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Diagnostic information value of EMG envelope algorithm for superficial paraspinal muscles in postural stereotypes of patients with scoliosis grades III and IV

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Asymmetry of paraspinal muscle tone is incorporated in pathogenesis for spinal deformities having diagnosis information value and it can be hypothesised to be involved in curve aggravation. **Objective** To evaluate diagnostic information value of EMG envelope algorithm for paraspinal muscles in postural stereotypes of patients with scoliosis grades III and IV **Material and methods** Profiles of postural asymmetry (computer optical topography) and bioelectrical tone (EMG envelope algorithm) of paraspinal muscles were reviewed in 115 patients with scoliosis grades III and IV of different etiology using V.D. Chaklin methodology. The patients aged 6 to 32 years with mean age of 16.2 ± 6.14 years. **Results** The sampling population showed normal symmetrical distribution of profiles in the asymmetry of superficial paraspinal muscle tone with evidently asymmetrical distribution of spinal curve. Surgical elimination of spinal deformity resulting in appropriate correction of postural profiles made no statistically significant impact on orthostatics distributing quantitative and qualitative bioelectrical parameters of paraspinal muscles. No contingency and specific differences were observed in paraspinal muscle tone depending on postural asymmetry and etiology of the curve. **Conclusion** The hypothesis that asymmetry of superficial paraspinal muscle tone aggravates with the curve progression is not supported. No correlation between profiles of postural and muscle tone asymmetry was observed in patients with scoliosis grades III and IV. Diagnostic information value of EMG envelope algorithm is patient-specific and be identified in the postural systems that cannot support motor stereotypes using motor programmes without additional compensation muscle activity due to particular circumstances.
Keywords: spine, scoliosis, envelope EMG, profiles of postural and muscle tone asymmetry

INTRODUCTION

Electromyographic recording is one of the main and widespread instrumental methods of objective functional muscular activity control. Being a convenient quantitative measurement, the control of muscular activity by surface electrodes is not invasive and well tolerated by patients [1], but the diagnostic relevance of EMG use in assessing the tonic activity in practical medicine is either forgotten [2, 3], or remains at the level of research [4].

One of the research areas is the use of EMG envelope for paraspinal muscles to assess the severity of back pain [5]. However, if there are no special disagreements in the diagnosis of acute pain, conflicting results are reported in the diagnosis of chronic pain. According to some authors, the increasing manifestations of EMG activity are recorded [6], but according to the others, clear specific patterns of EMG activity are not observed [7].

Another area of research is the search for diagnostic criteria in assessing the disorders in the vertical orientation of the spine [8, 9, 10]. In the field of vertebrology, most authors point out that the priority use of the EMG envelope technique is the evaluation of muscle tone [11, 12], and muscular balance in paravertebral muscles is considered as the norm. With scoliotic deformities, uneven changes occur in the functional features of the muscles of the right and left sides of the trunk, associated with the unequal biomechanical conditions of their performance.

Electromyographic studies have shown that the stretched muscles of the convex side generate higher amplitude of bioelectrical activity than the muscles of the concave side, which are in a state of relative contracture. This contributes to the inclination of the spine in the direction of weakened muscles and creates biomechanical conditions for further spinal deformity progression [13]. In particular, in idiopathic scoliosis of grades I and II, the asymmetry of the electromyographic activity of the paravertebral muscles is more pronounced along the convex side of the deformity curve [14]. The available publications do not provide diagnostic criteria that allow differentiation of the bioelectric activity asymmetries caused by postural needs or pathological processes. If the asymmetric activity of paraspinal muscles is manifested in the early stages of scoliotic deformity and is involved in the pathogenesis of scoliosis formation, then the statement that the progression of the deformity increases the tonic asymmetry of muscles would be true.

The aim of our study was to estimate the diagnostic informative value of EMG envelope of paraspinal muscles in postural stereotypes of patients with scoliosis grades III and IV of various origins.

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MATERIAL AND METHODS

One hundred fifteen patients in the mean age of 16.2 ± 6.14 years (range: 6–32 years) with grade III and IV scoliosis of various etiology (according to V.D. Chaklin) were examined. Twenty three of them had congenital, 76 patients had idiopathic, 3 individuals had combined, 6 neurogenic, and 7 subjects had systemic types of scoliosis. Thirty one patients were examined between 6 and 12 months after the first surgical intervention.

A complex assessment of the shape of the spine and postural parameters of the trunk (frontal profiles of the trunk shape asymmetry) was carried out with computer optical topography (Novosibirsk) in standing position [15]. For this, the patients under examination were positioned in a habitual standing posture on the background of the reference plane, parallel to its surface in a special movable installation.

In orthostatic position, the EMG envelope of the paravertebral muscles was recorded on the third (elite) version of the diagnostic computer system *Rheograf analyzer RGPA-6/12* (Taganrog city), which includes the option of recording superficial electromyograms. The software interface displayed the processed curve of the EMG envelope, representing the averaged values of the amplitude of the oscillations and their root-mean-square deviation (RMS) for 100 values [16]. Depending on the characteristics of the signal received from the electrodes, the sensitivity of the channels was set from the range: 0.5; 1.0; 2.0; 5.0; 10.0; 20.0; 50.0; 100.0; 200 μV/cm at a recording speed of 60 mm/sec.

In orthostatic position, the EMG envelope was recorded paravertebral with respect to the palpable vertebrae C7, T2, T4, T6, T8, T10, T12, L1, L2, L3. Surface electrodes with a surface area of 20 mm^2 were used. The distance between the electrodes was 20 mm. Electrodes were mounted in a plastic frame, so that the distance between them did not change, and there was a uniform pressure on the muscle. The frame was attached to the skin with an adhesive plaster. The lead electrodes were located on the skin surface on the right and left sides at a distance of 4-5 cm from the vertebrae. The results were digital and graphical. Normally, the amplitude of the EMG envelope of paravertebral muscles is 1-10 μV, and asymmetry is possible up to 25 % [1]. To characterize the paravertebral tonic activity profiles, the asymmetry coefficients (KA) of the amplitude values of the EMG envelope were determined by the formula:

$$KA,\% = \frac{\mathrm{dex}(C_7 + T_2 + \cdots + L_3) - \mathrm{sin}(C_7 + T_2 + \cdots + L_3)}{\mathrm{dex}(C_7 + T_2 + \cdots + L_3) + \mathrm{sin}(C_7 + T_2 + \cdots + L_3)} \times 100, \quad (1)$$

where dex, sin ($C_7 + T_2 + \ldots + L_3$) – is the sum of the averaged values of the amplitudes of the paravertebral muscle activity recorded on the right or left at the level of the corresponding vertebrae. The positive KA values reflect the right-side dominance of the tonic profile of the asymmetry, and the negative values of KA are left-sided.

When analyzing the EMG envelope values, the bioelectric activity of paravertebral muscles in each patient was assessed qualitatively and quantitatively. Traditionally used qualitative evaluation criteria were correlated by comparison of such activity with normative values. They were characterized by the following combinations from a combination of characteristics. Namely, the tonic bioelectrical activity and the asymmetry amplitude correspond to the values of the norm; only a decrease in the total electrical activity of the muscles or only an increase in the functional state of the neuromotor apparatus is recorded; irritative damage to peripheral motor neurons is observed; tonic activity corresponds to the normal values for right- or left-sided asymmetries of more than 25 %; right- and left-side asymmetries are combined with a decrease in the total electrical activity of the muscles or with an increase in the functional state of the neuromotor apparatus; irritative damage to peripheral motor neurons is combined with right or left asymmetries.

Quantitative characteristics of bioelectrical activity in orthostatic stereotypes included the calculation of the asymmetry coefficients of the bioelectrical activity profiles in paravertebral muscles. The postural (topographic) asymmetry profiles (side of deformity) were compared with tonic asymmetry profiles from the RMS mean values of the EMG envelope by comparing the right- and left-side values and calculating the asymmetry coefficient (KA) by the formula (1).

Statistical processing of the material was carried out using Microsoft EXEL-2007 and AtteStat data analysis packages [17]. We used correlation and regression analysis, parametric methods of variation and descriptive statistics with calculation of the arithmetic average, standard deviation – σ, coefficient of variation – CV. The normality of the distribution was evaluated by the asymmetry criteria, kurtosis, Kolmogorov-Smirnov, and the reliability of the differences by Fisher's F-criterion, the Student's t-test and the χ^2-test.

RESULTS

The informative analysis of the superficial paravertebral muscle bioelectric activity using the EMG envelope was conducted based on the results of the distribution of their qualitative characteristics (**Table 1**).

By the first approximation, even visually, with significant differences in the samples compared parame-

ters, the percentages of the occurrence of the signs did not differ noticeably. Statistical instrumental assessment of the proportions of this distribution in patients before and after surgical treatment confirmed the validity of this observation. As a result of the use of the χ^2 test with a threshold level $p < 0.01$, the following values were obtained: $\chi^2 = 0.561$, $\alpha\chi^2 = 3.57$, i.e. the frequency of occurrence of qualitative signs of bioelectrical activity of paravertebral muscles in patients before and after surgery did not have statistically significant differences. And, consequently, the diagnostic informative value of the qualitative characteristics of the bioelectrical activity of these muscles in the combination and form studied did not appear even after such a powerful effect as surgical correction of the spine. In addition, the asymmetric distribution of such a qualitative feature, no less important in the postural organization, as the right- or left-side deformity was not always consistent with the distribution of asymmetry profiles of the bioelectric tone of paravertebral muscles (**Fig 1** and **2**).

According to the literature, the increase in total values (μV) in patients with idiopathic scoliosis of grades I–II is larger on the convex side of the curve [14], but according to our data, the distribution of bioelectric activity profiles of paravertebral muscles in amplitude of the EMG envelope in patients with grades III–IV scoliosis was 57 % for the right- and 43 % for left-side dominance, and in the RMS of the EMG envelope it was 62 % and 38 %, respectively. According to computer optical topography in postural stereotypes the right-sided location of the apex of the scoliotic deformity curve prevailed in C-shaped scoliosis in 89 % and in S-shaped scoliosis in 91 % of cases, which agrees with the literature data obtained on large selective series of idiopathic scoliosis [19, 20]. This means that the percentage of discrepancies along the sides between the profiles of the main deformity arc and the bioelectrical tone asymmetry profiles of the paravertebral muscles was 33 % in the amplitude of the EMG envelope, and 28 % in the RMS of the EMG envelope. In addition, four patients, who were examined twice after the surgical treatment with an interval of one month revealed significant and diametrically opposite changes in the asymmetry profile of the bioelectric tone of the superficial paraspinal muscles.

The results of quantitative assessments of the bioelectric asymmetry profiles of the paravertebral muscles in terms of amplitude and RMS of the EMG envelope are presented in Table 2. With the increase in the volume of population sample $\overline{X}$, the amplitude of the EMG decreases; with an increase in the number of observations, the number of right- and left-sided profiles in the sample sets is equalized, and, consequently, we are dealing with a t-distribution, which in the general mass, must definitely approach "normal" with an increase in the sample size [18].

Table 1

Frequency of detection of qualitative signs of bioelectrical activity in the paravertebral muscles according to the amplitude of the EMG envelope in patients with scoliosis of grades III–IV

Qualitative signs	Frequency of detection, %	
	Before surgery (n = 84)	After surgery (n = 31)
Tonic activity and asymmetry amplitude correspond to normal values	19.0 % (16 subjects)	16.1 % (5 subjects)
Tonic activity corresponds to normal values, asymmetry more than 25 % D > S	4.7 % (4 subjects)	9.6 % (3 subjects)
Tonic activity corresponds to normal values, asymmetry more than 25 % S > D	4.7 % (4 subjects)	9.6 % (3 subjects)
Bilateral decrease in total electric activity of muscles	4.7 % (4 subjects)	9.6 % (3 subjects)
Combination of decrease in total electric activity of muscles and right-side asymmetry	1.2 % (1 subject)	0
Combination of decrease in total electric activity of muscles and left-side asymmetry	2.4 % (2 subjects)	3.2 % (1 subjects)
Bilateral increase in the functional state of neuromotor apparatus	25.0 % (21 subjects)	19.4 % (6 subjects)
Combination of increase in the functional state of neuromotor apparatus and right-side asymmetry	8.3 % (7 subjects)	6.4 % (2 subjects)
Combination of increase in the functional state of neuromotor apparatus and left-side asymmetry	7.1 % (6 subjects)	12.9 % (4 subjects)
Irritative damage to peripheral motoneurons	10.7 % (9 subjects)	9.6 % (3 subjects)
Combination of irritative damage to peripheral motoneurons and right-side asymmetry	8.3 % (7 subjects)	3.2 % (1 subject)
Combination of irritative damage to peripheral motoneurons and left-side asymmetry	3.6 % (3 subjects)	0

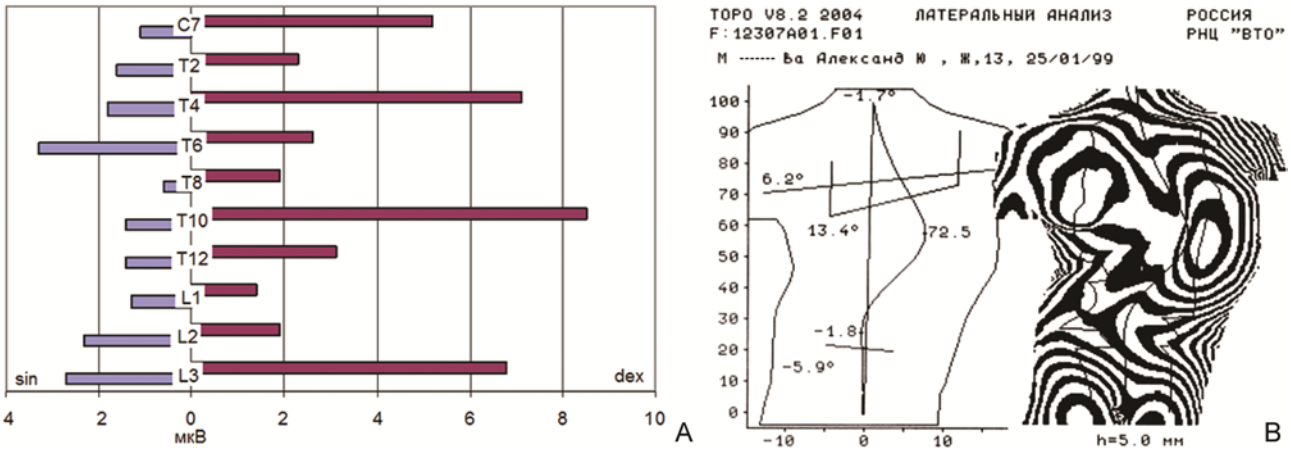

Fig. 1 Patient M., 13 years old. Systemic thoracolumbar kyphoscoliosis of grade IV (according to V.D. Chaklin) associated with neurofibromatosis type I. According to the radiography data, the apex is Th2–3, the angle of 42º is open to the right; Th11 – 120º open to the left; L4 – 75º, open to the right. Graphical display of the EMG envelope of the paravertebral muscles: **A** functional state of the neuromotor apparatus corresponds to the normal values, but the asymmetry of the EMG envelope values is 57.1 % D > S (an increase on the side of the curvature apex); **B** grade IV scoliosis in the topogram in frontal view, a rotated vertebra in horizontal view (pronounced twisting), other disorders in the sagittal one

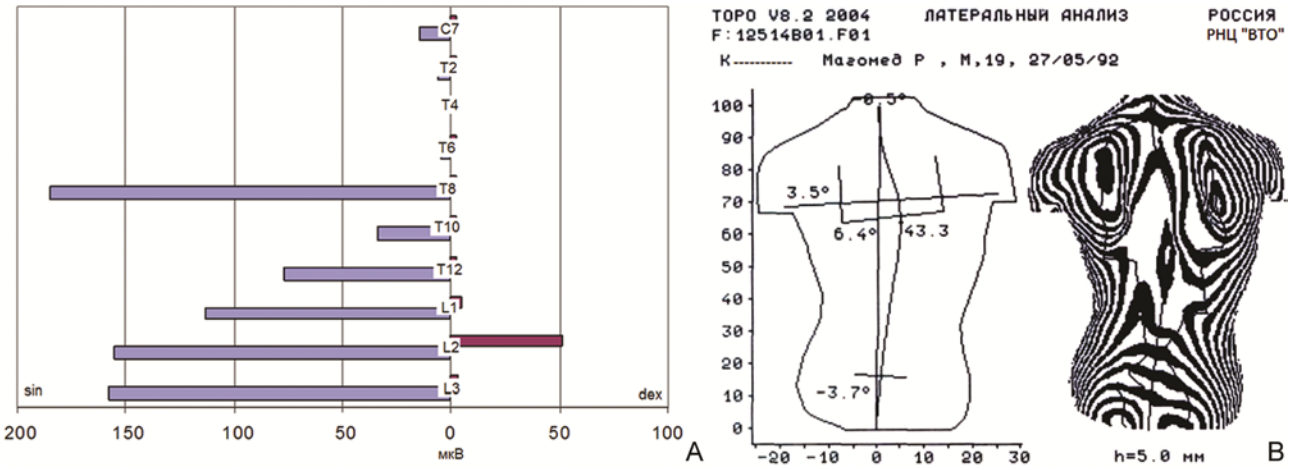

Fig. 2 Patient K., 19 years old. Idiopathic scoliosis of the thoracic spine in grade III (according to V.D. Chaklin). Radiographs detected the apex at Th8–9, with the angle angle 45º open to the right. Graphical representation of the values of the EMG envelope of the paravertebral muscles: **A** asymmetry of the values of 89.8 % S > D; pathological manifestation of muscle activity at rest at the level of the lumbar spine; amplitude of potentials of fasciculations of 150–170 μV is typical for the irritic damage to peripheral motoneurons. **B** Topogram in frontal projection shows grade III scoliosis, in horizontal projection – rotated posture (moderate twisting), flat back (deformity of the spine) in sagittal one

Table 2

Parameters of asymmetry profiles of bioelectrical activity of paravertebral muscles in patients with scoliosis grades III–IV of various etiologies

Etiology	EMG envelope amplitude			RMS of the EMG envelope amplitude		
	$\bar{X}$	Σ	KV	$\bar{X}$	σ	KV
Before surgery						
Idiopathic (n = 52)	2.79	50.9	1824.4	0.05	0.56	1120.0
Congnital (n = 19)	6.99	32.2	460.6	0.04	0.43	1075.0
Neurogenic (n = 4)	49.6	12.3	24.8	0.59	0.28	47.5
Systemic (n = 6)	40.3	24.6	61.0	0.03	0.24	800
Combined (n = 3)	-16.4	41.4	252.4	-0.11	0.81	736.4
Right-side asymmetry	n = 66			n = 71		
	35.8	25.9	72.3	0.37	0.29	78.4
Left-side asymmetry	n = 49			n = 44		
	-33.6	27.3	81.2	-0.42	0.32	76.2
6-12 months after the 1st stage of surgical management						
Idiopathic (n = 24)	12.7	35.7	281.1	0.08	0.48	600.0
Congenital (n = 4)	-10.7	36.1	337.4	-0.22	0.36	163.6

Note: $\bar{X}$ – average arithmetic value of the indicator in the sample; σ is RMS of the asymmetry index in the sample; KV is coefficient of variation of the asymmetry index in the sample

Estimation of the distribution of asymmetry profiles of the paravertebral muscles bioelectrical activity in EMG amplitude in patients before treatment (n = 84) and in patients after surgical treatment (n = 31) with a threshold value of $p < 0.01$ by modified criteria of Kolmogorov, Smirnov, asymmetry and kurtosis (**Table 3**) showed that the hypothesis of normality does not deviate, i.e. the indicators studied follow the "law of normal distribution" before and after surgical treatment.

Despite the differences in the number of observations, the sample sets with right- and left-side profiles of tonic asymmetry practically did not differ in scalar mean values and varied identically. According to Fisher's F-criterion, the following results were obtained: $p = 0.704$ for the asymmetry profiles of the bioelectrical muscle tone by the amplitude of the EMG envelope and $p = 0.487$ for $\alpha = 0.01$by the RMS of the EMG envelope, i.e. not only the scalar values of the mean values turned out to be practically equivalent (**Table 2**), but the null hypothesis about the equality of general variances at the significance level of 0.01 is accepted. The situation with the distribution of the profiles of the tonic asymmetry of the paravertebral muscles according to the RMS amplitude of the EMG envelope was somewhat different, although its derivatives from the amplitude of the value had a strong positive correlation ($r = 0.861$, $n = 2330$, $p < 0.001$) and were most accurately described by the polynomial regression equation of the 2nd grade:

$$Y = -0.0017X^2 + 1.16X-1.79$$

by $n = 2330$, $R^2 = 0.8344$. $p < 0.001$,

where Y is the RMS value of the EMG envelope, X is the value of the amplitude of the EMG envelope at each registration point obtained during post-computer processing of recordings.

Table 3

Calculated values of the distribution normality criteria

Normal distribution tests	Before treatment (n = 84), α = 0.01				After treatment (n = 31), α = 0.01			
	EMG envelope amplitude		RMS of EMG envelope amplitude		EMG envelope amplitude		RMS of EMG envelope amplitude	
	Stat. cr	p	Stat. cr	p	Stat. cr	p	Stat. cr	p
Modified Kolmogorov test	0.058	0.331	0.091	0.091	0.102	0.460	0.132	0.178
Modified Smirnov test	0.039	0.102	0.069	0.211	0.102	0.331	0.132	0.087
Asymmetry coefficient	-0.285	0.138	-0.422	0.054	0.179	0.334	0.425	0.156
Kurtosis	-0.408	0.216	-0.454	0.191	0.295	0.359	-0.186	0.410

Note: Stat. cr – statistics of the criterion, p – statistical significance level

DISCUSSION

The data of the literature show that a marked asymmetry of the electromyographic activity according to the RMS [21] and the amplitude of the EMG envelope of the paravertebral muscles with their greatest activity in the standing position is recorded in grades II to III of idiopathic scoliosis [14, 22]. The assumption that the asymmetry of muscles should increase along with deformity progression was not confirmed. In addition, a statistical analysis of the material obtained showed that the coupling is absent not only in the degrees of asymmetry between the profiles, but also in their distribution.

According to the theory of functional systems, the stability of the orthostatic posture is provided by sensory multilevel integration (visual, vestibular and proprioceptive systems) and motor coordination [23]. To diagnose the state of complex systems, including postural ones, basic principles have been formulated, according to which the most important condition is the identification of the object's (diagnostic) informative parameters [24]. According to the results obtained, the activity parameters of superficial paraspinal muscles do not reflect the essential characteristics of the postural system and those states in which its adaptive role is realized in the form of motor stereotypes. Since no conjugation between the asymmetry profiles was detected, the involvement of superficial paraspinal muscles in adaptive motor stereotypes is not deterministic. Consequently, the activation of these muscles by motor programs is realized randomly according to the residual principle, when due to certain circumstances, the necessary efforts from the deep paravertebral muscles do not meet postural needs. Apparently, for this reason, the distribution of the asymmetry profiles of the bioelectric tone of the superficial muscles before and after surgical treatment remained unchanged both in terms of qualitative and quantitative criteria.

We believe that the organization of orthostatic activity is very individual, and the adaptive profiles of bioelectric asymmetry are more associated with current postural needs than with any pathogenetic mechanisms of spinal deformity. A convincing confirmation of this was the results of patients after surgical treatment of spine pathology: in four patients examined with an interval of one month, the asymmetry profiles of the bioelectrical tone of the paravertebral muscles changed to diametrically opposite, without any visible causes, regardless of deformity location.

In other words, the motor programs that regulate the bioelectrical activity of the muscles analyzed in these patients were not determined by disease pathogenesis but depended on the current postural requirements and simply provided for their adaptation to environmental conditions. Therefore, it is just as wrong to judge about the state of

such a complex postural system by the asymmetries of the activity of individual elements as it is wrong to judge the quality of the image by asymmetries of illumination of several liquid crystals on the monitor. It should be noted that sensory and motor asymmetries are observed everywhere and can be expressed very noticeably as a result of sports specialization, but their manifestations are not the grounds for association of the latter with any pathogenetic mechanisms [25].

Asymmetries are only external characteristic manifestations of life activity, but what mechanisms they are conditioned by, adaptive or pathogenetic, is a matter of a specific individual consideration. According to the literature, various versions of functional tests in the form of dynamic exercises are used that reveal the inconsistency of individual motor stereotypes only in specific patients and are accompanied by compensatory involvement of additional motor elements in the adaptive process [26, 27]. In any case, the search for individual diagnostically informative elements of activity using the EMG envelope lies in the basis of the application of biological feedback for treatment of idiopathic and dysplastic scoliosis of grade I–II [28, 29].

CONCLUSIONS

1. The assumption that the asymmetry of superficial paraspinal muscles tone would aggravate with the curve progression in patients with scoliosis grades III and IV was not supported. Correlation was absent both in asymmetry degrees between the profiles and their distributions before and after surgical treatment.

2. Motor programs that regulate bioelectrical activity of the superficial paraspinal muscles are determined by postural needs and are not associated with pathogenic mechanisms of scoliotic deformities.

3. Evaluation of superficial paraspinal muscle tone with the method of EMG envelope is not informative in the screening for scoliotic deformity detection.

4. Diagnostic informative value of EMG envelope is patient-specific and has a diagnostic value only by individual monitoring using functional tests.

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