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Gait analysis in children with multiple sclerosis

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ABSTRACT

BACKGROUND: According to various sources, children account for 3 to 10% of all patients diagnosed with multiple sclerosis. In 75% of all affected individuals, gait abnormalities are present even at early disease stages. However, the 2022 clinical guidelines issued by the Ministry of Health of the Russian Federation do not address the use of instrumental gait analysis in pediatric patients.

AIM: To investigate the motor status of children with relapsing-remitting multiple sclerosis using instrumental gait analysis and surface electromyography.

MATERIALS AND METHODS: Our study was an observational, single-center, prospective, and continuous study. The study population consisted of patients (*n*=38), aged 9–17 years, from the department of psychoneurology at the Russian Children's Clinical Hospital with a confirmed diagnosis of multiple sclerosis. All patients underwent the following assessments: instrumental gait analysis using surface electromyography of the lower limb muscles, the 6-minute walk test, contrast-enhanced MRI of the brain and spinal cord.

RESULTS: Patients exhibited low disability levels (EDSS ⩽2.5) and maintained independent ambulation. The 6-minute walk test demonstrated an average walking distance of 520.92 m, consistent with age norms. surface electromyography analysis revealed characteristic abnormalities in 44.74% of cases, particularly in the gastrocnemius muscles during the single-support phase, manifesting as premature activation and sustained activation with a secondary peak in the electromyography signal.

CONCLUSION: The study documented decreased tolerance to physical exertion, along with characteristic surface electromyography changes in the gastrocnemius muscles, specifically: sustained activation during the resting phase of the gait cycle and premature activation during the stance phase. These findings may serve as biomarkers for rehabilitation indications and treatment effectiveness assessment. However, further studies are required due to the limited sample size.

Keywords: multiple sclerosis; surface electromyography; rehabilitation; gait.

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Анализ походки у детей с рассеянным склерозом

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АННОТАЦИЯ

Обоснование. Из общего количества пациентов с установленным диагнозом рассеянного склероза, по разным источникам, от 3 до 10% составляют дети. В 75% случаев у всех заболевших уже на ранней стадии наблюдаются изменения походки, но в клинических рекомендациях, утверждённых Минздравом Российской Федерации 2022 г., нет данных по использованию инструментальных методов её оценки у детей.

Цель исследования — изучить особенности двигательного статуса детей с ремиттирующим рассеянным склерозом с помощью инструментального анализа походки с применением поверхностной электромиографии.

Материалы и методы. Наше исследование обсервационное, одноцентровое, проспективное, сплошное. Объект исследования — пациенты (*n*=38) Российской детской клинической больницы от 9 до 17 лет из отделения психоневрологии с подтверждённым диагнозом рассеянного склероза. Всем больным провели инструментальную диагностику походки с применением поверхностной электромиографии мышц нижних конечностей, тест 6-минутной ходьбы, а также магнитно-резонансную томографию с контрастированием головного и спинного мозга.

Результаты. Пациенты имели низкий уровень инвалидизации (по шкале EDSS не более 2,5 баллов) и были способны к самостоятельному передвижению. При 6-минутном тесте у большинства больных пройденное расстояние соответствовало возрастной норме, среднее значение составляло 520,92 м. При анализе результатов поверхностной электромиографии в 44,74% случаев зафиксированы характерные изменения электромиографической активности икроножных мышц в фазе одиночной опоры в двух вариантах — преждевременная активация и продолжающаяся активация мышцы с появлением второго пика на графике.

Заключение. В результате исследования зарегистрировано снижение толерантности к физической нагрузке, а также характерные изменения по данным поверхностной электромиографии в икроножных мышцах в виде двух вариантов — продолжающаяся активация мышцы в фазе отдыха в течение цикла шага и преждевременная активация в период опоры. Выявленные изменения могут служить маркерами показаний к проведению медицинской реабилитации и оценки эффективности лечения. Из-за ограничения объёма выборки исследования данного феномена требуется дальнейшее изучение.

Ключевые слова: рассеянный склероз; поверхностная электромиография; реабилитация; походка.

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多发性硬化患儿步态分析

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摘要

论证。据不同文献报道，在被诊断为多发性硬化的患者中，儿童占比约3%–10%。在所有患者中，约75%在疾病早期即出现步态异常。然而，在俄罗斯联邦卫生部于2022年批准的临床指南中，尚无针对儿童步态分析的仪器评估方法的数据。

研究目的。 利用步态分析仪器结合表面肌电图，研究复发缓解型多发性硬化患儿的运动状态特征。

材料与方法。本研究为单中心、前瞻性观察性全样本研究。研究对象为Russian Children’s Clinical Hospital精神神经科确诊为多发性硬化的9–17岁患者（*n*=38）。所有患者均接受下肢肌群的步态分析和表面肌电图评估，同时进行了6分钟步行测试以及 增强磁共振成像以评估 脑部和脊髓病变情况。

结果。研究对象的残疾程度较低（EDSS评分≤2.5），均可独立行走。6分钟步行测试 结果显示，大多数患者的步行距离符合该年龄段正常范围，平均步行距离为520.92米。在表面肌电图分析中，44.74%的患者表现出腓肠肌在单腿支撑相期间的肌电活动异常，表现为肌肉过早激活以及步态周期支撑相的持续激活，并出现第二个峰值。

结论。研究发现，患儿对运动负荷的耐受性降低，并在表面肌电图评估中显示腓肠肌存在异常激活模式，即步态周期的非负重期持续激活以及支撑期的过早激活。这些变化可作为医学康复的潜在指征，并有助于评估治疗效果。由于样本量的限制，该现象仍需进一步研究。

关键词：多发性硬化；表面肌电图；康复；步态。

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BACKGROUND

Demyelination is a key element in the pathogenesis of multiple sclerosis (MS). The myelin sheath performs several essential functions, including increasing impulse conduction velocity, a protective function, and preventing cross-talk between fibers in mixed nerves. Demyelination affects impulse conduction along the fibers of the nervous system, leading to conduction block or slowed conduction velocity. Remyelination exerts a neuroprotective effect, whereas persistent demyelination deprives axons of trophic and metabolic support, resulting in irreversible injury and axonal loss. Additionally, demyelinated fibers may become hyperexcitable and generate ectopic impulses at demyelination sites. Clinically, patients may present with paroxysmal symptoms such as tonic spasms, dysarthria, paresthesias, and pain. Another notable phenomenon observed in demyelinated fibers is their increased excitability in response to mechanical deformation, which accounts for the Lhermitte sign and transversely propagated activation in partially demyelinated axons [1].

One of the notable symptoms in MS is the so-called clinical dissociation syndrome. This phenomenon was described in 1976 by D.A. Markov and A.L. Leonovich and is characterized by a discrepancy between the patient's subjective sensations and objective clinical signs of tract involvement [2]. This presentation is more often associated with conduction block rather than slowed conduction or impaired high-frequency impulse transmission. Notably, even marked delays in impulse conduction may go unnoticed by patients, with the exception of impaired vibration sensation [3]. Functional conduction disturbances tend to correlate more closely with clinical manifestations than with structural damage in the central nervous system (CNS) [4].

Despite the fact that MS is a CNS disorder, studies have shown that changes may also occur in the peripheral nervous system and may be detectable via electroneuromyography. For example, Domres reported a reduction in M-response amplitude and F-wave alterations as early electroneuromyographic signs of spasticity [5].

Despite these various features, motor impairment in patients with MS carries major clinical significance, as it is the primary factor limiting function and contributing to disability. Signs of pyramidal tract involvement are observed in 91.7% of patients, typically manifesting as pathological reflexes and varying degrees of paresis. Even at mild disease severity (Expanded Disability Status Scale [EDSS] score ⩽ 3), motor impairments are present in 30.5% of cases [6]. In patients with primary progressive and secondary progressive MS, gait disturbances occur 20% more frequently than in those with relapsing-remitting MS. Numerous studies have been devoted to gait analysis with the development of diagnostic capabilities. In adults with MS, changes in gait parameters detected through instrumental analysis may result from a wide range of contributing factors, including muscle weakness, fatigue, spasticity, sensory deficits, cerebellar and vestibular dysfunction, and visual impairment. Gait alterations can be detected even at early stages of MS, in the absence of patient complaints and with short disease duration. Clinically significant gait impairment is observed in 75% of patients during the early stages of the disease, despite mild disability [7]. This issue garners considerable attention due to the significant impact of gait disturbances on both quality of life and degree of disability. Despite adaptive processes in the brain (neuroplasticity), damage continues to accumulate. The severity of impairment increases in parallel with disease progression.

An analysis of gait reveals kinematic and kinetic changes predominantly in the ankle and knee joints [8]. Gait becomes increasingly asymmetrical and less coordinated as the disease progresses. A decrease in ankle push-off power in MS is a key factor contributing to gait inefficiency, likely resulting from neurological impairments in dorsiflexor and plantar flexor muscles, such as weakness, spasticity, and altered motor unit recruitment [9]. In patients with minimal impairment, reductions in walking speed, step length, and the duration of double support have been observed [10, 11]. At an EDSS score of 1–1.5, decreased walking speed, reduced lower limb muscle strength, and impaired balance may already be present. Alterations have been identified in the vertical, longitudinal, and transverse components of the ground reaction force, indicating a decline in the lower limb's supporting function [12]. These impairments are commonly associated with pyramidal tract dysfunction, cerebellar involvement, and, in some cases, apraxia. Pyramidal tract dysfunction is more frequently associated with asymmetry in step time and single-leg support. Load redistribution tends to occur toward the heads of the second and third metatarsal bones. However, in cases of sensory impairment, gait quality may remain relatively preserved. In some patients with cerebellar symptoms, increased load on the fourth and fifth metatarsal bones has been reported [5]. Patients with MS often demonstrate reduced load on the heel and central metatarsal region, contributing to the more frequent occurrence of a cavus foot deformity [13].

Several studies have reported a reduction in hip extension amplitude during the stance phase, decreased knee flexion amplitude during the swing phase, reduced dorsiflexion amplitude at the ankle joint during the single support phase, and decreased plantar flexion amplitude during the second double support phase [11].

During walking, patients with MS often experience fatigue, which is associated with greater exertion and, consequently, higher energy expenditure. Surface electromyography (sEMG) during gait has proven effective in detecting abnormal load responses. For example, some studies have reported fatigue of the soleus muscle during prolonged walking [9], although electromyographic changes may reflect a combination of MS-related symptoms.

Using sEMG, muscle dysfunction has been identified in the form of increased coactivation. The coactivation

process—also known as reciprocal action—is characterized by the coordinated, graded contraction of agonist and antagonist muscles during movement at a single joint, enabling smooth motion and joint stabilization during activity. Excessive coactivation is an early, objective sign of impaired muscle balance and, consequently, of disrupted motor control, which may result in joint instability. This imbalance contributes to increased energy expenditure during walking and leads to greater fatigue, altered joint torque, and increased stiffness [8]. Thus, reduced gait stability is also associated with axonal loss in the corticospinal tract, which may serve as a sensitive indicator of neurodegeneration [14].

Other studies have described the characteristics of bioelectrical activity in paretic muscles, manifested as decreased amplitude along with altered phasic activity. Prolonged phasic bioelectrical activity has been interpreted as a compensatory response to reduced strength in the affected muscles, aimed at maintaining sufficient limb support capacity [12].

Gait studies in pediatric MS have also revealed changes, including a reduced range of motion in the hip joints and decreased walking speed compared with healthy peers [15]. The clinical guidelines for MS rehabilitation, approved in the Russian Federation in 2022, do not include recommendations on the use of instrumental gait analysis methods for early diagnosis or for assessing treatment effectiveness [16].

The advantage of this method using sEMG over other standard tests lies in its ability to support early diagnosis of the disease, when other symptoms may still be undetectable during clinical examination. Therefore, developing rehabilitation strategies based on these data allows for more targeted and, consequently, more effective interventions.

AIM

The work aimed to investigate data from instrumental gait analysis in children with MS to optimize early diagnosis of gait impairment and improve approaches to medical rehabilitation.

METHODS

Study Design

It was an observational, single-center, prospective, continuous study.

Eligibility Criteria

Inclusion criteria:

- Confirmed diagnosis of multiple sclerosis (G35) based on the international McDonald criteria;
- Age between 9 and 17 years;
- Ability to walk independently without additional rehabilitation devices and preserved visual function;
- Signed informed consent for participation in the study.

Non-inclusion criteria:

- General contraindications to therapeutic physical exercise;
- Functional gait limitations due to other diseases.
- Exclusion criteria:
- Patient's withdrawal from the study;
- Development of a comorbidity during the study.

Study Setting

The study was conducted at the Department of Medical Rehabilitation for Children and the Department of Pediatric Psychoneurology for Older Children of the Russian Children's Clinical Hospital, a branch of the N.I. Pirogov Russian National Research Medical University.

Study Duration

The study was conducted from February to December 2024.

Medical Study Description

Upon planned admission to the Department of Pediatric Psychoneurology, patients were referred for a consultation with a physician specializing in therapeutic physical exercise. During this consultation, motor status and eligibility for study inclusion were evaluated. All patients provided signed informed consent to participate in the study. During hospitalization, each patient underwent contrast-enhanced magnetic resonance imaging (MRI) of the brain and spinal cord. The results were compared with previous MRI scans from earlier hospitalizations. All patients had undergone MRI examinations prior to the study. Each patient completed a single assessment of exercise tolerance using the 6-minute walk test, along with instrumental gait analysis performed on the Stedis system (Neurosoft, Russia). The assessments were conducted by a physician specializing in therapeutic physical exercise, who held a medical degree and had completed a clinical residency in the relevant field. The specialist conducting the gait analysis also held certification in gait analysis training courses (Clinical Gait Analysis: CPD; Pediatric Gait Analysis and Orthotic Management: Oscar). All data were analyzed by professionals with more than 10 years of experience in pediatric rehabilitation.

As part of the instrumental gait analysis, EMG activity of the gastrocnemius muscle was evaluated. In his study, Winter described the EMG pattern of this muscle in healthy individuals as a bell-shaped curve with a peak at approximately 40% of the gait cycle, during the single support phase, corresponding to the moment of maximal isometric contraction of the gastrocnemius muscle, followed by a rapid and complete decline (Fig. 1) [17].

Recording Methods

Instrumental gait analysis with sEMG of the gastrocnemius muscles was performed in accordance with the SENIAM (Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles) recommendations. The procedure included the following steps:

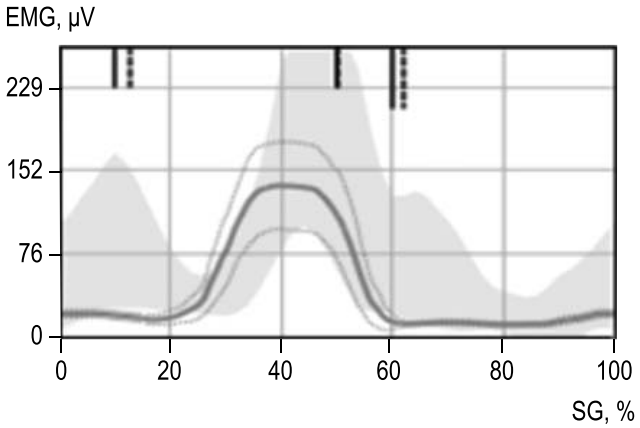

Fig. 1. Graph of the envelope amplitude of gastrocnemius muscle electromyography during the gait cycle.
EMG — electromyography envelope; SG — step cycle.

1. Circular electrodes with a diameter of 10 mm were used.

2. The interelectrode distance (measured center to center) was 20 mm.

3. The free portion of the electrode cables was secured to the leg using an elastic band.

4. Hair at the electrode placement site was shaved, and the skin was cleaned with alcohol. Skin peeling was then performed. Electrodes were applied only after the skin was completely dry.

5. Electrode placement was guided by the Atlas of Electromyography and Manual Muscle Testing, targeting the most prominent area of the muscle belly and aligning the bipolar electrode pair along the direction of the muscle fibers.

6. Disposable bipolar Ag/AgCl surface electrodes with an insulating layer were used.

7. High-pass filtering was set at 5 Hz; power line interference was filtered at 50 Hz. EMG signals were recorded at a rate of 2000 Hz.

Outcomes Registration

To capture gait parameters, eight inertial sensors were attached to the patient's lower limbs: on the feet, distal third of the lower legs, proximal third of the thighs, over the sacrum, and at the level of the 12th thoracic vertebra. The sensors were secured using elastic bands and holders. Each sensor recorded acceleration and angular velocity along three axes. Two sensors, located on the distal third of the tibia, also recorded sEMG via two differential channels at a rate of up to 2000 Hz, targeting the tibialis anterior and gastrocnemius muscles. Patients were instructed to walk continuously for 2 minutes, covering at least 8–10 straight steps, during which the sensors collected gait parameters. The recorded data were transmitted wirelessly via Wi-Fi to a personal computer for storage and further analysis. The software installed on the computer converted the raw sensor data into clinically meaningful outputs, including temporal, spatial, and kinematic gait parameters, as well as amplitude envelopes of the EMG signals with corresponding values expressed in microvolts (μV). These processed data could be directly used to analyze existing abnormalities and make clinical conclusions.

Statistical Analysis

Principles of sample size calculation

The sample size in this study was determined by the number of pediatric patients hospitalized during the study period. Although the incidence of MS in children is relatively low, the specific focus of our hospital allows observation of a sufficient number of patients referred from various regions across the Russian Federation.

Statistical data analysis methods

Statistical analysis was performed using Statistica, version 10. The Shapiro–Wilk test was used to assess the normality of data distribution. As the data were not normally distributed, descriptive statistics are presented as the median, first quartile (Q1), and third quartile (Q3). Comparisons of qualitative independent samples were performed using the chi-square test with contingency tables (for the analysis of associations between multiple categorical variables) and Yates correction, as some expected frequencies were < 10. For comparisons of continuous variables, the t test was used.

RESULTS

Participants

A total of 38 patients aged 9–17 years with a confirmed diagnosis of relapsing-remitting MS were included in the study. The median age was 15 years (interquartile range [IQR], 12–16 years). All patients had a low level of disability, with EDSS scores not exceeding 2.5. The median disease duration was 2 years (IQR, 1–4 years). The proportion of female patients was higher than that of male patients, accounting for 68.4% and 31.6%, respectively.

Primary Results

The most frequently reported complaint during clinical evaluation was fatigue (Table 1). All patients completed the 6-minute walk test, during which the total distance walked in 6 minutes was recorded. There are no established normative formulas for walk test distance in pediatric populations, as the results are highly dependent on age, sex, and ethnic background. Therefore, a population-based study of healthy children in the Russian Federation that provided percentile values by sex and age was used for comparison [18]. Each patient's result was compared with these reference values, and most were found to fall within the average range for their respective age group (Fig. 2).

Further assessment of the instrumental gait analysis data was conducted. Due to potential cross-talk artifacts in the recordings from the quadriceps and tibialis anterior muscles,

Table 1. Frequency of complaints presented by patients with relapsing-remitting multiple sclerosis with mild disability

Complaint	Patients reporting the complaint, %
Balance impairment	18.4
Sensory disturbances	2.6
Headaches	13.2
Gait disturbances	5.3
Fatigue	47.4
Weakness	7.9

reliable evaluation of changes in their sEMG activity envelopes was not feasible; therefore, only the gastrocnemius muscles were analyzed. In 17 patients (44.74%), alterations in the shape of the sEMG activity envelope were observed and classified into several distinct patterns.

The first pattern was characterized by the appearance of a second activity peak, shifted toward the end of the gait cycle and preceded by a brief, incomplete reduction in activity. The amplitude of the second peak varied among patients. In this study, we focused on the frequency of this secondary peak within the patient cohort, which was observed in 10 patients (26.32%) (Fig. 3).

The second pattern involved premature EMG activation (early onset of EMG activity). This was observed in 7 patients (18.42%) (Fig. 4).

According to MRI findings, deterioration compared with the previous hospitalization—manifested as new lesions—was observed in 17 patients (44.7%). In the remaining 21 patients (55.3%), MRI findings remained stable. All patients received maintenance pharmacological therapy prescribed by a neurologist between hospitalizations. The average interval between hospitalizations was 9 months.

Secondary Results

Adverse Events

No adverse events were observed during the study.

DISCUSSION

Summary of Primary Results

In this additional diagnostic study, we identified gait abnormalities in children diagnosed with MS. These changes were associated with both the distance covered during the 6-minute walk test and the EMG activity of the muscles, particularly the gastrocnemius muscle, and were present in 44.74% of the patients examined.

Interpretation

The results of the 6-minute walk test demonstrated that in most children with MS and a low level of disability, the

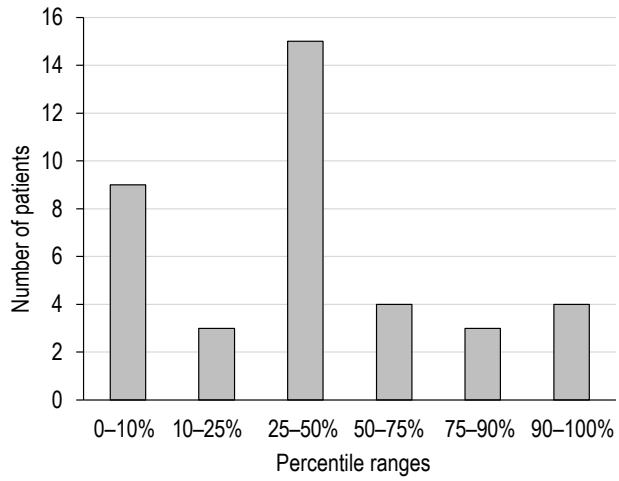

Fig. 2. The graph of the distribution of the results of the 6-minute walking test in children with multiple sclerosis by percentile intervals of standard values.

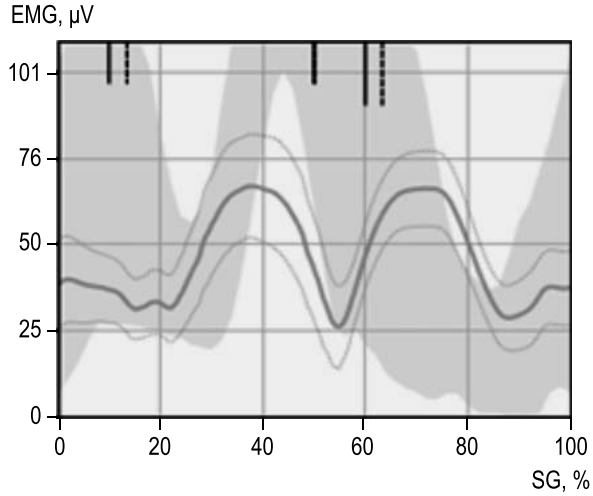

Fig. 3. Modified amplitude graph of the gastrocnemius muscle's electromyography envelope during the gait cycle, showing continued or prolonged activation and the appearance of a second peak.
EMG — electromyography envelope; SG — step cycle.

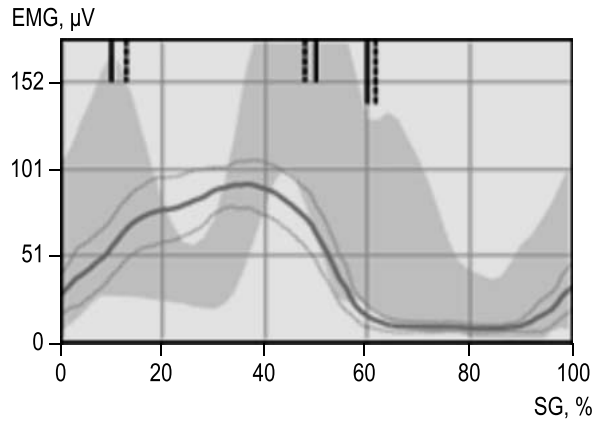

Fig. 4. Modified amplitude graph of the gastrocnemius muscle's electromyography envelope during the gait cycle, showing premature activation.
EMG — electromyography envelope; SG — step cycle.

distance covered was consistent with age-appropriate normative values, suggesting preserved exercise tolerance.

The biphasic pattern of gastrocnemius muscle EMG activity identified in children with MS has not been previously reported in the published data. EMG patterns characterized by premature activation (early onset of EMG activity) have been described in adults; however, the EMG pattern identified in our study—a biphasic curve with sustained muscle activation—differs substantially from those previously reported [15]. The principal distinction lies in the fact that, in prior studies, the EMG peak reflected premature activation of the muscle before its typical onset. In contrast, in our study, the activation of the gastrocnemius muscle was prolonged into the swing phase—a period during which this muscle is normally inactive to ensure biomechanically appropriate gait.

This sustained activation of the gastrocnemius muscle affects the biomechanics of ankle joint movement, as it overlaps with the normal activation of antagonist muscles in the subsequent phase of the gait cycle. The phenomenon of simultaneous activation of antagonist muscles is referred to as co-contraction. Under physiological conditions, co-contraction enhances joint stability and contributes to movement precision in the limbs, and it is associated with increased energy expenditure. Whereas increased joint stiffness during the stance phase may be attributed to impaired motor control and can serve a compensatory function, such a phenomenon during the swing phase lacks a compensatory role and pathologically alters gait biomechanics. At the same time, qualitative assessment of joint stiffness remains challenging for both experimental and computational methods. In contrast, the quantitative evaluation of muscle co-activation using the co-contraction index (CCI), based on electromyographic (EMG) data, is more feasible and may serve as an alternative measure of joint stability.

Several methods exist for calculating co-contraction index. The most commonly used are CCI_1 (Rudolph et al., 2000) and CCI_2 (Falconer and Winter, 1985) [19, 20].

CCI_1 quantifies antagonist muscle activation relative not only to the combined activation of agonist and antagonist muscles but also to agonist activation alone. In contrast, CCI_2 assesses antagonist activation solely in relation to total muscle activation. Based on the findings of Li et al., who compared these indices and analyzed their correlation with joint stiffness, CCI_2 demonstrated superior performance. Therefore, this index was selected to assess the contribution of co-contraction to pathological joint stiffness [21].

Formula CCI_2:

$$CCI_2(t)=\frac{2\times Input_L(t)}{Input_L(t)+Input_H(t)},$$

where $Input_L$ is the minimum EMG amplitude and $Input_H$ is the maximum EMG amplitude.

To compare the results with gait parameters in healthy individuals, we recruited a control group of nine conditionally healthy children matched for age and sex with those who exhibited a pathological gait pattern characterized by a second peak in gastrocnemius muscle activity. In the study group, the mean co-contraction index was 64.2, whereas in the control group, the corresponding value was 45.9. Given that the gait cycle comprises distinct and complex phases of muscle activity, the co-contraction index was calculated separately for the stance and swing phases. In the study group,

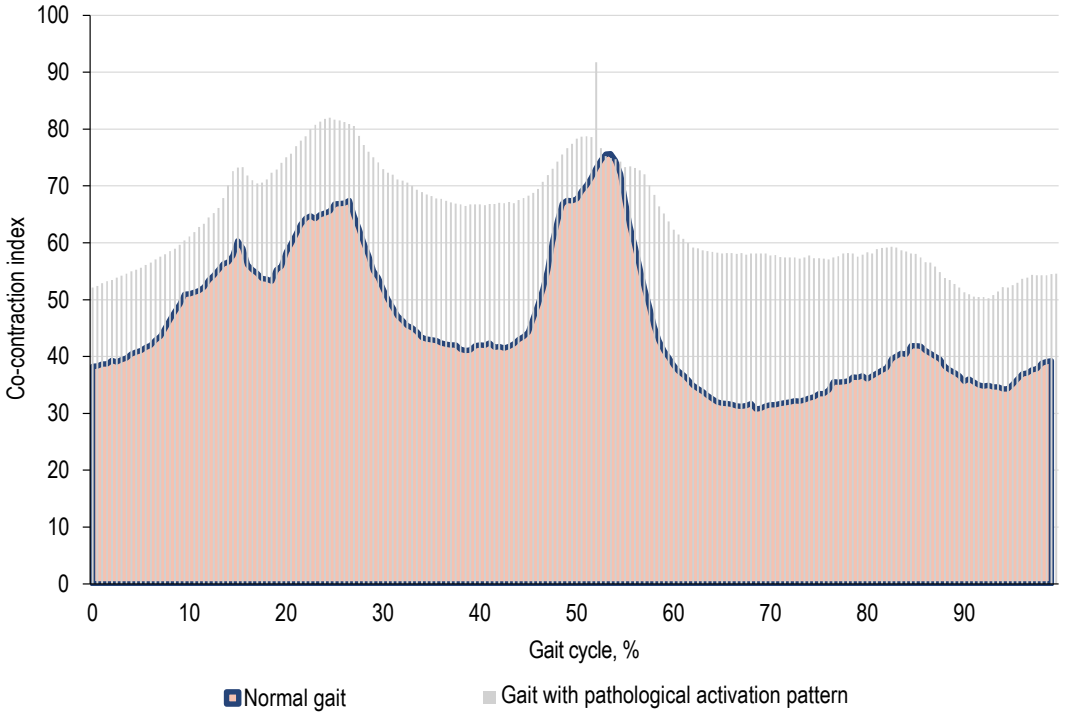

Fig. 5. Comparison graph of the Co-Contraction Index during the gait cycle in healthy individuals and patients with MS-related muscle activation disturbances.

the CCI for the stance and swing phases was 69.4 and 55.7, respectively, compared with 52.9 and 35.7, respectively, in the control group. Comparative analysis showed that the average co-contraction index for the entire gait cycle in children with relapsing–remitting MS was 40% higher than in healthy children. During the stance phase, the difference was 31%, and during the swing phase it was 59%, further emphasizing the greater pathological impact of this gait pattern during the swing phase (Fig. 5).

We hypothesized that the observed alteration in gastrocnemius muscle activity is associated with demyelination of the corticospinal tract responsible for its innervation. This assumption is supported by the shift in the frequency spectrum toward lower frequencies observed in this activation pattern. The likely explanation involves altered impulse conduction in demyelinated nerve fibers. One of the known properties of a nerve fiber is its inability to conduct a subsequent impulse for a certain period following an initial stimulus—referred to as the refractory period [22]. A demyelinated nerve fiber loses the capacity to transmit rapid, successive impulses due to a prolonged refractory period following a single action potential. Additionally, signal conduction becomes slower even at lower frequencies. Clinically, this may manifest as impaired vibration sensation.

As a result, we observed a distinct alteration in the sEMG profile of the gastrocnemius muscle, characterized by a biphasic activity curve and a shift in the frequency spectrum (Fig. 6), which may serve as an indicator of demyelination severity.

In the second pattern of gastrocnemius muscle activation, no shift in the frequency spectrum was observed, suggesting a different underlying mechanism, likely representing a compensatory response to altered gait biomechanics. This typically occurs in the context of impaired postural stability, which, in turn, is linked to axonal damage in the corticospinal tract [23].

In both patterns, excessive muscle activation results in increased energy expenditure during walking, greater fatigue, and reduced exercise tolerance.

Additionally, we evaluated the relationship between the double-peaked EMG activation pattern in the gastrocnemius muscle and progression on MRI. The analysis was conducted using Pearson's chi-squared test with contingency tables and Yates correction. In five children, the altered EMG pattern coincided with the appearance of new lesions on MRI over the past year. In another five patients, the pathological pattern was observed despite stable MRI findings. In nine patients, no changes in gastrocnemius surface EMG were observed, while new lesions were detected on MRI. In 12 patients, no changes were found in either the gastrocnemius EMG or MRI. The resulting p-value was > 0.05, suggesting no association between the pathological gastrocnemius activation pattern and radiologic deterioration on brain and spinal cord MRI.

All patients who reported weakness were found to exhibit a pathological activation pattern in the gastrocnemius muscle.

In addition, a specific association was observed in patients who were not included in the main study group. These patients had higher disability scores and were diagnosed with either secondary progressive or primary progressive forms of the disease. The proportion of the first and second types of pathological patterns in the gastrocnemius muscle differed. Among the studied group of children with low levels of disability, the prevalence of the sustained activation pattern exceeded that of the early activation pattern—33.3% vs 18.5%. In contrast, among children with disability scores > 2.5 on the EDSS, the sustained activation pattern remained more prevalent (54.5% vs 10%) (Fig. 7).

Study Limitations

This study included a relatively small sample of 38 patients. Patients walked at a self-selected speed, and sEMG

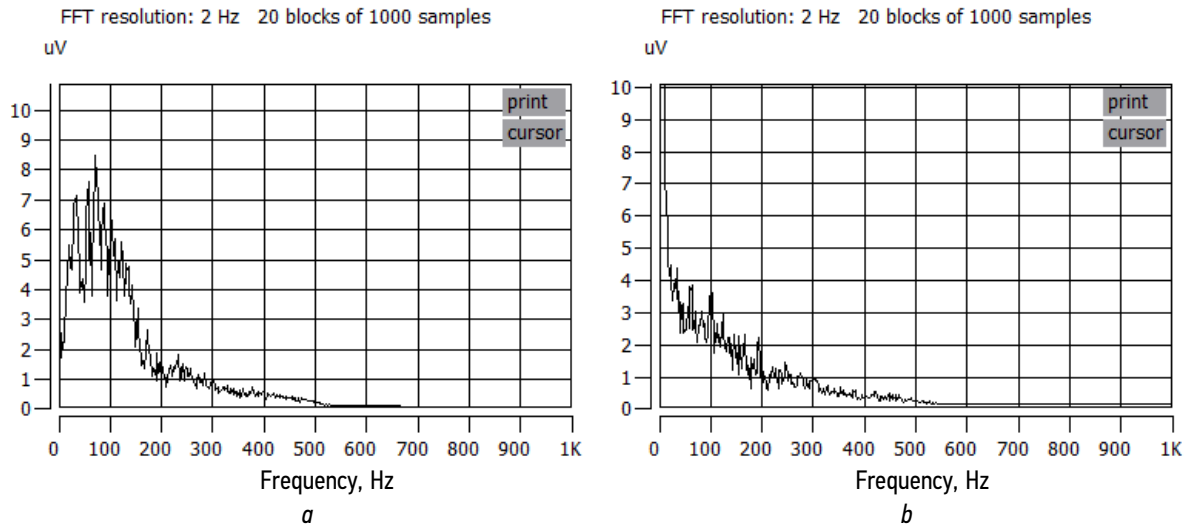

Fig. 6. Frequency spectrum graph of gastrocnemius muscle activity under normal conditions (*a*) and in the altered EMG activity pattern with continued activation in children with multiple sclerosis (*b*).

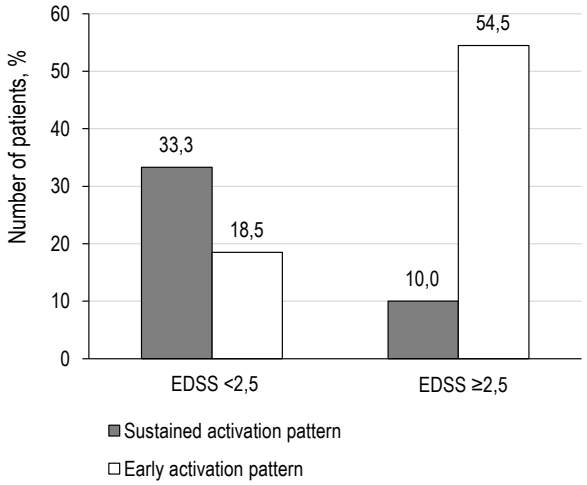

Fig. 7. Diagram showing the percentage distribution of the pathological pattern in the gastrocnemius muscle among children with different disability score multiple sclerosis.

data were not normalized to maximal isometric contraction. Due to crosstalk, we assessed only changes in activity of the gastrocnemius muscles.

CONCLUSION

Gait disturbances were identified in patients diagnosed with relapsing-remitting MS who had low levels of disability. In 44.74% of the children included in our study, instrumental gait analysis using sEMG revealed altered activity of the gastrocnemius muscle, manifested in two distinct patterns. The first pattern involved sustained activation of the muscle during the stance phases of the gait cycle; the second one was early activation of the muscle. The EMG activity pattern of the gastrocnemius muscle with sustained activation has not been previously described in the pediatric population with MS. We associate this pattern with demyelination in the CNS, slowed nerve conduction, and concurrent remyelination processes, which may result in impaired synchrony of impulse transmission. The restoration of damaged myelin sheaths and the activation of compensatory mechanisms are believed to occur actively in patients at early disease stages, contributing to the preservation of low disability levels. No association was found between this EMG pattern and either clinical exacerbation at the time of diagnosis or radiologic progression on MRI during the previous year. Clinical examination revealed no overt gait abnormalities in this group of patients, consistent with the dissociation phenomenon typical of MS. Therefore, this diagnostic approach serves as a convenient and effective tool for detecting subclinical motor pathology. Such detailed assessment of motor function offers advantages in selecting appropriate rehabilitation strategies and in developing individualized treatment plans. The identified changes can serve as markers for the selection of rehabilitation methods and assessment of treatment efficacy. However, given the limitations of the present study, this phenomenon warrants further investigation.

ADDITIONAL INFORMATION

Author contributions. M.A. Borovik — literature review, selection and examination of patients, collection and analysis of literary sources, writing and editing of the article; I.O. Vedernikov — carrying out the procedure of instrumental gait research, preparation and writing of the text of the article; O.A. Laysheva — scientific supervisor of the study; E.Yu. Volkova — patient management neurological profile, diagnosis; T.S. Kovalchuk — curation of the work. All authors made a substantial contribution to the conception of the work, acquisition, analysis, interpretation of data for the work, drafting and revising the work, final approval of the version to be published and agree to be accountable for all aspects of the work.

Ethics approval. The study was approved by the local ethics committee of the Russian Children's Clinical Hospital — a branch of the Pirogov Russian National Research Medical University (Pirogov University). Extract from protocol N. 25 dated 11/26/2024. All study participants voluntarily signed an informed consent form before inclusion in the study.

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Statement of originality. In creating this work, the authors did not use previously published information (text, illustrations, data).

Data availability statement. The editorial policy regarding data sharing does not apply to this work, and no new data was collected or created.

Generative AI. Generative AI technologies were not used for this article creation.

Provenance and peer-review. This paper was submitted to the journal on an unsolicited basis and reviewed according to the usual procedure. Two external reviewers, a member of the editorial board, and the scientific editor of the publication participated in the review.

ДОПОЛНИТЕЛЬНАЯ ИНФОРМАЦИЯ

Вклад авторов. М.А. Боровик — обзор литературы, отбор и осмотр пациентов, сбор и анализ литературных источников, написание текста и редактирование статьи; И.О. Ведерников — проведение процедуры инструментального исследования походки, подготовка и написание текста статьи; О.А. Лайшева — научный руководитель исследования; Э.Ю. Волкова — ведение пациентов по неврологическому профилю, выставление диагноза; Т.С. Ковальчук — курация работы. Все авторы одобрили рукопись (версию для публикации), а также согласились нести ответственность за все аспекты работы, гарантируя надлежащее рассмотрение и решение вопросов, связанных с точностью и добросовестностью любой её части.

Этическая экспертиза. Проведение исследования одобрено локальным этическим комитетом РДКБ — филиала РНИМУ им. Н.И. Пирогова (Пироговский университет). Выписка

из протокола № 25 от 26.11.2024. Все участники исследования добровольно подписали форму информированного согласия до включения в исследование.

Источники финансирования. Отсутствуют.

Раскрытие интересов. Авторы заявляют об отсутствии отношений, деятельности и интересов за последние три года, связанных с третьими лицами (коммерческими и некоммерческими), интересы которых могут быть затронуты содержанием статьи.

Оригинальность. При создании настоящей работы авторы не использовали ранее опубликованные сведения (текст, иллюстрации, данные).

Доступ к данным. Редакционная политика в отношении совместного использования данных к настоящей работе не применима, новые данные не собирали и не создавали.

Генеративный искусственный интеллект. При создании настоящей статьи технологии генеративного искусственного интеллекта не использовали.

Рассмотрение и рецензирование. Настоящая работа подана в журнал в инициативном порядке и рассмотрена по обычной процедуре. В рецензировании участвовали два внешних рецензента, член редакционной коллегии и научный редактор издания.

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