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CLINICAL AND FUNCTIONAL EFFICIENCY OF COMPREHENSIVE KINESIOTHERAPY AND NEUROMUSCULAR STIMULATION IN VERTEBROGENIC PAIN SYNDROMES IN CHILDREN

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ABSTRACT

The article presents the results of clinical and functional assessment and effectiveness of complex medical rehabilitation in children with idiopathic scoliosis, muscular torticollis and spina bifida. The aim of the study was to develop and test personalized programs aimed at correcting biomechanical disorders, reducing neurological manifestations and improving the quality of life of patients. The study included 54 children distributed across nosological groups. Validated motor function assessment scales, electromyography data, visual analog scale (VAS) and the PedsQL quality of life questionnaire were used. The analysis revealed pronounced and moderate therapeutic effects from the implementation of a multi-level rehabilitation model, which confirms its clinical validity and the need for an interdisciplinary approach in pediatric rehabilitation.

KEY WORDS: *Medical Rehabilitation, Idiopathic Scoliosis, Muscular Torticollis, Spina Bifida, Myelomeningocele, Children, Electroneuromyography, Quality of Life, Biomechanics, Personalized Approach.*

RELEVANCE

Modern approaches to the rehabilitation of children with congenital and acquired pathologies of the musculoskeletal system require scientifically based systematization taking into account the clinical specifics and functional capabilities of the growing organism [1,2]. In recent years, there has been a steady increase in the number of pediatric patients with conditions such as idiopathic scoliosis, muscular torticollis and spina bifida, which requires increasing the effectiveness of rehabilitation programs adapted to specific clinical and functional characteristics [3,4].

Despite the existing algorithms for rehabilitation treatment, their effectiveness remains ambiguous, especially in terms of a personalized approach, assessment of objective biomechanical and neurophysiological parameters, and assessment of quality of life [5,6]. At the same time, the introduction of instrumental and quantitative methods (electromyography, MRC and PedsQL scales, Romberg test, etc.) opens up new prospects in monitoring the dynamics and adaptation of individual programs [7,8].

Scientific publications of recent years have emphasized the need for comprehensive multidisciplinary rehabilitation models that include not only traditional physiotherapeutic measures, but also an assessment of the psychoemotional status, social functioning, and family participation in the rehabilitation process [9,10].

Of particular relevance is the study of the effectiveness of interventions in children with muscular torticollis and spina bifida, since in these conditions, movement patterns are disrupted, asymmetry is formed, secondary pathology develops in the joints, spine and central nervous system [11,12]. In this regard, comprehensive medical rehabilitation requires an interdisciplinary approach involving pediatricians, neurologists, rehabilitation specialists, orthopedists and psychotherapists [13,14].

Thus, the relevance of this study is due to the need to develop and scientifically substantiate a comprehensive rehabilitation model with a quantitative assessment of clinical effectiveness and with an emphasis on improving the quality of life of children with idiopathic scoliosis, muscular torticollis and spina bifida [15,16].

AIM OF THE RESEARCH

To evaluate the clinical and functional effectiveness of a comprehensive medical rehabilitation program using kinesiotherapy and neuromuscular electrical stimulation in children aged 7–15 years with vertebrogenic pain syndromes compared to standard treatment.

MATERIALS AND METHODS OF THE RESEARCH

The study was parallel, prospective and controlled. The observation period was six weeks. The study involved 97 children aged 7 to 15 years with a diagnosis of mild to moderate vertebrogenic pain syndrome (children with idiopathic scoliosis n=38, with muscular torticollis n=32 and with (spina bifida n=27). All participants were hospitalized in a specialized medical rehabilitation center.

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After the initial assessment, the children were randomly assigned to two groups for each nosology. The main group included 54 children (with idiopathic scoliosis n=21, with muscular torticollis n=18 and with (spina bifida n=16), who underwent complex kinesiotherapy. It included individually selected active exercises and sessions of neuromuscular stimulation based on the use of electromyostimulation. The control group consisted of 43 children with idiopathic scoliosis n=17, with muscular torticollis n=14 and with (spina bifida n=11, undergoing a standard rehabilitation program, including drug therapy, therapeutic exercise classes according to the generally accepted method and prescribed physiotherapeutic procedures. Children were allowed to participate in the study if the following criteria were met: confirmed diagnosis of vertebrogenic pain syndrome based on clinical, neurological and instrumental examination; age from 7 to 15 years; written consent of parents or legal representatives to participate in the study. Children with severe neurological disorders, with established scoliotic deformity of the spine of the third and fourth degree, as well as with epilepsy or other contraindications to neuromuscular stimulation were excluded from the number of participants.

The following methods were used to evaluate the effectiveness of the therapy. The intensity of the pain syndrome was determined using a visual analogue scale. The range of active movements in the cervical and lumbar spine was measured using goniometry. The functional state of the muscular system was assessed based on electroneuromyography data. The level of physical activity was recorded based on the results of a questionnaire adapted for children in accordance with the international system for assessing physical activity. The quality of life was assessed using the Pediatric Quality of Life Assessment Scale. Quality of Life Inventory.

All participants underwent two assessment stages: before the start of the rehabilitation course (baseline assessment), and after completion of the six-week course of therapy.

All data were processed using SPSS Statistics version 26.0 (IBM Corp., Armonk, NY, USA). The distribution of quantitative variables was checked for normality using the Shapiro-Wilk test. For variables with normal distribution, the mean and standard deviation (M ± SD) were calculated. Comparison between groups (main and control) was performed using Student's t-test or Mann–Whitney test depending on the nature of the data distribution. Intragroup analysis (before and after the intervention) was performed using the paired t-test or Wilcoxon test. Cowan's d coefficients and partial η^2 (eta-squared) were used to determine the strength of the effect. The level of statistical significance was set at $p < 0.05$.

RESEARCH RESULTS

As a result of the clinical and functional analysis, data were obtained reflecting the dynamics of the condition of patients with idiopathic scoliosis, muscular torticollis and myelomeningocele (spina bifida) against the background of the use of a comprehensive personalized rehabilitation program. A comparative assessment was carried out on key clinical, biomechanical and psychophysiological indicators before and after the rehabilitation course in the main and control groups. The tables below demonstrate reliable changes in a number of parameters, including the range of motion, severity of pain syndrome, electromyographic activity and quality of life, which allows us to judge the effectiveness of the proposed intervention.

Table 1
Dynamics of indicators in children with idiopathic scoliosis (main group, n=21)

Indicator	Before the intervention	After the intervention	Δ, %	r
Pain intensity (VAS, points)	5.4 ± 1.2	2.1 ± 0.9	-61.1%	p < 0.001
Amplitude of motion (°)	68.5 ± 5.1	82.7 ± 6.4	+20.8%	p < 0.001
EMG activity (μV)	45.6 [39.2–51.3]	59.8 [53.1–66.4]	+31.2%	p < 0.001
Functional index	62.4 ± 7.9	78.3 ± 6.8	+25.5%	p < 0.001

As can be seen from Table 1, there was a statistically significant decrease in the intensity of pain syndrome according to the VAS scale from 5.4 ± 1.2 to 2.1 ± 0.9 points (a decrease of 61.1%; $p < 0.001$), which indicates the effectiveness of the analgesic component of the therapy. The range of motion in the affected segment increased by 20.8% (from 68.5 ± 5.1° to 82.7 ± 6.4°; $p < 0.001$), which reflects an improvement in the flexibility and mobility of the spinal column. Electromyographic (EMG) activity values increased from a median of 45.6 μV [39.2–51.3] to 59.8 μV [53.1–66.4] (an increase of 31.2%; $p < 0.001$), which may indicate the restoration of symmetry and functionality of the back muscles. The functional index also improved, increasing by 25.5% (from 62.4 ± 7.9 to 78.3 ± 6.8; $p < 0.001$), reflecting an overall improvement in physical activity, coordination and quality of life of the patients.

Table 2
Dynamics of indicators in children with idiopathic scoliosis (control group, n=17)

Indicator	Before the intervention	After the intervention	Δ, %	r
Pain intensity (VAS, points)	5.3 ± 1.3	4.7 ± 1.2	-11.3%	p > 0.05
Amplitude of motion (°)	67.9 ± 5.4	71.2 ± 5.9	+4.9%	p > 0.05
EMG activity (μV)	46.2 [38.7–52.0]	49.5 [41.8–56.3]	+7.1%	p > 0.05
Functional index	61.8 ± 8.1	65.2 ± 7.6	+5.5%	p > 0.05

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Analysis of the data presented in Table 2 demonstrates the dynamics of clinical and functional indicators in children with idiopathic scoliosis in the control group (n=17) who received standard therapy.

There is a slight decrease in the intensity of pain syndrome according to the VAS scale - from 5.3 ± 1.3 to 4.7 ± 1.2 points (-11.3%), but this change was statistically insignificant ($p > 0.05$). The amplitude of movements increased by only 4.9% (from 67.9 ± 5.4° to 71.2 ± 5.9°), which also did not reach the level of statistical significance ($p > 0.05$). The increase in EMG activity was 7.1% (from a median of 46.2 μV to 49.5 μV), and the functional index increased by 5.5% (from 61.8 ± 8.1 to 65.2 ± 7.6), but these changes are also not significant ($p > 0.05$). Thus, in the control group, only a tendency towards improvement of the indicators was noted, without a statistically significant effect from the treatment. This emphasizes the importance of introducing personalized rehabilitation programs.

Table 3
Dynamics of indicators in children with muscular torticollis in the main group (n=18)

Indicator	Before the intervention	After the intervention	Δ, %	r
Head tilt amplitude (degrees)	19.2 ± 3.5	34.8 ± 4.2	+81.3%	$p < 0.001$
Pain level according to VAS (cm)	5.6 ± 1.1	2.1 ± 0.9	-62.5%	$p < 0.001$
Asymmetry index of SCM (%)	28.5 ± 4.6	14.3 ± 3.7	-49.8%	$p < 0.001$
Electrical activity of the SCM (μV)	9.8 ± 1.7	6.2 ± 1.2	-36.7%	$p < 0.001$
Neck mobility index (in points)	4.1 ± 0.9	7.3 ± 1.0	+78.0%	$p < 0.001$

Table 3 shows reliable positive dynamics of clinical and functional indicators in children with muscular torticollis of the main group (n=18) after complex intervention. Thus, the amplitude of head tilt increased from 19.2 ± 3.5 ° to 34.8 ± 4.2° (an increase of 81.3%, $p < 0.001$), indicating a significant restoration of the range of motion in the cervical spine. The level of pain on the visual analogue scale (VAS) decreased from 5.6 ± 1.1 cm to 2.1 ± 0.9 cm (a decrease of 62.5%, $p < 0.001$), indicating an effective analgesic effect of the applied rehabilitation.

A significant decrease in the asymmetry index of the sternocleidomastoid muscle (SCM) (from 28.5 ± 4.6% to 14.3 ± 3.7%, a decrease of 49.8%, $p < 0.001$) indicates a significant equalization of muscle tone. The electrical activity of the SCM, reflecting the level of muscle tension, also decreased from 9.8 ± 1.7 to 6.2 ± 1.2 μV (–36.7%, $p < 0.001$), which further confirms muscle relaxation. In addition, the neck mobility index increased from 4.1 ± 0.9 to 7.3 ± 1.0 points (an increase of 78.0%, $p < 0.001$), demonstrating an improvement in the overall functional state of the cervical spine. Thus, the presented data indicate the high efficiency of the applied medical rehabilitation complex in children with muscular torticollis.

Table 4
Dynamics of indicators in children with muscular torticollis in the control group (n=14)

Indicator	Before the intervention	After the intervention	Δ, %	r
Head tilt amplitude (degrees)	18.9 ± 3.4	24.1 ± 3.8	+27.5%	$p > 0.05$
Pain level according to VAS (cm)	5.4 ± 1.2	4.2 ± 1.1	-22.2%	$p > 0.05$
Asymmetry index of SCM (%)	27.8 ± 4.9	23.6 ± 4.5	-15.1%	$p > 0.05$
Electrical activity of the SCM (μV)	9.5 ± 1.9	8.8 ± 1.6	-7.4%	$p > 0.05$
Neck mobility index (in points)	4.0 ± 1.1	4.6 ± 1.0	+15.0%	$p > 0.05$

Table 4 reflects the changes in the functional and clinical parameters in children with muscular torticollis observed in the control group without the use of active rehabilitation methods. The head tilt amplitude increased from 18.9 ± 3.4° to 24.1 ± 3.8°, which corresponds to an increase of 27.5%. Despite the positive dynamics, statistically significant differences were not recorded ($p > 0.05$). The pain level on the visual analogue scale (VAS) decreased from 5.4 ± 1.2 cm to 4.2 ± 1.1 cm (a decrease of 22.2%), but this change also did not reach statistical significance ($p > 0.05$). The sternocleidomastoid muscle (SCM) asymmetry index decreased by 15.1% - from 27.8 ± 4.9% to 23.6 ± 4.5%, indicating a tendency to decrease the severity of muscle imbalance. The SCM electrical activity (EMG) slightly decreased - from 9.5 ± 1.9 μV to 8.8 ± 1.6 μV (–7.4%), which may indicate a partial decrease in muscle tension. The neck mobility index, reflecting the functional capabilities of the cervical spine, increased from 4.0 ± 1.1 to 4.6 ± 1.0 points (+15.0%), but this improvement did not reach the level of statistical significance ($p > 0.05$). In general, children in the control group showed a tendency towards positive dynamics of indicators, but without statistically significant changes, which indicates the limited effectiveness of standard approaches without targeted rehabilitation intervention.

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Table 5
Dynamics of indicators in children with spina bifida (main group, n=16)

Indicator	Before the intervention	After the intervention	Δ, %	r
Pain intensity (VAS), points	5.9 ± 1.1	2.8 ± 0.9	-52.5%	$p < 0.001$
Range of motion (ROM), °	49.3 ± 6.2	65.4 ± 5.9	+32.6%	$p < 0.001$
Muscle strength (MRS scores)	2.4 ± 0.7	3.6 ± 0.6	+50.0%	$p < 0.001$
Electromyography (signal amplitude)	32.5 ± 4.3 μV	45.6 ± 3.9 μV	+40.3%	$p < 0.001$

Table 5 reflects the positive dynamics of functional and clinical-instrumental indicators in children with spina bifida after a comprehensive rehabilitation program. The intensity of pain syndrome, assessed by the visual analogue scale (VAS), decreased from 5.9 ± 1.1 to 2.8 ± 0.9 points, which corresponds to a decrease of 52.5% ($p < 0.001$), indicating a pronounced analgesic effect of the intervention. The range of active movements (ROM) in the affected limbs significantly increased from 49.3 ± 6.2 ° to 65.4 ± 5.9 °, which is equivalent to an increase of 32.6% ($p < 0.001$), indicating the restoration of mobility. Muscle strength, measured by the MRS scale, increased from 2.4 ± 0.7 to 3.6 ± 0.6 points - by 50% ($p < 0.001$), indicating a significant improvement in motor function. The signal amplitude in electromyography increased from 32.5 ± 4.3 μV to 45.6 ± 3.9 μV (+ 40.3%, $p < 0.001$), reflecting an increase in neuromuscular activity and confirming the effectiveness of stimulation-active rehabilitation. Thus, the presented data demonstrate a statistically significant improvement in key parameters of the motor and pain sphere in children with spina bifida after treatment.

Table 6
Dynamics of indicators in children with spina bifida (control group, n=11)

Indicator	Before the intervention	After the intervention	Δ, %	r
Pain intensity (VAS), points	5.8 ± 1.0	5.1 ± 0.8	-12.1%	$p > 0.05$
Range of motion (ROM), °	50.1 ± 5.8	53.2 ± 6.1	+6.2%	$p > 0.05$
Muscle strength (MRS scores)	2.5 ± 0.6	2.7 ± 0.5	+8.0%	$p > 0.05$
Electromyography (signal amplitude)	33.1 ± 4.1 μV	34.8 ± 3.9 μV	+5.1%	$p > 0.05$

Table 6 demonstrates the dynamics of clinical and functional indicators in children with spina bifida in the control group (n=11) before and after standard rehabilitation. Unlike the main group, the control group showed minor positive changes in all the parameters studied, but they did not reach a statistically significant level ($p > 0.05$). Thus, the level of pain syndrome according to the VAS scale decreased by only 12.1%, the range of motion in the joints increased by 6.2%, muscle strength according to the MRC scale - by 8%, and the amplitude of the electromyographic signal increased by 5.1%. These data indicate the low efficiency of the traditional approach compared to the comprehensive rehabilitation program used in the main group.

Table 7
Effectiveness of intervention in children with idiopathic scoliosis

Indicator	Effect size (Cohen's d / η^2)	Interpretation
Cobb's Corner	d = 1.15	Strong effect
Posture index (visual analysis)	d = 0.89	Moderate effect
Pain according to the VAS scale	d = 0.76	Moderate effect
EMG of paravertebral muscles (ampl .)	d = 1.22	Strong effect
Quality of Life (PedsQL)	d = 0.98	Moderately strong

Table 7 presents a generalized characteristic of the clinical effectiveness of the rehabilitation program in children with idiopathic scoliosis. The assessment is based on the calculation of the effect size (Cohen's d), which allows for a quantitative assessment of the degree of influence of the intervention on various parameters of the patients' condition. The most pronounced changes were recorded according to such objective criteria as a decrease in the Cobb angle (d = 1.15) and improvement in electromyographic paravertebral muscle indices (d = 1.22), indicating a marked restoration of muscle balance and correction of spinal deformity. These results are classified as strong effects.

A moderate effect of the intervention was observed in relation to the pain syndrome indicators (VAS, d = 0.76) and the posture index assessed by the visual analysis method (d = 0.89), which reflects both a subjective improvement in the condition and a partial restoration of postural control. Positive dynamics were also noted in the quality of life indicator according to the PedsQL scale (d = 0.98), which is characterized as a moderate-strong effect and indicates an overall increase in the level of physical and psychoemotional well-being in patients. Thus, the data in Table 7 confirm the complex positive impact of personalized rehabilitation on clinical and functional parameters in children with idiopathic scoliosis.

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Table 8
Effectiveness of intervention in children with muscular torticollis

Indicator	Effect size (Cohen's d / η^2)	Interpretation
Head rotation amplitude	d = 1.08	Strong effect
Discomfort on palpation (VAS)	d = 0.81	Moderate effect
EMG of the sternocleidomastoid	d = 1.03	Strong effect
Quality of Life (PedsQL)	d = 0.91	Moderately strong

Table 8 reflects the effectiveness of the rehabilitation program in children with muscular torticollis (n=18) based on the calculation of the effect size according to Cohen 's d. The most pronounced positive changes were recorded in the head rotation amplitude (d = 1.08) and electromyographic characteristics of the sternocleidomastoid muscle (d = 1.03), indicating a strong effect of the intervention. Moderate-strong improvement was noted on the quality of life scale (PedsQL) (d = 0.91), confirming the clinical significance of the rehabilitation measures. There was also a moderate decrease in discomfort during palpation, reflected in changes on the VAS scale (d = 0.81). Thus, the presented data confirm the high effectiveness of an individualized approach to rehabilitation in children with muscular torticollis, aimed at eliminating muscle imbalance, pain syndrome and functional limitations.

Table 9
Effectiveness of intervention in children with spina bifida (myelomeningocele)

Indicator	Effect size (Cohen's d / η^2)	Interpretation
Lower limb activity (MRC scale)	d = 0.94	Moderate effect
Coordination (Romberg test) mod	d = 0.79	Moderate effect
EMG of the quadriceps and anterior tibialis	d = 1.10	Strong effect
Quality of Life (PedsQL)	d = 0.88	Moderate effect

Table 9 demonstrates the effectiveness of the implemented rehabilitation program in children with spina bifida (myelomeningocele) (n=16), based on the calculation of the effect sizes according to Cohen 's d. The most pronounced positive changes were recorded in the electromyographic activity of the quadriceps and anterior tibialis muscles (d = 1.10), indicating a strong effect of the intervention and indicating an increase in neuromuscular conductivity and functional potential of the lower limbs. Lower limb activity according to the MRC scale improved with a moderate effect (d = 0.94), reflecting the positive dynamics of muscle strength. Significant changes were also noted in the coordination test (modified Romberg test) (d = 0.79) and the quality of life scale (PedsQL) (d = 0.88), both of which indicate a moderate effect. Thus, the data in the table confirm the effectiveness of a comprehensive rehabilitation program aimed at improving motor function, coordination of movements and the general psychophysical state of children with spina bifida bifida.

DISCUSSION

The data obtained during the study allow a comprehensive assessment of the effectiveness of a comprehensive rehabilitation program in children with idiopathic scoliosis, muscular torticollis and spina bifida (myelomeningocele), taking into account clinical-functional, instrumental and psycho-social parameters. Discussion of the results seems appropriate in the logic of the identified nosological forms.

In patients with idiopathic scoliosis, significant improvements were observed in most parameters: increased spinal flexibility, improved balance (according to stabilometric indicators), decreased severity of muscle imbalance (according to EMG), and an improvement in the psychosocial component of health (according to the PedsQL scale). The effect sizes according to the Cohen scale in most cases ranged from moderate to strong (d> 0.8), indicating a clinically significant result.

Comparison with literature data shows that our intervention gave comparable or better results compared to traditional methods. For example, the use of neuromuscular stimulation and corrective exercise therapy showed an effectiveness similar to those described in the Rigo studies et al. (2018) and Negrini et al. (2020), but were accompanied by improvements in quality of life indicators, which highlights the comprehensive nature of the proposed approach.

In children with muscular torticollis, significant improvement in the angle of head rotation, decreased pain sensitivity during palpation of the SCS muscle, normalization of bioelectrical activity (EMG), and an increase in the quality of life scale scores were noted. The effect size (Cohen's d) ranged from moderate (0.81) to strong (1.08), especially for functional parameters.

These results are consistent with the findings of Chen's work. et al. (2017), which emphasizes the importance of an integrated approach including kinesiotherapy, myofascial release and orthopedic correction. However, our study additionally emphasizes the impact of therapy on subjective and psychosocial aspects, including pain syndrome and quality of life, which has not been sufficiently covered previously.

In the group of children with myelomeningocele , statistically significant improvements were also achieved in all key indicators: muscle strength of the lower limbs increased (according to the MRC scale), coordination improved (according to the modified Romberg test), bioelectrical activity (EMG) indicators increased, and a reliable improvement was observed according to the PedsQL scale.

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The effect sizes for most measures were moderate to large (up to d = 1.10). These data support the possibility of functional recovery even in congenital neural tube defects. This is consistent with the studies of Vles et al. (2019), which emphasize the importance of a multidisciplinary approach and the inclusion of motor training, physiotherapy and psychosocial support.

CONCLUSION

The summary analysis demonstrates that the use of an individualized and nosologically oriented rehabilitation program in children with various forms of musculoskeletal disorders provides not only an improvement in biomechanical and neurophysiological indicators, but also a significant increase in the quality of life. The identified strong effects in a number of parameters confirm the high sensitivity of the assessment methods used.

A special feature of this study is the inclusion of multidisciplinary criteria of effectiveness, which expands the framework for understanding the success of rehabilitation. In the future, this model can be adapted to wider populations of children with other disorders, as well as introduced into clinical practice in specialized rehabilitation centers.

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