуды суммарной электромиографии *m. rectus femoris*. Показатели Н-рефлексов оставались на дооперационном уровне. При анализе температурно-болевой чувствительности обнаружена более выраженная реакция в сравнении с моторным компонентом. Изменения показателей этого вида чувствительности в группах подростков с идиопатическим сколиозом и врожденными деформациями носили противоположный характер. При идиопатическом сколиозе преобладала отрицательная динамика чувствительности, у подростков с врожденными деформациями — положительная. Данный факт обусловлен тем, что величина коррекции основной и компенсаторных дуг деформации в группе обследуемых с идиопатическим сколиозом была больше на 48 % ($p = 0{,}0004$) и 51 % ($p = 0{,}011$) соответственно.

Заключение. После хирургической коррекции деформаций позвоночника подростков реакции сенсорной системы температурно-болевой чувствительности более выражены, чем моторной сферы.

Ключевые слова: идиопатический сколиоз; врожденные деформации позвоночника; подростки; хирургическая коррекция деформации; моторные вызванные потенциалы; М-ответы; Н-ответы; электромиография (ЭМГ); температурно-болевая чувствительность; интраоперационный мониторинг.

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BACKGROUND

Spinal cord injury remains a severe consequence despite all the fundamental and applied research, contemporary method advantages, and used surgical hardware to correct spinal deformity [1, 2]. One of the most serious complications is a neurological deficit, with an incidence of 0.37%–10% [3].

Spinal cord injury can occur after surgical interventions, including the correction of scoliosis and kyphosis, because these manipulations are aimed to elongate the spinal column and impart the spinal cord with significant tension, which results in prolonged injury [2].

Literature analysis revealed an increased incidence of spinal cord distraction injuries with the use of a growing rod system which is widely used to correct spinal deformities [4, 5]. Additionally, the number of incidents of traction spinal cord injuries increased over time from 0.72% in 1975 [6] to 1% in 1987 [7] and reached 17% in 2011 [8].

Most researchers agree that excessive distraction is the main cause of spinal cord damage and dysfunction during the correction of spinal deformities [9, 10].

Currently, surgeons argue about the optimal length and time of distraction to avoid paralysis [1, 11, 12]. However, an experimental model has shown that hypoxic events even during minor spinal distraction (in the absence of spinal cord open mechanical or vascular injuries) can cause metabolic deterioration in motor spinal neurons and permanent functional deficits [2, 13]. Concurrently, other authors bear evidence of increased spinal cord blood flow with a minor spinal distraction when the amplitude of the evoked potentials of the spinal cord is 80%–100% of the norm [14, 15]. Additionally, spinal cord dysfunction occurs from excessive tensile stress (affecting the pathways) and delayed onset of spinal cord ischemia in the upper thoracic region, which may be induced by a similar mechanical process acting on the internal blood vessels of the spinal cord, in acute or gradual spinal column elongation of the monkey [16].

Delayed postoperative neurological deficit is a potentially hazardous condition after the correction of kyphoscoliotic spinal deformity. Neurological disorders occur within several hours or days after the surgical intervention. Single reports have been published on this subject [4, 17, 18].

Subclinical changes in the sensorimotor system state are most often neglected by doctors and researchers; therefore, delayed postoperative responses of the sensitive and motor spheres of adolescents with scoliosis of various genesis to surgical treatment should be further investigated [19–21].

The study aimed to investigate the sensorimotor system responses of adolescents after surgical correction of spinal deformity.

MATERIALS AND METHODS

This study examined 34 patients with spinal deformities aged 11–18 years. Subjects were distributed into two groups based on disease etiology, namely, 1) idiopathic scoliosis in 21 adolescents and 2) congenital spinal deformities in 13 adolescents. The control group consisted of 32 healthy children aged 11–17 years.

A comparative analysis of anthropometric parameters revealed no significant differences in height, weight, and body mass index (BMI) in adolescents with idiopathic scoliosis before surgery from those of healthy peers (Table 1).

Adolescents with congenital scoliosis were shorter (–7.2%, $p = 0.00035$) and weighed less (–13.4%, $p = 0.041$) than healthy children and adolescents with idiopathic scoliosis. However, the BMI did not differ from the values of other groups of subjects ($p = 0.589$). The main curve angle in the group of patients with idiopathic scoliosis did not differ from the values of this indicator in adolescents

Table 1. Characteristics of the examined adolescents ($M \pm m$)

Indicators	Adolescent groups		
	healthy $n = 32$	with idiopathic scoliosis, $n = 21$	with congenital spinal deformities, $n = 13$
Age, years	14.5 ± 1.6 (range: 11–17)	15.0 ± 0.36 (range: 12–18)	14.0 ± 0.6 (range: 11–17)
Gender	Boys: 15; girls: 17	Boys: 6; girls: 15	Boys: 7; girls: 6
Height, cm	161.0 ± 1.1	161.2 ± 1.6	150.0 ± 3.0*
Weight, kg	54.0 ± 1.2	53.2 ± 2.3	46.1 ± 2.2*
BMI, kg/m^2	20.8 ± 0.3	20.6 ± 0.9	20.5 ± 0.8
Angle of the main curve of the deformity, °	–	51.3 ± 3.3	61.5 ± 4.9
Angle of the compensatory curve of the deformity, °	–	34.0 ± 4.7 $n = 10$	52.6 ± 5.0* $n = 9$

* Significant difference from the indicators of healthy adolescents, $p < 0.05$. BMI: body mass index.

with congenital scoliosis (p = 131). The compensatory curve was <35% (p = 0.016).

Adolescents with idiopathic scoliosis did not have any motor, reflex, or sensory disorders. Various vertebral changes at the deformity apex were determined (computed tomography), namely, vertebral body deformity, thinning of the arches, and rotation. The spinal canal dimensions were not reduced, and there was no compression of its structures. The main deformity curve was located at the vertebral Th_7–Th_{12} levels, and the compensatory curve was located at the vertebrae L_1–L_3 levels.

The study of adolescents with congenital spinal deformities revealed various developmental vertebral abnormalities, including wedge- and butterfly-shaped vertebrae, semivertebrae, and block vertebrae, as well as vertebral segmentation and developmental disorders. Of the 13 patients, 7 were diagnosed with scoliosis, 4 had kyphoscoliosis with a leading scoliotic component, and 2 had kyphosis.

There were no intracanal abnormalities in patients with congenital scoliosis. The main curve of the spinal deformity was located at the Th_6–L_4 vertebral levels and the compensatory curve was at the Th_9–L_3 vertebral levels. Movement disorders were registered in 3 (21%) patients, including lower monoparesis on the right and lower spastic paraparesis.

We analyzed the changes in the sensory and motor sphere status in the immediate postoperative period (after 6–21 days, on average after 11.2 ± 0.9 days) to study the delayed responses of the sensorimotor system of adolescents after spinal deformity corrections.

During the study, the amplitudes of motor (M-responses) and reflex (H-reflexes) potentials were evaluated, as well as interference electromyogram (EMG) at the maximum voluntary muscle tension of the lower extremities. EMG was examined according to the design developed by A.P. Shein [20], using the Viking EDX digital system (Natus Medical Incorporated, USA). Previously published data [22] were used as the norm (control group).

The temperature and pain sensitivity was determined in Th_1–S_2 dermatomes using an electric esthesiometer (thermistor manufactured by EPCOS Inc., Germany). The control group consisted of 32 healthy adolescents aged 11–17 years.

Adolescents with spinal deformity underwent surgical correction. One-stage spinal deformity correction and stabilization were performed using transpedicular fixation systems during the surgical intervention. Spinal osteosynthesis was performed according to the Cotrel-Dubousset Instrumentation concept, and the level of fixation depended on the Lenke type of scoliosis.

The ISIS IOM system (Inomed Medizintechnik GmbH, Germany) was used to perform intraoperative neuromonitoring with the registration of motor evoked potentials (MEPs) of the lower extremity muscles upon stimulating the corresponding projection zones of the motor cortex [23].

Statistical result processing was performed using the Microsoft Excel 2010 program, the AtteStat add-on (Russia), and the Statistical Package for the Social Sciences program (SPSS Inc., Chicago, Illinois, USA). The studied data distribution normality was tested using the Shapiro–Wilk and Kolmogorov–Smirnov tests. The significance of changes in a normal type of distribution was assessed using the Student's parametric t-test, after evaluating the condition for equality of variances using Levene's test. The nonparametric principle of statistical processing was used in the absence of a normal distribution. The rate of recurrence (%, f) of different variants of the pyramidal system reaction to the spinal deformity correction was calculated as the ratio of the number of cases (n) of different neuromonitoring variants to the total number of cases (N). The significance of the differences between them was evaluated using the Z-test for the difference in shares and the χ^2 test. The critical level of significance was equal to 0.05 when testing the statistical results.

RESULTS

A magnitude analysis of the deformity correction showed that the reduction in deformity in the main and compensatory curves was 77.8% ± 4.0% and 72.0% ± 5.2%, respectively, in idiopathic scoliosis, (Table 2). The amount of correction was lower, with 52.0% ± 5.9% and 48.0% ± 6.5% in the main and compensatory curves, respectively, in adolescents with congenital spinal deformities (Table 3).

High-amplitude and well-reproducible MEPs were obtained in all patients at the beginning of the surgical

Table 2. Values of spinal deformity correction in adolescents with idiopathic scoliosis ($M \pm m$, n = 21)

Parameter	Before treatment	After treatment	Magnitude of change, %
Angle of the main curve of deformity, °	51.3 ± 3.3 (35–85)	12.7 ± 2.9* (0–50) p = 0.00006	77.8 ± 4.0 (25–100)
Angle of the compensatory curve of deformity, °	34.0 ± 4.7 (15–65)	10.6 ± 3.5* (3–40) p = 0.0051	72.0 ± 5.2 (39–88)

* Significance of difference from the preoperative level, p < 0.05.

Table 3. Values of spinal deformity correction in adolescents with congenital spinal deformities ($M \pm m$, $n = 13$)

Parameter	Before treatment	After treatment	Magnitude of change, %
Angle of the main curve of deformity, °	61.5 ± 4.9 (40–81)	30.0 ± 4.1* (11–60) *p* = 0.0004	52.0 ± 5.9 (20–77)
Angle of the compensatory curve of deformity, °	52.6 ± 5.0 (35–80)	28.4 ± 5.1* (15–61) *p* = 0.0054	48.0 ± 6.5 (24–77)

* Significance of difference from the preoperative level, $p < 0.05$.

intervention, which was used as a basic level of the spinal tract condition. Figure 1 presents variants of MEP changes during surgical spinal deformity corrections.

The diagram illustrates that an uneventful course of surgery prevailed ($p > 0.05$) without significant changes in MEP relative to the baseline in the group of patients with idiopathic scoliosis compared with patients with congenital deformities ($p > 0.05$).

This response variant does not indicate the occurrence of danger for the spinal tracts but may be a precursor of a hazardous situation [24]. The number of cases of a dangerous decrease in MEP in both comparison groups did not exceed 10%, without statistically significant differences ($p > 0.05$) (Fig. 1). The surgeon's actions were adjusted in such situations [23, 24]. Not a single case of clinical manifestation of newly acquired motor deficit was revealed in the analyzed sample after the end of the surgery.

The sensorimotor system response evaluation of adolescents with idiopathic scoliosis to the spinal deformity correction in the postoperative period demonstrated the ambiguity of the extent of motor and sensory sphere changes.

The analysis of the neuromuscular system responses to the spinal deformity correction revealed an insignificant change. There was an increase in the amplitude of M-responses of *m. rectus femoris* (4%, $p = 0.008$), *m. flexsor digitorum brevis* (7%, $p = 0.001$), and *m. gastrocnemius* (5%, $p = 0.008$) (Table 4).

Changes in the total EMG amplitude of *m. tibialis anterior*, *m. gastrocnemius*, and those of total EMG frequencies of *m. rectus femoris* and *m. tibialis anterior* was not registered. A significant decrease was found in the total EMG amplitude of *m. rectus femoris* (15.4%, $p = 0.005$) and the frequency of *m. gastrocnemius* (9%, $p = 0.042$). The amplitude of H-reflexes in the postoperative period corresponded to the initial level. Thus, it was 4.9 ± 0.6 mV preoperative and 5.0 ± 0.6 mV postoperative in *m. gastrocnemius*. The study on *m. soleus* revealed that the postoperative amplitude of H-reflexes (6.7 ± 1.1 mV) did not significantly differ from the preoperative level (6.2 ± 0.9 mV, $p = 0.21$).

The study on the change of temperature and pain sensitivity indicators in adolescents with idiopathic scoliosis

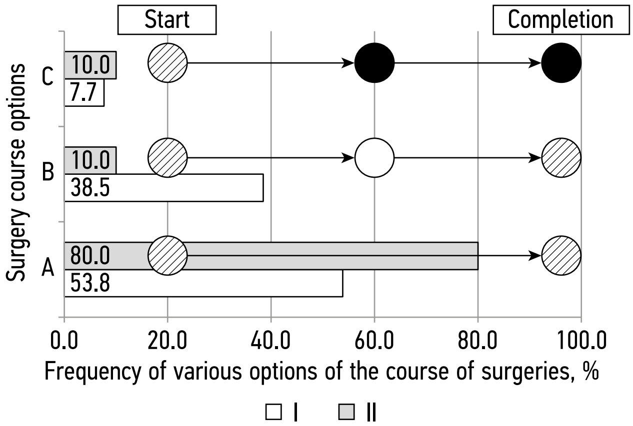

Fig. 1. Changes in motor evoked potentials (MEPs) during surgical spinal deformity correction in patients with congenital deformity (I) and idiopathic scoliosis (II). The abscissa axis is the frequency (%) of various surgical options. The ordinate axis presents surgical options: A) uneventful course of surgical intervention; B) emergence of unstable MEPs in form and characteristics; C) dangerous decrease in MEP amplitude. Hatching indicates high-amplitude stable basic MEPs and responses that remained at the base level at the end of the surgery. The white color indicates unstable MEPs in form and characteristics. The black color indicates a critical decrease in the MEP amplitude

registered pronounced responses of this sensory system. Thus, the analysis of thermal sensitivity on average for the sample showed a decrease in cases of normal (54.1%, from 15.7% ± 3.6% to 7.2% ± 2.8%, $p = 0.0001$) and increased (20%, from 48.5% ± 3.7% to 39.0% ± 2.3%, $p = 0.008$) thresholds. An increased number of thermoanesthesia cases was noted (52.1%, from 35.5% ± 2.1% to 54.0% ± 3.1%, $p = 0.000002$). The thermal sensitivity improvement prevailed only in three dermatomes (Th_1, Th_3, and Th_7). The deterioration of indicators prevailed in other dermatomes (Fig. 2). This was especially pronounced in the Th_9–L_1 dermatomes (zone of the main and compensatory curves of deformity and surgical intervention). The predominance of negative changes is also confirmed by an increased threshold of thermal sensitivity by an average of 1.1° ± 0.1° for the sample (from 39.2° ± 0.4° to 40.3° ± 0.4°, $p = 0.0001$).

Changes in pain sensitivity on average for the sample revealed a decreased number of cases of normal thresholds

Table 4. M-response amplitude and total electromyography of lower limb muscles in adolescents with idiopathic scoliosis before and after deformity correction ($M \pm m$)

Muscles	Amplitude of M-responses, mV			Indicators of total electromyography			
				before correction		after correction	
	control group	before correction	after correction	amplitude, mV	frequency, turn/s	amplitude, mV	frequency, turn/s
M. rectus femoris	21.7 ± 0.7 *n* = 32	19.6 ± 0.6 2*n* = 36	20.4 ± 0.5* 2*n* = 36 *p* = 0.008	0.38 ± 0.03 2*n* = 40	252.0 ± 13.0 2*n* = 32	0.32 ± 0.03* 2*n* = 40 *p* = 0.005	276.0 ± 19.0 2*n* = 32 *p* = 0.083
M. tibialis anterior	7.7 ± 0.3 *n* = 32	8.6 ± 0.3 2*n* = 36	8.6 ± 0.3 2*n* = 36	0.47 ± 0.02 2*n* = 40	368.0 ± 16.0 2*n* = 32	0.50 ± 0.03 2*n* = 40 *p* = 0.21	357.0 ± 18.8 2*n* = 32 *p* = 0.176
M. extensor digitorum brevis	10.6 ± 0.7 *n* = 32	8.3 ± 0.5 2*n* = 36	8.7 ± 0.5 2*n* = 36	–	–	–	–
M. flexsor digitorum brevis	17.0 ± 1.1 *n* = 32	19.3 ± 0.8 *n* = 38	20.6 ± 1.0* *n* = 38 *p* = 0.001	–	–	–	–
M. gastrocnemius	31.5 ± 1.2 *n* = 32	30.0 ± 1.3 2*n* = 36	31.4 ± 1.2* 2*n* = 36 *p* = 0.008	0.22 ± 0.02 2*n* = 40	358.4 ± 20.0 *n* = 32	0.23 ± 0.02 *n* = 40	325.8 ± 16.8* 2*n* = 32 *p* = 0.042

* Significant difference from the preoperative level, $p < 0.05$. 2*n* is the number of limbs. Turn is a change in the curve direction on the electromyogram with a curve amplitude of at least 100 μV.

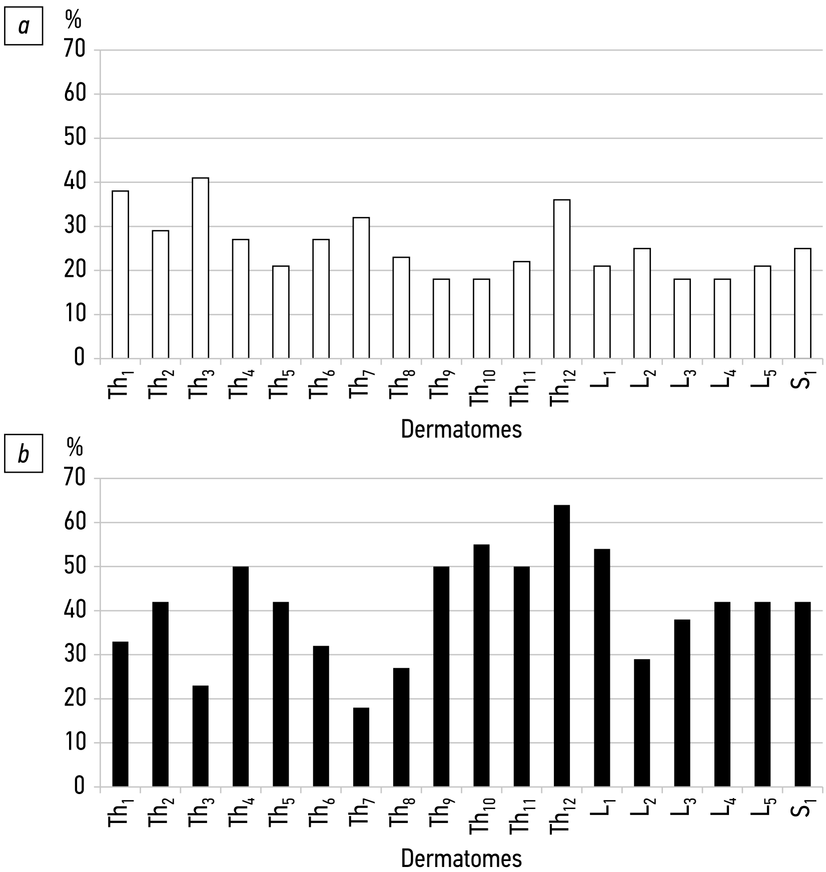

Fig. 2. Thermal sensitivity (%) improvement (*a*) and deterioration (*b*) in adolescents with idiopathic scoliosis 12.0 ± 1.2 days after surgical spinal deformity correction

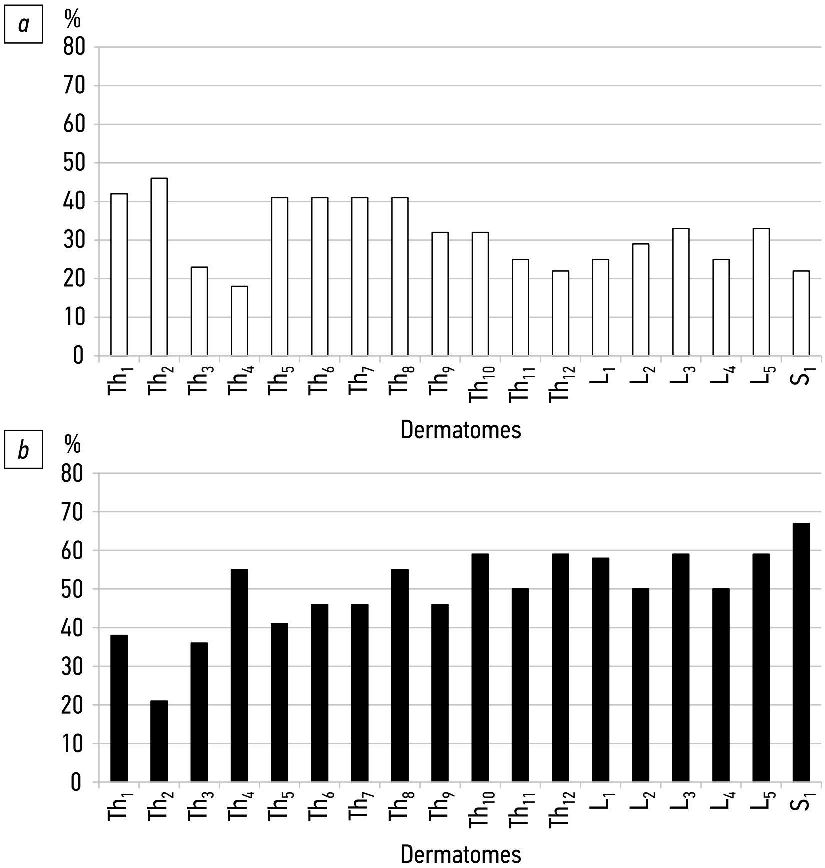

Fig. 3. Positive (*a*) and negative (*b*) pain sensitivity changes in adolescents with idiopathic scoliosis 12.0 ± 1.2 days after surgical spinal deformity correction

(34.5%, from 29.0% ± 3.3% to 19.0% ± 3.1%, $p = 0.001$), as well as an increased number of cases of elevated thresholds (16.7%, from 63.0% ± 4.9% to 73.5% ± 5.6%, $p = 0.0004$). The volume of reduced thresholds remained (8.4% ± 2.4% pre-treatment and 5.9% ± 2.2% post-treatment, $p = 0.13$).

Pain sensitivity improvement prevailed in the Th_1 and Th_2 dermatomes; while positive and negative changes were in the same proportions in the Th_5 dermatome (Fig. 3). The negative change in indicators prevailed in other dermatomes (43%–67% of cases). An increased pain sensitivity threshold was also registered by 1.0° ± 0.1° on average for the sample (from 43.7° ± 0.4° to 44.5° ± 0.5°, $p = 0.0001$).

Thus, the change of the M-response amplitude of *m. rectus femoris*, *m. flexsor digitorum brevis*, and *m. gastrocnemius* was unpronounced in the immediate period after deformity correction in adolescents with idiopathic scoliosis. The total EMG amplitude of *m. rectus femoris* and the frequency of *m. gastrocnemius* significantly decreased. There were no changes in the total EMG amplitude of *m. tibialis anterior* and *m. gastrocnemius*, the total EMG frequencies of *m. rectus femoris* and *m. tibialis anterior*, and the amplitude of H-reflexes.

Negative temperature and pain sensitivity changes were detected at the subclinical level in most of the studied dermatomes, and there were no changes in the neurological status.

The analyses of the neuromuscular system changes after the deformity correction revealed a decreased total EMG amplitude of *m. rectus femoris* (by 21%, $p = 0.0046$) (Table 5), as well as an increased M-responses of *m. flexsor digitorum brevis* (by 11.5%, $p = 0.0033$) and *m. gastrocnemius* (by 19.2%, $p = 0.016$) in adolescents with congenital spinal deformities, as well as idiopathic scoliosis, although these changes were more pronounced than in idiopathic scoliosis.

There were no significant changes in other indicators. The h-reflex amplitude of *m. gastrocnemius* did not significantly differ before and after deformity correction (6.3 ± 0.8 mV and 6.4 ± 0.9 mV, respectively). Temperature and pain sensitivity changes revealed an increased number of cases of normal thermal sensitivity thresholds by 96% (from 6.8% ± 3.0% to 13.3% ± 3.6%, $p = 0.001$).

The volume of elevated thermal sensitivity thresholds remained at the preoperative level (38.3% ± 3.3% before surgery and 35.2% ± 1.7% after surgery, $p = 0.177$), as well as the proportion of thermoanesthesia, with 55.0% ± 3.0% before surgery and 50.6% ± 3.6% after surgery ($p = 0.14$). The thermal sensitivity threshold did not significantly change on average for the sample, as it was 40.9° ± 0.6° before treatment and 40.4° ± 0.6° after treatment ($p = 0.55$).

Table 5. M-response amplitude and total electromyography of lower limb muscles in adolescents with congenital deformities before and after deformity correction ($M \pm m$)

Muscles	Amplitude of M-responses, mV			Indicators of total electromyography			
				before correction		after correction	
	control group	before correction	after correction	amplitude, mV	frequency, turn/s	amplitude, mV	frequency, turn/s
M. rectus femoris	21.7 ± 0.7 *n* = 32	19.5 ± 0.9 2*n* = 24	18.1 ± 0.7 2*n* = 24 *p* = 0.61	0.377 ± 0.04 2*n* = 24	377.9 ± 20.1 2*n* = 14	0.299 ± 0.03* 2*n* = 24 *p* = 0.0046	348.2 ± 16.3 2*n* = 14 *p* = 0.077
M. tibialis anterior	7.7 ± 0.3 *n* = 32	8.8 ± 0.4 2*n* = 24	9.4 ± 0.6 2*n* = 24 *p* = 0.117	0.440 ± 0.04 2*n* = 24	413.0 ± 46.1 2*n* = 14	0.418 ± 0.04 2*n* = 24 *p* = 0.076	414.3 ± 45.2 2*n* = 14 *p* = 0.49
M. extensor digitorum brevis	10.6 ± 0.7 *n* = 32	7.5 ± 0.8 *n* = 22	7.5 ± 1.0 *n* = 22	–	–	–	–
M. flexsor digitorum brevis	17.0 ± 1.1 *n* = 32	17.4 ± 2.1 2*n* = 22	19.4 ± 2.1* 2*n* = 22 *p* = 0.0033	–	–	–	–
M. gastrocnemius	31.5 ± 1.2 *n* = 32	24.0 ± 2.5 2*n* = 24	28.6 ± 2.0* 2*n* = 24 *p* = 0.016	0.273 ± 0.03 *n* = 22	359.0 ± 40.2 2*n* = 14	0.250 ± 0.04 2*n* = 22 *p* = 0.226	310.0 ± 40.1 2*n* = 14 *p* = 0.104

* Significant difference from the preoperative level, $p < 0.05$. Turn is a change in the curve direction on the electromyogram with the curve amplitude of at least 100 μV.

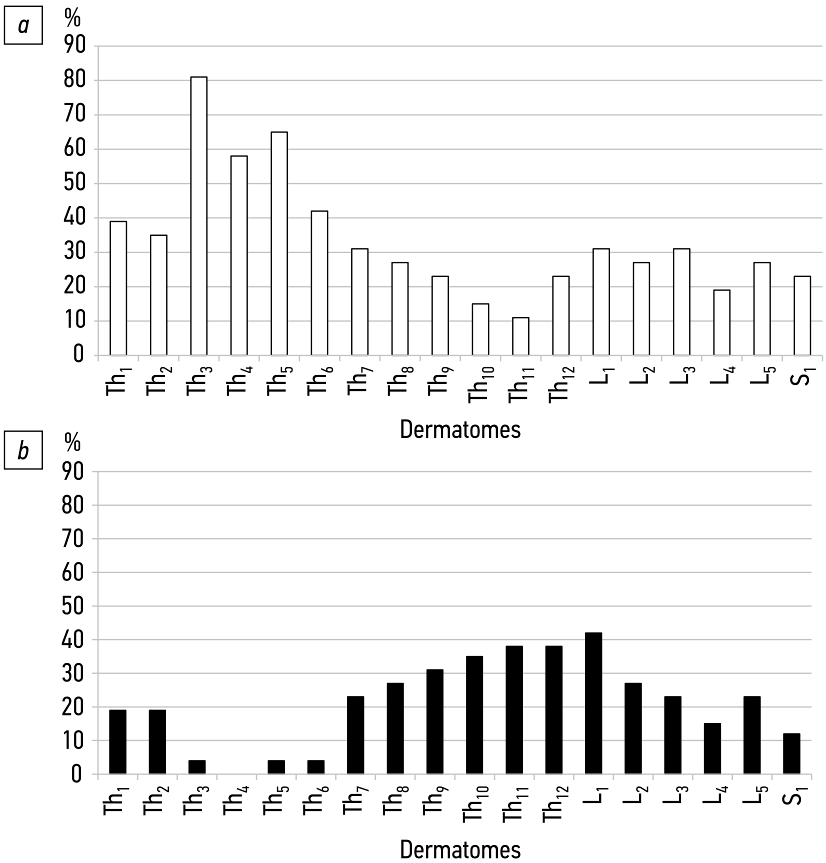

Fig. 4. Proportion (%) of positive (*a*) and negative (*b*) changes in thermal sensitivity of adolescents with congenital spinal deformities 10.0 ± 0.7 days after surgical spinal deformity correction

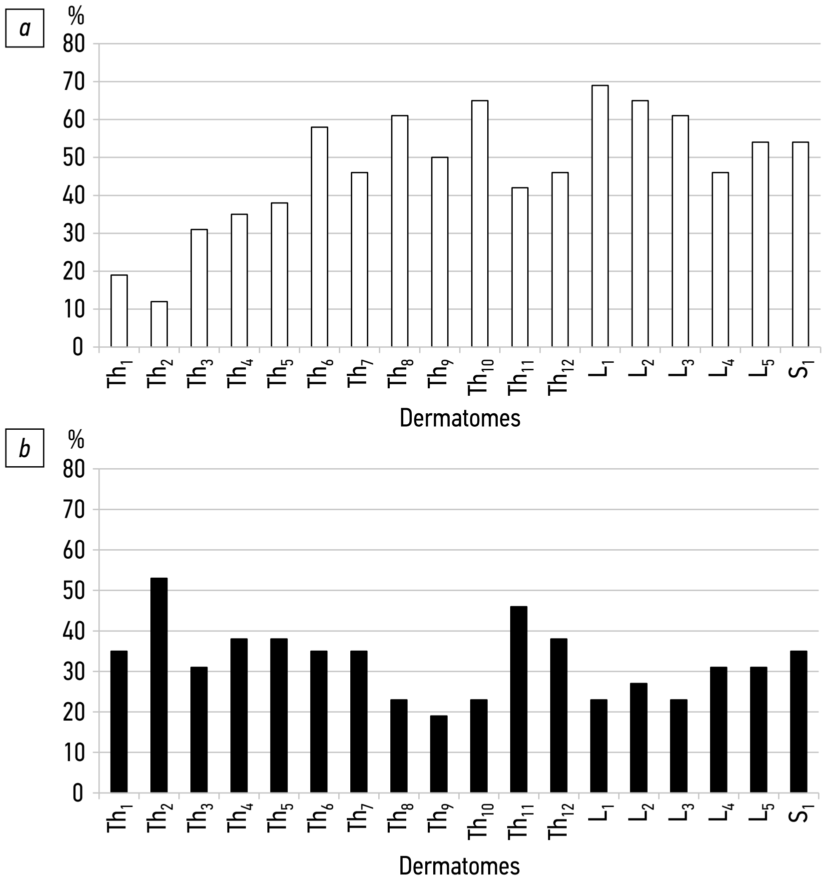

Fig. 5. Positive (*a*) and negative (*b*) pain sensitivity changes (%) in adolescents with congenital spinal deformities 10.0 ± 0.7 days after surgical spinal deformity correction

The dynamics of positive and negative thermal sensitivity changes in different dermatomes can be registered in antiphase (Fig. 4). Thus, the improvement prevailed in Th_1–Th_7 dermatomes (Fig. 4*a*). Negative changes were minimal (Fig. 4*b*). The parity of negative and positive changes was registered in the Th_8 dermatome. The deterioration of thermal sensitivity prevailed from the Th_9 to L_1 levels (area of the main and compensatory curves of deformity and surgical intervention). The same values of multidirectional changes were recorded in the L_2 and S_2 dermatomes. Positive changes prevailed in L_3, L_4, L_5, and S_1.

A characteristic feature of pain sensitivity changes in the postoperative period was an increase by 3.6 times in the proportion of dermatomes with hyperesthesia (from 3.3% ± 1.6% to 15.3% ± 3.3%, $p = 0.0002$). The number of cases of normal thresholds decreased by 42% (from 18.2% ± 4.3% to 10.5% ± 2.8%, $p = 0.013$). The decreased proportion of dermatomes with elevated thresholds was minimal (by 6%, from 78.2% ± 6.05% to 73.6% ± 5.4%, $p = 0.012$). A predominantly positive change of pain sensitivity was registered in the area of dermatomes from Th_6 to S_2 (Fig. 5). The increased proportion of dermatomes with decreased thresholds most probably determined the average decrease in the pain sensitivity threshold by 1.1° ± 0.09° in the sample (from 46.0° ± 0.5° to 44.9° ± 0.5°, $p = 0.00000000022$).

Thus, a decreased total EMG amplitude of *m. rectus femoris* was registered, as well as an increased M-responses of *m. flexsor digitorum brevis* and *m. gastrocnemius*, in the immediate period after surgical deformity correction in adolescents with congenital spinal deformities. There were no significant changes in other muscle activation parameters. A predominant improvement in temperature and pain sensitivity was noted in most of the studied dermatomes.

In conclusion, similar changes in the activation characteristics of muscles occurred in adolescents with idiopathic scoliosis and congenital spinal deformities in the immediate period after surgical deformity correction, which were more pronounced in congenital scoliosis.

However, the revealed changes in the sensory aspect of temperature and pain sensitivity in these two groups of adolescents were opposite: 1) deterioration in indices prevailed in idiopathic scoliosis, and 2) improvement prevailed with congenital spinal deformity. Temperature and pain sensitivity indicators changed at the subclinical level because there were no dynamics in the neurological status of adolescents. However, delayed postoperative negative responses to the sensitive aspect may be prerequisites for possible neurological disorders.

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DISCUSSION

The analysis of various literature sources revealed a small number of objective instrumental studies of the sensorimotor system of adolescents with idiopathic scoliosis after surgical correction of spinal deformity [19, 20, 25]. The functional capabilities of the pyramidal structures of the spinal cord [20], various characteristics of voluntary and evoked bioelectrical activity of the lower limb muscles [19, 20], characteristics of changes in paraspinal muscle EMG parameters [19, 26], and temperature and pain sensitivity [21] were analyzed.

Our study revealed that the neuromuscular system responses to the correction of spinal deformity showed an increased M-response amplitude of *m. rectus femoris*, *m. flexsor digitorum brevis*, and *m. gastrocnemius*.

Our study results are confirmed by the findings of other authors who determined that the functionality of the sensorimotor system of the lower extremities improves in 37.8% of cases [20], and the conduction velocity along motor axons increases after spinal deformity correction [19]. An improvement in the functionality of the back muscles was also recorded, and the EMG indicators became more balanced [19, 26].

Cases of decreased amplitude characteristics of the electrical activity of the muscles, which were accompanied or not accompanied by motor disorders, should be paid with heightened attention by a neurologist not only in the postoperative period but also before the next stage of surgical treatment [24].

The analysis of temperature and pain sensitivity thresholds revealed a more pronounced negative reaction at the subclinical level compared to the motor component because of the peculiarities of surgical correction (transpedicular fixation), surgical intervention localization (dorsal approach), sensory conductor and ganglia location, and the scope of spinal deformity correction.

Posterior instrumental transpedicular fixation has several advantages, including a smaller number of vertebral fixation, the possibility of selective correction [27], and adequate deformity correction [28]. However, it has a disadvantage, namely the implementation of only single-stage correction [29]. All maneuvers are reduced to simultaneous distraction traumatic manipulations for the spinal cord [29, 30].

Negative temperature and pain sensitivity changes may be due to single-stage intraoperative spinal traction (derotation maneuver) when indirect spinal cord effects and reactive changes in blood vessels (microvascular ischemic events) can impair the spinal cord functions and structures [31].

The improvement in this type of sensitivity may be because the initially tense and compressed superficial meningeal arteries and some radicular arteries are in more optimal conditions after spinal deformity correction, and this leads to an improved trophism and neural structure functioning.

Literature analysis revealed no information in scientific publications about instrumental studies of the responses of the sensitive and motor aspects in adolescents with congenital spinal deformities.

Our study revealed that changes in the neuromuscular system after the deformity correction were almost the same in patients with congenital spinal deformities as in patients with idiopathic deformity, although the magnitude of the shifts was greater.

The registered changes in the study of temperature and pain sensitivity in adolescents with congenital deformity were predominantly positive, in contrast to the deterioration of this type of sensitivity in idiopathic scoliosis. Notably, the deformity correction value (%) in the group of subjects with idiopathic scoliosis was 48% higher ($p = 0.0004$) than in the absence of significant differences in the initial angle of the main curve of deformity in these groups of adolescents ($p = 0.131$). Correction of the compensatory curve in idiopathic scoliosis was also greater (by 51%, $p = 0.011$) than in congenital deformity.

The reduced rate of deformity correction in congenital pathology may be due to an increased proportion of cases of detected critical MEP changes during intraoperative monitoring, which indicates dangerous changes in the functional state of the spinal cord.

CONCLUSION

The study of responses of the sensorimotor system of adolescents with idiopathic scoliosis and congenital spinal deformities revealed an increased M-response amplitude of *m. rectus femoris*, *m. flexsor digitorum brevis*, and *m. gastrocnemius*, as well as decreased total EMG amplitude of *m. rectus femoris* in the immediate period after surgical treatment. Indicators of H-reflexes remained at the preoperative level.

The responses of the sensitive aspect (temperature and pain sensitivity) were more pronounced than those of the motor component, although at the subclinical level. Changes in groups of adolescents with idiopathic scoliosis and congenital spinal deformities were opposite because negative changes in the indices prevailed in idiopathic scoliosis, and temperature and pain sensitivity improved in congenital deformities. This is because the amount of deformity correction in the group of subjects with idiopathic scoliosis was greater by 48% in the absence of significant differences in the initial angle of the main curve of deformity. Correction of the compensatory curve in idiopathic scoliosis was also greater by 51% than in congenital deformities.

The reduced volume of the deformity correction in congenital deformities may be due to an increased proportion of cases with a critical decrease in the MEP amplitude during intraoperative monitoring.

ADDITIONAL INFORMATION

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Ethical considerations. The research subject was approved at a meeting of the ethics committee of the National Ilizarov Medical Research Center for Traumatology and Orthopedics of the Ministry of Health of the Russian Federation (Kurgan) dated November 13, 2018 No. 4 (59). This work has been conducted following the ethical standards of the Declaration of Helsinki, as amended. All patients or their legal representatives (in case the work described the data of studies involving minors) signed informed consent to the publication of data obtained as a result of the studies, without personal identification.

Author contributions. *E.N. Shchurova* created the study concept and design, wrote the text of the article, and edited the article text. *M.S. Saifutdinov* created the study concept and design, performed statistical processing of the material, wrote the text of the article, and edited the article text. *M.A. Akhmedova* collected and processed the material, and performed statistical processing. *D.M. Savin* collected and processed the material, and edited the article text. *M.A. Bogatyrev* processed the data and analyzed the archival material.

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