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Adaptive changes in muscle activity after cryotherapy treatment: Potential mechanism for improvement the functional state in patients with multiple sclerosis

Aleksandra Radecka[a], Anna Knyszyńska[a], Joanna Łuczak[b,c] and Anna Lubkowska[a,*]
[a]*Department of Functional Diagnostics and Physical Medicine, Pomeranian Medical University in Szczecin, Szczecin, Poland*
[b]*College of Engineering and Health in Warsaw, Faculty of Health Sciences, Warsaw, Poland*
[c]*Department of Cardiological Rehabilitation, Central Clinical Hospital of the Ministry of Internal Affairs and Administration in Warsaw, Warsaw, Poland*

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Abstract.

BACKGROUND: The available literature lacks data about the influence of whole body cryotherapy (WBC) on muscle activity in patients with sclerosis multiplex (MS).

OBJECTIVE: Assessment of the influence of the 20 WBC series on the surface electromyography (sEMG) signal and the relationship between it and the functional state in patients with MS.

METHODS: The study group was 114 of MS patients (aged 45.24 ± 11.88yr.,) which 74 of them received 20 of WBC. An assessment was made of: the hand grip (HGS), Timed 25-Foot Walk, Fatigue Severity Scale, sEMG signal from the dominant limb.

RESULTS: After a series of 20 WBC: in the rest electromyograms, an increase of extensor carpi radialis (ECR) and a decrease of flexor carpi radialis (FCR) amplitude were demonstrated (non-normalized signal ECR $p = 0.0001$); significant differences in sEMG rest signals between ECR and FCR have decreased; for voluntary contraction in both assessed antagonistic muscle amplitude was significantly decreased ($p = 0.0005$; $p = 0.0316$, $p = 0.0185$); an increase of HGS ($p < 0.001$); gait improvement ($p = 0.001$); decrease fatigue ($p = 0.024$). No significant changes were observed in the control group.

CONCLUSIONS: Series of 20 WBC improves the functional state and reduces fatigue in patients with MS, which may be due to adaptive changes in bioelectrical muscle activity.

Keywords: Surface electromyography, whole-body cryotherapy, multiple sclerosis, hand grip strength, fatigue severity scale, timed 25-foot walk

1. Introduction

Multiple sclerosis (MS) is the most common chronic, inflammatory, and degenerative disease of the central nervous system (Milo & Kahana, 2010). MS is characterized by a wide spectrum of symptoms, many related to dysfunction of the musculoskeletal system being the cause of loss of function and disability in young adults and also a decrease of functional state and quality of life (Reich et al., 2018).

Positive effects of cold exposure are observed in patients with MS, both in the subjective assessment

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[*] Address for correspondence: Anna Lubkowska, ŻoŁnierska 54 Str., 71-210 Szczecin, Poland. E-mail: anna.lubkowska@pum.edu.pl.

of patients and functional studies. It is not surprising then, that cooling therapy is used as complementary therapy in MS patients (Schwid, 2003) (Pawik, et al., 2019) (Miller et al., 2016) (Miller et al., 2013).

Whole body cryotherapy (WBC) is a form of extremely low temperature therapy. It is currently popular in rehabilitation, sport, and very often as a complement to therapy in patients with MS (Patel et al., 2019) (Pawik, et al., 2019) (Giemza et al., 2014). Previous research demonstrated the effect of WBC therapy in MS patients were: improvement of functional status, reduction of depressive symptoms and pain, reduction of the degree of disability and felt fatigue and increase uric acid blood level (Pawik, et al., 2019) (Miller et al., 2016) (Miller et al., 2013) (Schwid, 2003). Nevertheless, the mechanism of influence of WBC on the functional state of patients with MS has not been fully explained. There is definitely no information on the effects of daily WBC treatment on neuromuscular performance and function. On the basis of a few studies, it is postulated that the therapeutic "muscle effect" of WBC may be associated with a modification in its bioelectric tone as a result of the decrease of nerve conduction and reactivity of peripheral sensory-nerve endings (Ferreira-Junior et al., 2014) (Giemza et al., 2014).

One of the recommended research methods for assessing neuromuscular activity and efficiency is surface electromyography (sEMG). sEMG is used in the assessment of muscle activity both in healthy people and in various diseases, including MS patients (Scott et al., 2011) (Martin et al., 2006), neurological patients (Meigal et al., 2014) (Xu et al., 2015) (Qiao et al., 2019) and in the effects of temperature on muscle properties (Coletta et al., 2018) (Winkel & Jørgensen, 1991) (Bell, 1993).

Literature data demonstrated the stimulus effect of low temperature on the bioelectrical activity of the muscle as assessed by sEMG. It was for example demonstrated that change in skin temperature changed the EMG signal without any change in muscle activity in healthy volunteers (Winkel & Jørgensen, 1991) (Holewijn & Heus, 1992)

The influence of low temperature on sEMG signal was assessed for different forms of exposure: cold climate chamber (temperature 14°C) (Winkel & Jørgensen, 1991), local and whole body cooling (15°C water) (Holewijn & Heus, 1992) (Solianik et al., 2015) (Piedrahita et al., 2009), ice bag (Loro et al., 2019) (Akehi et al., 2016), localized air-pulsed cryotherapy (–30°C), (Gilhem et al., 2013), and WBC (Westerlund et al., 2009).

The first reports regarding change in muscle sEMG signal (Giemza et al., 2014) (Westerlund et al., 2009) were after WBC exposure, in the context of adaptive changes after a series of WBC therapy, but this has not been studied in patients with MS.

Based on previous knowledge from the mentioned clinical trials we assumed that cryostymulation could modify the muscles activity in the electromyographic assessment, and as a consequence of prolonged daily treatment could lead to positive adaptive changes in muscle tension within patients with MS.

Assessments of the impact of the WBC on patients with MS have been extended to a multifaceted analysis of the functional state (gait, grip strength and fatigue). The literature has previously demonstrated an improvement in the functional state after WBC procedures in MS patient (Pawik, et al., 2019) (Miller et al., 2016), which is why we wanted to combine the results of the functional assessment with the sEMG assessment. The functional assessment considered three main aspects: fatigue as a frequent symptom experienced by people with MS and an impact on the quality of life and functional state (Kos et al., 2008) (van Kessel & Moss-Morris, 2006), upper limb impairment assessment by hand grip strength (HGS) is often used as an indicator of arm function or overall functional decline in patients with MS (Newsome et al., 2019)(Lamers et al., 2013), and walking impairment is considered as a common clinical manifestation of MS (Cohen et al., 2014).

The purpose of this study was to assess potential changes in bioelectrical muscle activity during rest and contraction after exposure on 20 series of WBC in patients with MS and to assess potential relationships between the sEMG parameters and functional state in patients with multiple sclerosis pre and post 20 series of WBC.

2. Patients and methods

Research procedures were carried out at the Central Clinical Hospital of the Ministry of Interior and Administration in Warsaw (Centre for Therapeutic Improvement) in 2016 and 2017. The research was continued in 2018 and 2019 at the Research Center for Impact of Cryogenic Temperatures on the Human Body (Chair and Department of Functional Diagnostics and Physical Medicine, Pomeranian Medical University in Szczecin). The research was financed from funds granted by the Ministry of Science and Higher Education Republic of Poland

(No. WNoZ-318-01/S/13/2020, No. 6570/IA/SP/2016). The research project received prior approval of the Bioethical Committee of the Pomeranian Medical University in Szczecin (Decision No. KB-0012/34/15). This study was a single-blind randomized clinical trial, performed initially on 172 patients with MS (ICD10-G35). Twenty-five patients were excluded from the research and 33 resigned during the study. A total of 114 patients participated in all of the planned procedures of the research.

The participants were randomly assigned to the two groups, WBC and control (Fig. 1). The sample size was 60 in WBC, and 54 in the control group. The participants were informed in detail about the planned test procedures. Medical documentation was provided by them and their health status was verified through a detailed medical examination (including neurological examination) to exclude people who did not meet the inclusion criteria.

The inclusion criteria for the study were as follows: (1) documented diagnosis of MS, in accordance

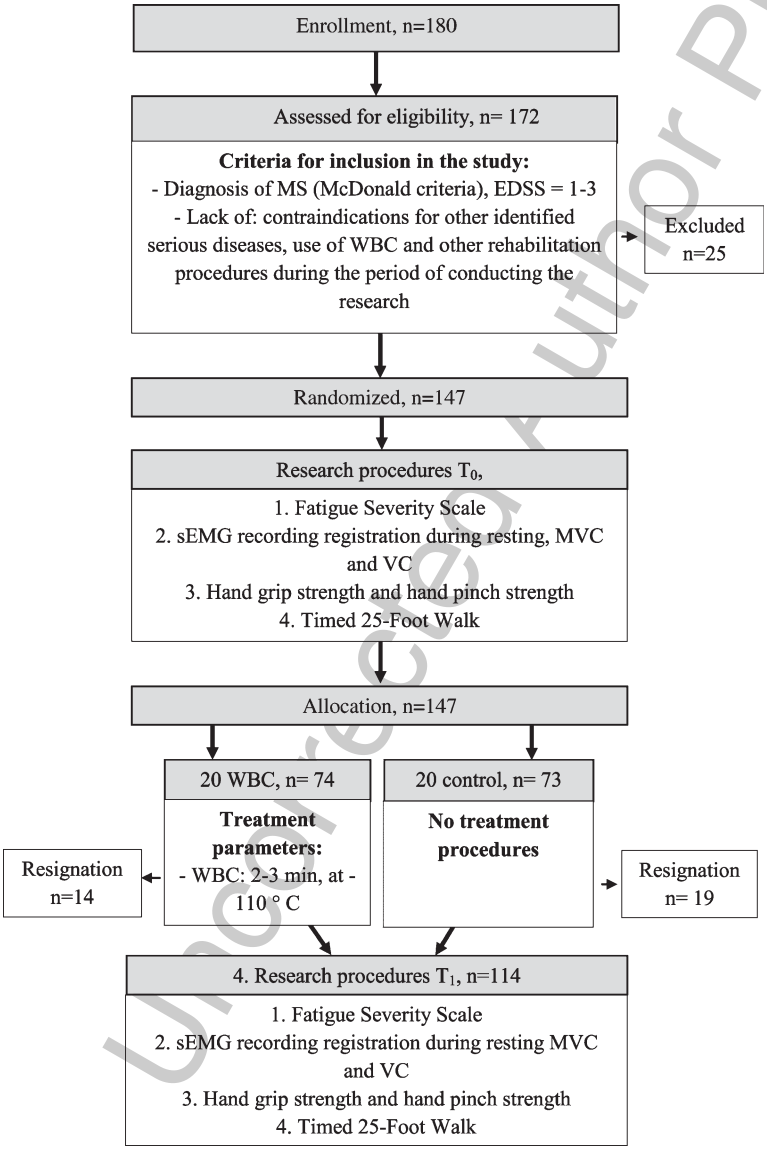

Fig. 1. The order of research procedures. Legend: SM - sclerosis multiplex, EDSS - Expanded Disability Status Scale, WBC - Whole Body Cryotherapy, sEMG - surface electromyography, MVC – maximum voluntary contraction, A_{RMS} - Root Mean Square Amplitude Legend: WBC - Whole Body Cryotherapy, power test for H0: Mi1 = Mi2 and alfa: *0.05; ** 0.2.

Table 1
Characteristics of the study group

	Study group, $n = 114$	WBC, $n = 60$	Control, $n = 54$	Mann-Whitney U test	
				Z	p
Sex	83♀/ 33 ♂	44♀/ 16 ♂	39♀/ 17 ♂		
Age [years]	45.24 ± 11.88	44.95 ± 11.83	45.09 ± 11.8	–0.27	0.79
Body weight [kg]	71.4 ± 24.17	71 ± 23.86	71.85 ± 24.72	–0.17	0.87
Body height [m]	169.24 ± 10.16	167 ± 0.1	168.29 ± 10.27	0.06	0.95
EDSS	1.77 ± 0.85	1.76 ± 0.63	1.79 ± 1.04	0.13	0.9
RRMS/SPMS	79/35	42 /18	37/17		
Disease duration [years]	15.24 ± 7.33	15.28 ± 7.35	15.19 ± 7.38	0.08	0.94

Legend: ♀– women, ♂– men, RRMS – Relapsing Remitting Multiple Sclerosis, SPMS – Secondary Progressive Multiple Sclerosis, EDSS – Expanded Disability Status Scale. T_O – before WBC, T_1 – after WBC;.

with the McDonald criteria (including revisions from 2017) (Solomon et al., 2019), (2) functional status classified according to the Expanded Disability Status Scale (EDSS) to a level lower or equal to 0–3 (Kurtzke, 1983), (3) no contraindications for WBC treatments found in the medical examination, (4) no other serious chronic diseases identified that may affect the results of the tests carried out, (5) readiness to participate in daily WBC, (6) a written statement that they had not had WBC treatments in the last 2 years, and (7) no use of other forms of physiotherapeutic and complementary therapies (other than planned in the procedures) for the period of this study. All qualified patients provided written informed consent to participate in the study (in accordance with the Helsinki Declaration). The general characteristics of the participants are presented in Table 1.

The testing procedures were carried out according to the diagram shown in Fig. 1. All testing procedures was performed on the day preceding the start of a series of research procedures (T_0) and between the second and the fourth day and after the end of a series (T_1). Testing before (T_0) and following (T_1) consisted of clinical assessment of fatigue, performed by the FSS (Rosti-Otajärvi et al., 2017), gait speed using Timed 25-Foot Walk (T25-FW) and HGS and sEMG of dominant hand.

T25-FW was maximum walking speed, across a clearly marked, linear 25 foot (7.62 m) course. The T25-FW score was an average in seconds from the two successive trials (Motl et al., 2017).

The HGS dominant hand was measured using a digital Saehan dynamometer (test-retest reliability $r = 0.981$ right hand and $r = 0.985$ left hand (Reis & Arantes, 2011) (Newsome et al., 2019). HGS measurements were performed in accordance with the recommendations of the American Society of Hand Therapists. The sEMG test was performed for extensor (extensor carpi radialis, ECR) and flexor (flexor carpi radialis, FCR) muscles of the wrist, for the dominant hand.

First, a 30-second electromyographic signal in the resting position (spontaneous activity of motor units) was recorded. Next, performed two isometric maximal voluntary contractions (MVC) of five seconds against a fixed handle separated by 90sec rest, for FCR and ECR of the dominant side. The participants were instructed to produce maximal force as rapidly as possible and maintain it for three seconds. The recommended position for isometric MVC was used to evaluate muscles (Rota et al., 2013), i.e.:

- FCR, wrist flexion with the forearm supinated and leaning on a table. The wrist is slightly extended and the elbow is flexed 120°;
- ECR, wrist extension with the forearm pronated and leaning on a table. The wrist is slightly flexed and the elbow is flexed 120°.

The limb position was controlled using a mechanical goniometer. The isometric MVC was used to normalize voluntary contractions and rest-activity. The sEMG normalization is recommended to compare data between different muscles, individuals and across time. Normalization involves rescaling data from microvolts to a percentage of a reference value obtained during standardized reproducible conditions. (Rota et al., 2013).

After 5 minutes of rest, the participants were tasked with performing voluntary contraction during 10 sec (wrist flexion and next extension against the fixed plates). Recording of VC was repeated three times.

The recording at rest was registered simultaneously from 4 muscles of the dominant forearm. The VC was registered separately from the contractions, the extensor muscles and then the flexor muscles of the dominant hand.

During the recording of rest activity MVC and VC the subjects were seated on a chair and they were strictly controlled and instructed to maintain the required position (Rota et al., 2013).

The recording of sEMG, both before and after a series of WBC treatments, took place between 8:00am and 10:00am at an ambient temperature of 22–24°C. Surface EMG for Non-Invasive Assessment of Muscles (SENIAM) recommendations for scientific research using sEMG were included. For recording the signal, Noraxon Ag/AgCl dual electrodes (with a 1-cm diameter and an inter-electrode distance of 2 cm) were used. The electrodes were placed on the abdomen of the respective carpal flexor and extensor muscles (Hermens et al., 2000). Electrodes were outlined with permanent marker for replacement during subsequent data collection sessions. Skin impedance was 2 kΩ. A 4-channel Myotrace 400 Noraxon electromyograph was used for the tests.

The WBC procedure consisted of a 2-3 min walk in the cryogenic chamber at –110°C. Immediately before the WBC procedures, the patients were provided with a special treatment suit. They were instructed as how to protect the parts of the body that are particularly vulnerable to frostbite and on the proper way of moving and breathing during the treatment. Excluding Saturdays and Sundays, the WBC treatments were performed daily for the next four weeks. Each time after the WBC the subjects participated in 15-minute kinesiotherapy exercises conducted in groups of 5-6 people. The exercises were of general improvement nature and took into account the mobility of the subjects. The control group did not receive any therapy, but they had the same testing procedures at the same time points (T_0 and T_1)

Mathematical analysis of electromyograms was performed using Myo Research XP Master Edition software (v. 1.08.27), using the Standard Amplitude Reports protocols. The signals were filtered to remove motion artefacts and high frequency noise (band-pass filters with cut-off frequencies of 20 and 500 Hz). In order to determine the objective values of the change in the amplitude of bioelectric potentials, rectification of the recording (straightening) and smoothing (creation of the enveloping curve) was performed by applying the root mean square (RMS) calculation algorithm.

The obtained results were subjected to statistical analysis using STATISTICA computer software (version 13.3 PL). The normality of distribution of the results of the tested parameters was determined using the Shapiro-Wilk test. The values of descriptive statistics were calculated (median, minimum and maximum values). For values showing an abnormal distribution, a nonparametric test for Wilcoxon dependent variables, for independent variables Mann-Whitney U test was used and Spearman's rank order correlation, assuming a significance level of $p < 0.05$. The test power was calculated for all the presented analyses.

3. Results

The calculated median values of the root mean square amplitude (A_{RMS} [μV]) and normalized to MVC A_{RMS} [%] for the recorded electromyograms of ECR and FCR muscles are summarized in Tables 2 and 3.

With regards to the rest electromyograms the A_{RMS} values (non-normalized and normalized) between the control group and WBC group did not differ significantly in the pre-test (T_0).

After a series of WBC significant decreases were found in non-normalized amplitude of ECR electromyograms ($p = 0.00$) in the therapy group, and no significant changes in A_{RMS} (non-normalized and normalized) in the control group, in post-test (T_1).

The comparison ECR A_{RMS} between WBC than the control group in the post-test demonstrated significantly lower value (both non-normalized and normalized) in WBC group ($p = 0.002$. $p = 0.04$). Detailed information is included in Table 2.

With regards to the VC electromyograms no significant differences were found between the WBC group and the control group in both pre- and post-tests. However, a significant decrease of electromyogram A_{RMS} value in ECR non-normalized [μV] ($p = 0.00$) and both ECR and FCR normalized [%] ($p = 0.02$, $p = 0.03$), was shown. Detailed information is included in Table 3.

Median values for HGS, FSS, and T25-FW measured in pre-test (T0) and post-test (T1) in both WBC and control group are presented in Fig. 2. The statistical analysis showed a significant increase of strength HGS and a decrease of fatigue assessed by FSS and decreased time needed to cover a distance of 7.6 meters following a series of WBC. At the same time, no significant change in the control group was found.

The correlation analysis in the WBC group showed significant negative relationships between the HGS value and the A_{RMS} of resting electromyograms.

Table 2

Change in the median values of mean square amplitude of electromyograms recorded at rest, before and after a series of procedures in patients with MS (dominant hand)

N = 114		Wrist rest median (min-max)		
			A_{RMS} [µV]	
		WBC	**Control**	**WBC vs control**
ECR	T_0	3.15 (1.64–7.07)	3.22 (1.61–8.37)	$p = 0.46$
	T_1	2.97 (1.49–8.53	3.24 (1.59–7.69)	$p =$ **0.002;** *0.72, **0.9
		$p =$ **0.00;** *0.72, **0.9	$p = 0.94$	
			A_{RMS} [%]	
	T_0	2.54 (0.6–11.67)	3.75 (0.7–15.93)	$p = 0.39$
	T_1	2.4 (0.57–9.94)	3.82 (0.9–14.25)	$p =$ **0.04:** *0.74, **0.9
		$p = 0.08$	$p = 0.92$	
			A_{RMS} [µV]	
FCR	T_0	1.72 (0.76–10.50) $^{***}\mathbf{T_0ECR}_{ARMS}\mathbf{;\ ^{*}\ 1}$	1.72(1.02–10.45)	$p = 0.98$
	T_1	2.19 (1.05–6.44) $p = 0.27$	1.76 (0.7–10.41) $p = 0.33$	$p = 0.17$
			A_{RMS} [%]	
	T_0	1.55 (0.26–19.84) $^{***}T_0ECR_{ARMS}$; *0.72, **0.89	1.88 (0.61–20.19)	$p = 0.17$
	T_1	1.75 (0.27–14.12) $p = 0.18$	1.94 (0.31–22.28) $p = 0.33$	$p = 0.49$

Legend: T_O – pre-test WBC, T_1 – post-test WBC, ECR - extensor carpi radialis, FCR - flexor carpi radialis, A_{RMS} - Root Mean Square Amplitude, $\%A_{RMS}$ – normalizes to MVC Root Mean Square Amplitude, power test for H0: Mi1 = Mi2 and alfa: *0.05, ** 0.2.

Table 3

Change in the median values of mean square amplitude of electromyograms recorded at voluntary contraction, before and after a series of procedures in patients with MS (dominant hand)

N = 114		VC median (min-max)		
			A_{RMS} [µV]	
		WBC	**Control**	**WBC vs control**
ECR	T_0	123.85 (45.36–354.53)	117.49 (42.36–356.53)	$p = 0.80$
	T_1	110.59 (35.54–312.61)	116.54 (43.06–354.73)	$p = 0.30$
	T_0vsT_1	$p =$ **0.00;** *0.96, **0.99	$p = 0.74$	
			A_{RMS} [%]	
	T_0	90.2 (77.43–100.25)	90.43 (75.08–101.61)	$p = 0.69$
	T_1	84.8 (44.88–122.73)	88.81 (54,63–112,48)	
	T_0vsT_1	**p = 0.03;***0.54, **0.79	$p = 0.19$	
			A_{RMS} [µv]	
FCR	T_0	111.8 (35.54–312.61)	113.17 (62.46–395.29)	$p = 0.70$
	T_1	109.25 (61.25–393.39)	112.12 (59.56–390.19)	$p = 0.74$
	T_0vsT_1	$p = 0.89$	$p = 0.07$	$p = 0.62$
			A_{RMS} [%]	
	T_0	91.3(67.95–343.30)	91.91 (70,31–245,65)	$p = 0.49$
	T_1	88 (65.18–136.7)	91.37 (64,83–137,42)	$p = 0.93$
	T_0vsT_1	**p = 0.02;** *0.3, **0.51	$p = 0.47$	

Legend: T_O – pre-test WBC, T_1 – post-test WBC, ECR - extensor carpi radialis, FCR - flexor carpi radialis, A_{RMS} - Root Mean Square Amplitude, $\%A_{RMS}$ – normalizes to MVC Root Mean Square Amplitude, power test for H0: Mi1 = Mi2 and alfa: * 0.05, ** 0.2.

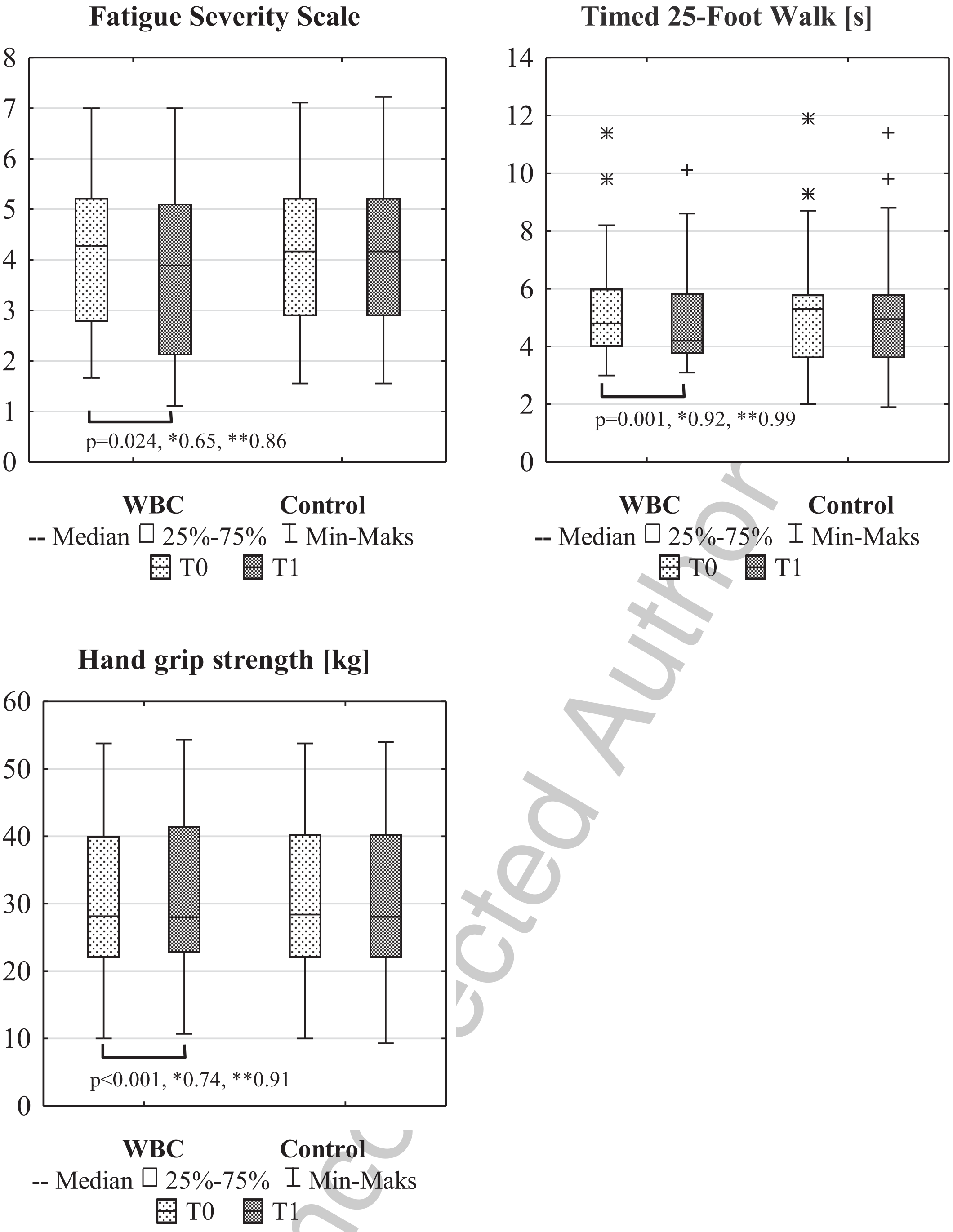

Fig. 2. Statistical analysis of the change of Fatigue Severity Scale, Timed 25-Foot Walk and hand grip strength following a series of WBC. Legend: T_O – before Whole Body Cryotherapy, T_1 – after Whole Body Cryotherapy, ECR - extensor carpi radialis, FCR - flexor carpi radialis, A_{RMS} - Root Mean Square Amplitude, MVC - maximum voluntary contraction. Power test for H0: Mi1 = Mi2 and alfa: *0.05; **0.2.

At the same time, a positive correlation was found between the A_{RMS} values of VC electromyograms and HGS. Detailed information is included in Table 4.

Demonstration of an increase in strength with a decrease in resting A_{RMS}, and an increase in VC A_{RMS} with an increase in HGS prompted us to

Table 4
Correlation values of electromyographic parameters with hand grip strength, before and after a series of WBC treatments in patients with MS (dominant hand)

sEMG	Spearman's rank order correlation	WBC group			
		T0		T1	
		R	*p*	R	*p*
		Hand grip strength [kg]			
Wrist rest A_{RMS}	ECR [uV]	**–0.3298** *0.74; **0.91	**0.0101**	**–0.2811** *0.59; **0.82	**0.0296**
	FCU [uV]	**–0.3376** *0.76; **0.92	**0.0083**	**–0.3234** *0.72; **0.9	**0.0117**
		Hand grip strength [kg]			
VC wrist A_{RMS}	ECR [uV]	**0.4537** *0.96;**0.99	**0.0003**	**0.542** *0,99;**1	**<0.0001**
	FCU [uV]	**0.7041** *1;	**<0.0001**	**0.6107** *0,99; **1	**<0.0001**

Legend: T_O – before WBC, T_1 – after WBC, ECR - extensor carpi radialis, FCR - flexor carpi radialis, A_{RMS} - Root Mean Square Amplitude, power test for H0: Mi1 = Mi2 and alfa: *0.05; **0.2.

analyze the A_{RMS} delta. Delta A_{RMS} (ΔA_{RMS}) is the value of the VC electromyogram minus the value of the resting electromyogram. Figure 3 shows the correlation of the ΔA_{RMS} with the HGS value of the dominant upper limb.

Analysis of the dependence of the parameters of the dominant limb showed a high correlation of the increase of ΔA_{RMS} and increase of HGS both for ECR ($p < 0.001$) and FCR ($p < 0.0001$) muscle, before WBC therapy. After a series of WBC, positive correlation between the ΔA_{RMS} ECR and HGS was strengthened, at the same time correlation between the HGS and FCR ΔA_{RMS} lost significance [Fig. 3].

Pre-testing in the WBC group showed no relationship was found between level fatigue and value of A_{RMS}. However post-testing showed a significant correlation between the increase of fatigue (FFS) and the increase of A_{RMS} of rest electromyogram ($p = 0.03$). At the same time, increase of fatigue was correlated with a decrease of A_{RMS} of VC electromyogram. A decrease in the level of fatigue felt was connected with along with the improvement of VC muscle activity [Table 5].

With regards to walking speed of the WBC group, pre-testing increase of A_{RMS} of rest electromyogram was correlated with a longer time to covering the 25-foot walk ($p < 0.00$). A longer time walk was correlated with a decreased of A_{RMS} of VC electromyogram ($p < 0.00$). At the same time, a longer time of walk was correlated with a decrease of A_{RMS} of VC electromyogram ($p < 0.00$) before 20 series of WBC. After 20 series of WBC strength of the described relationship has not changed ($p < 0.00$). These results may indicate that increased resting bioelectrical activity intensifies the symptoms of fatigue and reduces functional status [Table 5].

4. Discussion

The series of 20 WBC exposures significantly improved the functional status of patients with multiple sclerosis. Comparison of the group exposed to WBC with the control group revealed: decrease in the level of fatigue, increase in grip strength and walking speed after 20 WBC exposures. There were no similar changes in the control group [Fig. 2]. The demonstrated therapeutic effects may be a consequence of adaptive changes in the bioelectrical activity of muscles, which include postoperative normalization of the resting bioelectric voltage between the ECR and FCU, and a decrease in the amplitude of electrical signals produced by muscles during voluntary contraction [Tables 2.3]. Additionally, the relationship between the results of the applied functional tests and the value of the RMS amplitude was revealed [Tables 4.5, Fig 3].

As previously mentioned, a number of positive changes have been demonstrated after WBC exposure in MS patients (Pawik, et al., 2019)(Miller et al., 2016) (Miller et al., 2013), none of the research concerns neuro-muscular activity. This study tested the new hypothesis that a series of 20 WBC therapies can make adaptative changes to sEMG signals in patients with MS. The potential influence of WBC on electromyographic signals has previously been tested

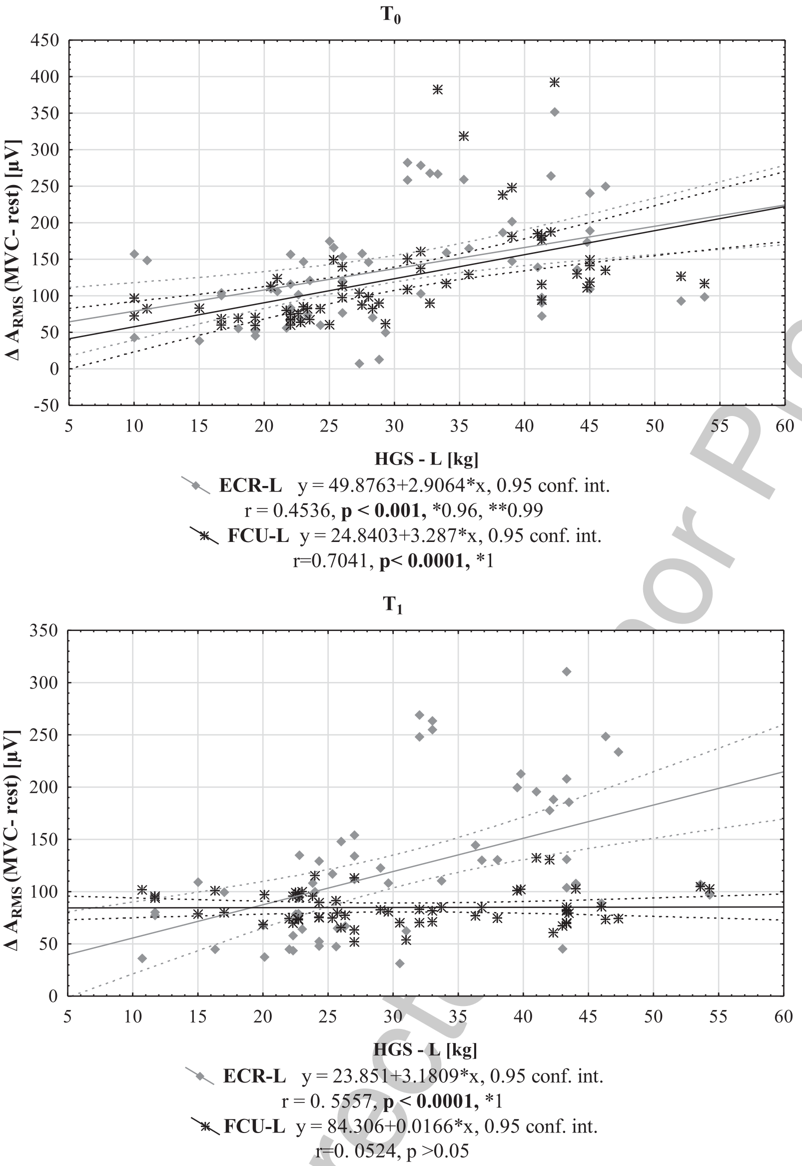

Fig. 3. Correlation between HGS value and value of delta A_{RMS} (VC - rest) dominant hand, before (T_0) and after (T_1) WBC treatments in patients with MS.

in healthy participants, but in the literature there is no information about the effect on muscle activity in patients with MS. sEMG is one of the methods of neurophysiological assessment of the efficiency of motor units of the skeletal muscles, and records even the smallest changes in muscle activity, allowing us to also detect changes in response to stimulus exposures (Del Vecchio et al., 2017) (Scott et al., 2011) (Giemza et al., 2014). sEMG was previously used to assess potential changes in muscle activity after exposure of different types of physical stimuli (neuromuscular electrical stimulation, low-level laser therapy, radial shock wave therapy) (Dymarek et al., 2016) (De Oliveira Melo et al., 2016) as well as to assess the impact of low temperatures (Winkel & Jørgensen, 1991) (Holewijn & Heus, 1992) (Solianik et al., 2015) (Piedrahita et al., 2009) (Loro et al., 2019) (Akehi et al., 2016) (Gilhem et al., 2013).

The amplitude values obtained in the mathematical analysis of electromyograms parameterize the level of muscle excitation as well as the efficiency of the motor units that form it (Del Vecchio et al., 2017). It has been shown that the achieved A_{RMS} values of exercise electromyograms depend on the

Table 5
Correlation values of electromyographic parameters with Fatigue Severity Scale, before and after a series of WBC treatments in patients with MS

sEMG	Spearman's rank order correlation	T_0		T_1	
		R	*p*	R	*p*
			Fatigue Severity Scale		
wrist rest A_{RMS}	ECR [μV]	0.1089	0.4074	–0.1176	0.3708
	FCR [μV]	0.0473	0.7197	**0.2739** *0.57; **0.81	**0.0342**
VC A_{RMS}	ECR [μV]	–0.0893	0.4974	**–0.3966** *0.89; **0.97	**0.0017**
	FCR [μV]	–0.1348	0.3045	**–0.4796** *0.98; **0.99	**0.0001**
			Timed 25-Foot Walk [sec]		
wrist rest A_{RMS}	ECR [μV]	**0.441** *0.95; **0.99	**0.0004**	**0.2655** *0.98; **0.78	**0.0403**
	FCR [μV]	**0.4338** *0.94; **0,99	**0.0005**	0.2079	0.111
VC A_{RMS}	ECR [μV]	**–0.507** *0.99; **1	**<0.0001**	**–0.4828** *0.99; **1	**0.0001**
	FCR [μV]	**–0.5116** *0.99; **1	**<0.0001**	**–0.4791** *0.99; **1	**0.0001**

Legend: T_0 – before WBC, T_1 – after WBC, ECR - extensor carpi radialis, FCU - flexor carpi radialis, A_{RMS} - Root Mean Square Amplitude, power test for H0: Mi1 = Mi2 and alfa: *0.05; **0.2.

training and strength of the assessed muscles (Rhodes & Alexander, 2018). The sEMG signal amplitude and frequency can be modified by a multitude of extrinsic and intrinsic factors (e.g. type of muscle contraction, electrode placement, skin resistance). Therefore, to minimize these factors, observance procedure by SENIAM and signal normalization using standardized and reproducible muscle contractions is recommended (Cid et al., 2018) (Rota et al., 2013). Therefore, A_{RMS} results were also analyzed in normalized values [%] to isometric MVC [Tables 2, 3].

In the presented research, after using a series of 20 WBC treatments, the A_{RMS} of the rest electromyograms did not change significantly or was slightly decreased [Table 2]. But it is worth noting that in pretest records significantly higher values of the A_{RMS} were observed in the electromyograms for the ECR than in those for the FCR [Table 2]. After a series of WBC treatments equalization of the amplitude values for antagonistic muscles were observed (there were no significant differences between the values of this parameter in the ECR and FCR muscles), which may suggest a normalizing effect of the WBC treatment on muscle tension [Table 2]. Similar conclusions have been drawn based on the study with a group of post-stroke patients in whom a decrease in the value of resting electromyograms observed up to 24 hours after stimulation with Radial Shock Wave Therapy (Dymarek et al., 2016). In healthy participants, similar to our MS patients, averaged sEMG amplitude after repeated WBC was decreased [Tables 1 and 2] (Westerlund et al., 2009). However, very limited data exist on the adaptation of neuromuscular to the series of cold exposure. Most data refers to a single exposure, immediately after cooling (cooling therapy, ice bag, immersion in water) (Winkel & Jørgensen, 1991) (Solianik et al., 2015) (Holewijn & Heus, 1992) (Loro et al., 2019) (Akehi et al., 2016). It is reported that cooling superficial tissues roughly doubles the sEMG amplitude, for example in healthy volunteers (Winkel & Jørgensen, 1991), and patients with symptoms of spasticity (Harlaar et al., 2001) as well as in patients in the early phases following knee surgery (Loro et al., 2019). It is known that temperature is an important modulator of the neuromuscular function. Nerve conduction velocity progressively reduces concomitantly with decrease skin temperature during cryotherapy (ice) (Algafly & George, 2007). It was reported that subjects who exercised and shivered at the same time, the antagonist muscle co-contracted together with the agonist muscle, which caused the observed increase in amplitude. It confirmed body cooling decreases the performance of muscles during dynamic exercise and changes the co-ordination of muscle contractions (Bawa et al., 1987) (Westerlund et al., 2009). It has been reported that after cooling, increased EMG activity enhances the utilization of the elastic components of the working muscles (Asmussen et al., 1976). The ability to adapt the muscles to the series of WBC exposures in the volunteers was also assessed by means of electromyography. In the mentioned studies the averaged electromyographic muscle activity increased immediately after first and 36 WBC exposure. However, the observed increase in electromyogram amplitude after the first exposure was higher than after 36 exposures. The adaptive effect was explained by the authors by the theory of the adaptation of the muscle spindle (Westerlund et al., 2009).

It should be emphasized that cold therapy uses different types of exposures (water, ice, air cold, nitrogen, carbon dioxide etc.). Typically, cooling is characterized by higher temperatures (>0°C) and longer exposure times (10 to 30 minutes) in comparison to typical cryotherapy (1–3 minutes at –30°C to –110 °C) (Giemza et al., 2014) (Loro et al., 2019) (Akehi et al., 2016) (Gilhem et al., 2013) (Westerlund et al., 2009). This is the probably because of the discrepancy in literature results. For example, in contrast to cooling by ice or cold water a single WBC session (3 min at – 110 °C) does not decrease neuromuscular performance of the elbow flexors in young men (Ferreira-Junior et al., 2014). Similarly, other studies did not observe any effect of a single WBC session on the EMG signals of the tibialis anterior or gastrocnemius medialis muscles during a drop-jump exercise, or on the carpi radialis during maximal isometric wrist flexion (Westerlund et al., 2009). Four applications of air-pulsed cryotherapy 3 days after a strenuous eccentric exercise showed no change in the sEMG signal of elbow flexor (Gilhem et al., 2013). In our research, as many as 20 WBC procedures were performed. In another study in which also adaptative change was observed, the subjects had 36 WBC exposures (Westerlund et al., 2009). Thus, it is important to highlight that the type of cold exposure (different temperature gradients, exposure time, and the conductivity of water and air) may be one of the reasons for the difference between study results. The second reason can be the number of exposures, which should also be considered in the comparison of studies.

In the presented study, after using a series of 20 WBC treatments, we also reported time decrease in T25-FW and decrease of fatigue (FSS) [Fig. 2]. However, we did not find any similar scientific research referring to WBC with which our results could be compared. Nevertheless, similar results were reported by researchers using cooling therapy (cooling garment 1 hour, 12–21 C°). The results of the research showed objective, measurable but modest improvements in motor function, assessed with MS Functional Composite (T25-FW, the 9-hole peg test, Paced Auditory Serial Addition Test) and less fatigue during the month of daily cooling (Modified Fatigue Impact Scale, MFIS) (Schwid, 2003).

It is worth noting that our study assessed the impact of a series of WBC treatments on the analyzed parameters that were conducted after a minimum of 24 hours from the end of a series of treatments in order to eliminate the effect of the last treatment per se.

We also showed a relationship between an increase in A_{RMS}, an increase in HGS, as well as an improvement in gait speed and a decrease in perceived fatigue [Tables 4, 5]. This is consistent with data from the literature that report positive effects of low temperatures on the functional status of MS patients (Schwid, 2003) (Pawik, et al., 2019) (Miller et al., 2016) (Op't Eijnde et al., 2014).

Among others, correlations of the increased amplitude with an increase in the isometric strength and endurance of the quadriceps femoris muscle and an increase in the global HGS on a hydraulic dynamometer after local stimulation with a low temperature were demonstrated (Xu et al., 2015) (Del Vecchio et al., 2017). After single partial-body cryotherapy (50-second session of PBC, temperature -130 to –160° C) an increase on the maximum HGS in healthy adults has been shown (De Nardi et al., 2017). It was also found that a brief session of local cryostimulation (–160° C) may acutely preserve maximal isometric force following a fatiguing protocol (De Nardi et al., 2019). Similarly, in our study we showed increased value of HGS after a series of WBC in MS patients [Fig. 2].

5. Conclusions

The study has shown that a series of WBC daily treatments affect the sEMG signal. At rest, spontaneous muscle activity slightly changed within antagonists, leading to comparable values of flexor and extensor amplitude, and normalization of the bioelectrical voltage between them. During active contraction, the change of bioelectrical activity was strongly marked by a decrease in RMS amplitude in both observed muscles. At the same time, prolonged daily cryotherapy improves the functional state and reduces fatigue in patients with MS which may be associated with the described adaptive changes observed in muscle bioelectrical activity. The positive functional changes observed in MS patients undergoing daily WBC described in the literature and confirmed by our research may have a cause in neuromuscular adaptive changes. There is still a lack of information on this topic, therefore further research is necessary.

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Conflict of interest

None declared.

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