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PRACA ORYGINALNA

ZALEŻNOŚĆ POMIĘDZY OBJAWEM ZWIĘKSZONEGO NAPIĘCIA MIĘŚNIOWEGO W SPOCZYNKU A PARAMETRAMI SKURCZU MAKSYMALNEGO W BADANIACH EMG POWIERZCHNIOWEJ U CHORYCH PO CZĘŚCIOWYCH URAZACH RDZENIA KRĘGOWEGO W ODCINKU SZYJNYM KRĘGOSŁUPA. BADANIE PILOTAŻOWE

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STRESZCZENIE

Wstęp. Kliniczna ocena objawów spastyczności i siły mięśni jest często wykorzystywana do planowania i monitorowania postępów leczenia fizjoterapeutycznego u pacjentów po niecałkowitym uszkodzeniu rdzenia kręgowego (iSCI). Jednakże oceny te są subiektywne, mogą mieć ograniczoną dokładność i mogą nie dostarczać szczegółowych informacji o zmianach neurofizjologicznych pojawiających się po urazie kręgosłupa. Określenie tych dwóch zależności w aktywności jednostek motorycznych mięśni może umożliwić personalizację zabiegów kinezyterapeutycznych u pacjentów po iSCI. Dotyczy to ukierunkowania zabiegów redukujących wzmożone napięcie mięśniowe oraz realizacji ćwiczeń wzmacniających do wybranych grup mięśniowych wykazujących największe deficyty w aktywności jednostek motorycznych.

Cel. W tej pracy zbadano korelacje między standardowymi ocenami klinicznymi spastyczności i siły mięśni a obiektywnymi i nieinwazyjnymi pomiarami neurofizjologicznymi aktywności mięśni u pacjentów z iSCI do 2 miesięcy po urazie.

Materiał i metody. Zbadano 19 pacjentów z iSCI (ASIA C=10 i D=9) po urazach kręgosłupa i rdzenia kręgowego C5-Th1, stosując zmodyfikowaną skalę Ashwortha (MAS) i skalę Lovetta (Lovett), a także elektromiografię powierzchniową (sEMG) rejestrowaną w spoczynku (rsEMG) oraz podczas próby maksymalnego skurczu (mcsEMG) wykonywane obustronnie w mięśniach odwodziciela krótkiego kciuka (APB) i mięśnia prostego uda (REC FEM).

Wyniki. Stwierdzono znaczące dodatnie korelacje pomiędzy wynikami MAS i rsEMG (r_s=0,701, p=0,008 w zapisach APB; r_s=0,672, p=0,021 w zapisach REC FEM) oraz Lovett i mcsEMG (r_s=0,525, p=0,008 w zapisach APB; r_s=0,408, p=0,028 w zapisach REC FEM) oraz ujemne korelacje pomiędzy wynikami rsEMG i mcsEMG (r_s=-0,581, p=0,008 w zapisach APB; r_s=-0,487, p=0,032 w zapisach REC FEM).

Wnioski. Wykryte korelacje pomiędzy ocenami klinicznymi a wynikami rejestracji sEMG ujawniają zjawisko zależności zwiększonego napięcia mięśniowego wywołującego obniżenie własności kurczliwych jednostek ruchowych mięśnia, które należy uwzględnić przy formułowaniu strategii kinezyterapeutycznych w rehabilitacji chorych po iSCI na poziomie szyjnym. Badania sEMG pozwalają na dokładniejszą charakterystykę czynności mięśni, umożliwiając w ten sposób wykrycie nawet subklinicznych zmian, które mogłyby pozostać niezauważone przy zastosowaniu innej diagnostyki klinicznej.

Słowa kluczowe: niecałkowite uszkodzenie rdzenia kręgowego, napięcie mięśniowe, maksymalny skurcz mięśnia, skala Ashworth, skala Lovett, elektromiografia powierzchniowa

Ahead-of-print

ORIGINAL ARTICLE

RELATIONSHIP BETWEEN THE SYMPTOM OF INCREASED MUSCLE TENSION AT REST AND MAXIMAL CONTRACTION PARAMETERS IN SURFACE EMG EXAMINATIONS IN PATIENTS WITH PARTIAL SPINAL CORD INJURIES AT THE CERVICAL LEVEL. PILOT STUDY

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SUMMARY

Introduction. Clinical assessments of spasticity symptoms and muscle strength are often used to plan and monitor the progress and the physiotherapeutic treatment in patients after an incomplete spinal cord injury (iSCI). However, these assessments are subjective, may have limited accuracy, and may not provide detailed neurophysiological changes that appear following spinal trauma. Determining these two dependencies in the activity of muscle motor units may enable the personalization of kinesiotherapy treatments in patients after iSCI. This concerns the targeting of treatments that reduce increased muscle tension and the implementation of strengthening exercises to specific muscle groups showing the greatest deficits in the activity of motor units.

Aim. In this study, we analyzed correlations between standard clinical assessments of spasticity and muscle strength and objective, and non-invasive neurophysiological measures of muscle activity in iSCI patients up to 2 months after injury.

Material and Methods. We evaluated 19 iSCI patients (ASIA C=10, and D=9) after C5-Th1 spinal injuries using the Modified Ashworth Scale (MAS) and the Lovett Scale (Lovett), as well as surface electromyography (sEMG) recordings at rest (rsEMG) and during the attempt of maximal contraction (mcsEMG) performed in abductor pollicis brevis (APB) and rectus femoris (REC FEM) muscles bilaterally.

Results. We have found significant positive correlations between MAS and rsEMG (r_s=0.701, p=0.008 in APB recordings; r_s=0.672, p=0.021 in REC FEM recordings), and Lovett and mcsEMG (r_s=0.525, p=0.008 in APB recordings; r_s=0.408, p=0.028 in REC FEM recordings) results, and negative correlations between rsEMG and mcsEMG scores (r_s=-0.581, p=0.008 in APB recordings; r_s=-0.487, p=0.032 in REC FEM recordings).

Conclusions. The detected correlations between clinical assessments and the results of sEMG recordings reveal the phenomenon of dependence on increased muscle tension causing a decrease in contractile properties of muscle motor units, which should be taken into account when formulating kinesiotherapeutic strategies in the rehabilitation of patients after iSCI at the cervical level. sEMG studies allow for more accurate characterization of muscle function, thus enabling the detection of even subclinical changes that could be unnoticed using other clinical diagnostics.

Keywords: incomplete spinal cord injury, muscle tension, maximal muscle contraction, Ashworth scale, Lovett scale, surface electromyography

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Introduction

Importance of evaluation of patients with incomplete spinal cord injuries in clinical and neurophysiological studies

In patients after the incomplete spinal cord injury (iSCI), the determination of its level and severity significantly impacts of the prognosis of functional status improvement following the treatment (Van Middendorp *et al.* 2011). A review of the literature shows that the ASIA impairment scale is most often used for this purpose. This evaluation is based on the assessment of motor and sensory functions using a light touch and pinprick (Furlan *et al.* 2011). Although the ASIA classification and AIS score are still utilized by many clinical centers and engaged in the treatment of iSCI patients as the gold standard, the latest research indicates that the AIS classification has a poor predictive ability toward the return of sensorimotor functions (Balbinot 2022). A complex assessment of the iSCI patient is important for planning the physiotherapeutic care, unfortunately, there are still no generally accepted international examination protocols for these purposes (Harvey 2016). The authors of the most relevant papers on this issue indicate, that it is particularly important to assess muscle strength and its tension in order to determine the treatment algorithm, which should be personalized for the particular patients with different advancements of iSCI (Biering-Sørensen *et al.* 2006, Peek and Pensuk 2013). It seems that reliable diagnostic information can be provided by neurophysiological examinations, in cases of muscle groups that cannot be directly evaluated in classical physical examinations (Van Middendorp *et al.* 2011, Wu *et al.* 2013). Testing the muscle strength and the muscle tension in a clinical condition, however, can sometimes cause problems, especially when it requires assessing muscle strength between 4 and 5 on the Lovett scale and 2 and 3 on the modified Ashworth scale (MAS)(Cuthbert and Goodheart 2007). Recent studies provided evidence of the high utility of electromyographical studies with the surface electrodes (sEMG), which besides the non-invasiveness, allow for the precise evaluation of the functional status of patients with iSCI (Wincek *et al.* 2021) and other movement disorders (Huber *et al.* 2021, Huber *et al.* 2022, Kaczmarek *et al.* 2022, Kaczmarek *et al.* 2022, Rajczewski *et al.* 2023). Nevertheless, little data is provided on the relationships between the parameters from the sEMG recordings and the results of clinical studies on the muscle's functional evaluation.

Assessment of the muscle strength

Medical databases indicate that manual muscle strength testing (MMT) is the most common and useful in examining patients with neuromusculoskeletal disorders (Cuthbert and Goodheart 2007). However, the reliability and validity of the study are affected by the clinical experience of the examiner and training in manual muscle testing (MMT), as well as adherence to the study protocol, which will allow for repeatability. MMT does not require equipment and is a widespread method, but the obtained data is analyzed on an ordinal scale, so this is not easily comparable in a mathematical way. It is not possible to conclude that patients who received the same score on the test are equally skilled and this assessment is considered as low precise and subjective. Historically it emerged from the studies of Lovett et al. (1912), that ranging from 0-5, depending greatly on the skills of the examiner, cannot capture subtle changes in muscle strength (Cuthbert and Goodheart 2007, Peek and Pensuk 2013).

Assessment of the spasticity symptom

Evaluation of spasticity in the clinical setting seems to be problematic, especially when it comes to its quantification. The authors continue to point to the need for a more objective assessment. Many scales have been developed to study spasticity in the clinical setting, the most commonly used being the Ashworth scale, the modified Ashworth scale, and the Tardieu scale or the modified Tardieu scale. It is difficult to determine whether the given scales are reliable, because spasticity depends not only on the etiology, but also can fluctuate during the day under the influence of many factors (Biering-Sørensen *et al.* 2006, Balci 2018). Despite the ease of use of the scales and the lack of requirements for additional equipment, MAS is not characterized by high specificity, as the assessment may be affected by the phenomenon of viscoelasticity of soft tissues and joints (Cha *et al.* 2018). Biering-Sørensen et al. (2006) emphasizes that as little repetitions, because with repeated repetitions, the level of resistance posed by tissues with viscoelastic properties decreases. In addition, the speed of the movement during the test is also crucial - it must be high enough to trigger the stretch reflex, but also repetitive, because the phenomenon of spasticity is speed-dependent (Biering-Sørensen *et al.* 2006, Balci 2018). Several papers recommend performing the test by a single, experienced researcher due to the high variability of the result between researchers. In addition, the need to standardize the test is indicated, as the terminology describing the scale leaves room for subjective interpretation. Researchers emphasize that the MAS score shows the resistance to passive movement in the joint and thus assesses all disorders associated with increased muscle tone and does not distinguish spasticity from other disorders of muscle tension (Balci 2018). A study by Cha et al. (2018) showed a significant positive correlation between skeletal muscle index of lower extremities (SMIL) and three different spasticity rating scales, highlighting the importance of accurately assessing spasticity before implementing rehabilitation.

Significance of surface EMG (sEMG) in evaluation of muscle function

The surface EMG (sEMG) examination gives the possibility of recording signals of electrical muscle activity from a large area from many places at the same time and is also painless (Wu *et al.* 2013). Despite its non-invasiveness, it is not widespread in clinical studies in people after iSCI (Balbinot 2022). The literature emphasizes that the sEMG test allows examination of the spontaneous activity of muscle motor units at rest, and is also a complementary tool for clinical evaluation (Huber *et al.* 2013, Lisiński and Huber 2017). It allows for obtaining more accurate quantitative data from muscles rated 0-2 in MMT (Balbinot 2022). The literature indicates the lack of sufficient knowledge and experience on the part of the researcher to interpret the results as the main limitations of the sEMG study. The time-consuming nature of the examination and the high cost of the equipment are also emphasized. The above-mentioned barriers make published articles based on studies conducted on a small number of patients (Cuthbert and Goodheart 2007, Campanini *et al.* 2020). Other researchers also indicate susceptibility to artifacts caused by movement and body temperature, as well as the possibility of signal interference by factors that increase skin resistance (Wu *et al.* 2013). Biering-Sørensen *et al.* (2006) emphasize that not only skin resistance can affect the sEMG measurements results, but also electrode placement and thickness layers of subcutaneous fat.

Correlation between clinical scales and sEMG results

So far, the correlation between the Ashworth and Lovett scales and sEMG tests in patients with partial spinal cord injury at the cervical level has not been fully established. Few authors indicate the possibility of associations between muscle strength measured in the Lovett scale and the decrease in EMG amplitude and the motor unit recruitment frequency during the 5-second maximal contraction in other diseases. They also showed a negative correlation between the values recorded in resting EMG and maximal contraction EMG (Huber *et al.* 2013, Lisiński and Huber 2017). Due to the subjectivity of the scales used for assessment in clinical conditions, determining whether there is a relationship between the listed scales (Lovett and the modified Ashworth scale) and more quantified methods such as sEMG seems to have a clinical measurable value.

Aim

In this study, we analyzed correlations between standard clinical assessments of spasticity and muscle strength and objective, and non-invasive neurophysiological measures of muscle activity in iSCI patients up to 2 months after injury.

Material and methods

Participants and study design

The study was conducted on patients diagnosed in the Department of Pathophysiology of Locomotor Organs at the Wiktor Dega Orthopedic and Rehabilitation Clinical Hospital in Poznań. Nineteen patients of both genders with the incomplete spinal cord injury confirmed in neuroimaging MRI studies at the cervical level from C5 to C8/Th1 were qualified for this study. The patients were assessed using the American Spinal Injury Association (ASIA) and their ASIA Impairment Scale (AIS) level was determined - according to which they belonged to two groups AIS C (10 people) and AIS D (9 people) (Table 1). The control group of healthy volunteers (N =20) was examined to obtain the reference values of control clinical and neurophysiological recordings. The age and height of the subjects have been adjusted for better comparison to the study group. There were no statistically significant differences between the age and height of patients in the study group and healthy volunteers in the control group (Table 1). The patients have been chosen considering the spinal cord levels and their similar degree of injury; the preservation of the spinal cord structure was from 1/3 to 1/4. All subjects have been studied once with standard clinical assessment tools such as the Modified Ashworth Scale (MAS) and the Lovett Scale (Lovett), and neurophysiological tests, including surface electromyography at rest (rsEMG) and during the attempt of maximal contraction (mcsEMG) performed in chosen key muscles; abductor pollicis brevis (APB) and rectus femoris muscles (REC FEM). Before the start of the clinical and neurophysiological studies, all subjects declared a stable psychosocial status and signed a written informed consent for participation in the study. The study was conducted in accordance with the Declaration of Helsinki and was approved by the Bioethics Committee of the Medical University in Poznań (Decision No. 942/2021).

Table 1. Anthropometric and traumas characteristics of the iSCI patients, and healthy volunteers from the control group. Minimum, maximum, mean values, and standard deviations are presented. $p < 0.05$ determines significant statistical differences.

Parameters Subjects	Patients N=19		Control (Healthy volunteers) N=20		p
	Min. – Max.	Mean ±SD	Min. – Max.	Mean ±SD	
Age (years)	19-62	38.7±12.8	18-60	38.1±8.4	0.09
Height (cm)	164-185	173.8±5.3	156-187	173.2±6.1	0.08

Parameters	n
ASIA impairment scale (AIS)	AIS C=10 AIS D=9
Spinal Cord Injury Level	C5/6=1 C5=5 C6=5 C6/7=1 C7=3 C8=3 C8/Th1=1

Abbreviations: AIS C-incomplete lesion, motor function is preserved, more than 50% of key muscle have a muscle grade less than 3; AIS D–as above but more than 50% of key muscle have a muscle grade of 3 or more

Clinical examinations

Participants underwent a clinical examination in the form of determining the level of AIS and assessing muscle strength and tension using the Lovett scale (0-5 score) and the modified Ashworth scale (0-4 score), respectively. The evaluation with the above-mentioned tests was carried out by one experienced researcher in order to reduce interrater changes (Bohannon and Smith 1987, Buckup 2004, Huber *et al.* 2013, Lisiński and Huber 2017).

Surface electromyography recordings

The sEMG examination was carried out using a 4-channel Keypoint system (Medtronic A/S, Skøvlunde, Denmark), in accordance with the guidelines of the International Federation of Clinical Neurophysiology-European Chapter (Huber *et al.* 2013, Lisiński and Huber 2017, Wincek *et al.* 2021, Huber *et al.* 2021, Kaczmarek *et al.* 2022, Huber *et al.* 2022, Kaczmarek *et al.* 2022, Rajczewski *et al.* 2023, Wesołek *et al.* 2023). Standard disposable Ag/AgCl surface bipolar electrodes with an active surface of 5 mm² were used; they were placed over the muscle belly of APB and REC FEM muscles bilaterally, with a reference electrode placed on the distal muscle tendons. The ground electrode was placed nearby (Figure 1). During the neurophysiological tests, sEMG was performed at rest during complete relaxation of the examined muscles (rsEMG), and then during the muscles maximal contraction (mcsEMG) lasting 5 seconds. All patients were instructed by a neurophysiologist to contract muscles as much as possible in the three times maximal contraction attempts. The examiner selected the best attempt for analysis; the one with the highest mean amplitude measured peak-to-peak with reference to the isoelectric line. The output measure was the amplitude measured in μV. Tests were performed in an air-conditioned room with an average temperature of 22°C. During recordings settings the upper 10 kHz and the lower 20 Hz filters were applied. sEMG recordings in both controls and patients were performed at a base time of 80 ms/D and an amplification of 20–1000 μV/D.

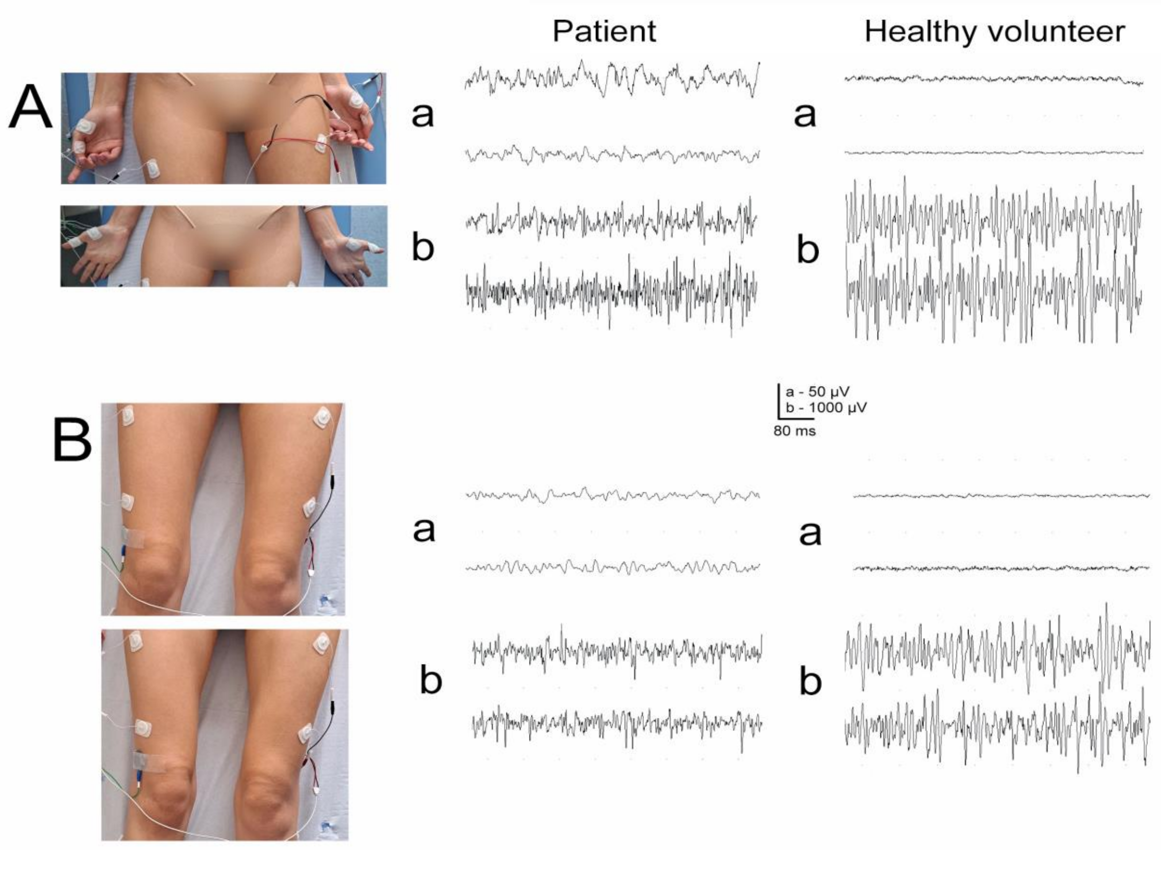

Figure 1. Photographs presenting the surface electromyography methodology with pairs of bilateral electrodes placed bilaterally during recordings from (A) abductor pollicis brevis (APB) and (B) rectus femoris (REC FEM) muscles performed at rest (a, rsEMG) and during the attempt of maximal contraction (b, mcsEMG) in a patient with iSCI and a healthy volunteer. Each upper recording was performed on the right side, and lower on the left side. Calibration bars for the amplification and a time base are the same for all the recordings.

Statistical Analysis

Data were analyzed with Statistica, version 13.1 (StatSoft, Kraków, Poland). Descriptive statistics included mean values, standard deviations (SD), and minimum (min) and maximum (max) values for measurable variables. Data mining was performed to match patients and healthy volunteers with age, sex and basic anthropomorphic properties like weight and height. The normality distribution and homogeneity of variances were conducted with Shapiro–Wilk tests and with Levene's tests. In patients with incomplete spinal cord injuries at the cervical levels, the mean values of parameters from sEMG tests and clinical tests were compared using Student's t-test and the Mann–Whitney test. It was assumed that a comparison of values at $p < 0.05$ determined significant statistical differences. The preliminary statistical analysis determined the required sample size using the primary outcome variables from sEMG recordings from rectus femoris muscles with a power of 80% and a significance level of 0.05 (two-tailed). The mean and standard deviation (SD) were calculated using the data from the twenty subjects, both in groups of patients and healthy controls. The sample size software estimated that at least 15 subjects from both groups were needed for the pilot study. The non-parametrical Spearman's rank correlation coefficient (r_s) was used to demonstrate correlations between clinical scale scores and rsEMG or mcsEMG amplitude measurement results, respectively. A $p < 0.05$ significance level was assumed as statistically significant for rank correlation.

Results

Data of the results from the clinical and neurophysiological studies is presented in Table 2. In general iSCI patients differed statistically from the healthy volunteers in results of both clinical and neurophysiological recordings at p from 0.045 to 0.006 with no difference on right and left side.

The mean amplitude of rsEMG recordings from APB muscles was twice as much greater than detected in healthy volunteers. The value of the amplitude recorded from APB during the maximal contraction in iSCI patients was twice as much lower than in controls. In clinical tests from APB muscles, we have found statistically significant symptoms of spasticity of both sides in MAS scores and the decrease of the muscle strength measured in Lovett scale at 4 and 3 on the right and the left sides. During mscEMG recordings from REC FEM muscles on both sides, the decrease of the amplitude parameter was almost at the same level as in the test from APB in a comparison to the refernce values. It was related to the MAS result evaluated bilaterally on 2. During mscEMG recordings the measured values of amplitudes were about 4.5 times smaller when recorded in patients after iSCI in comparison to those detected in healthy controls. These changes were complementary to scores measured in Lovett scale in REC FEM muscles bilaterally, which were evaluated as 1.

Figure 1 presents the examples of original rsEMG and mcsEMG recordings in one of the patients after C6 iSCI and the healthy volunteer for comparison. It can be observed that the increase of the amplitude parameter in rsEMG recordings in a patient both from APB and REC FEM muscles at rest is associated with the decrease of the same parameter measured during mscEMG tests during the attempts of the muscle maximal contraction.

Table 2. Collection of results from neurophysiological and clinical studies in the group of patients with incomplete spinal cord injuries and group of healthy volunteers for comparison and at different levels. Ranges, means and standard deviation values are presented. $p < 0.05$ determines significant statistical differences marked in bold.

Examined muscle	Test	Healthy volunteers (Control)		Patients C5–Th1		p Control vs. Patients C5-Th1	
		Right	Left	Right	Left	Right	Left
APB	rsEMG Amplitude (μV)	10-25 16.5±1.7	10-25 16.9±1.6	10-150 32.4±31.3	10-150 40±37.5	**0.015**	**0.011**
	mcsEMG Amplitude (μV)	1100-2500 1572.1±101.3	1000-2450 1523.4±109.2	50-2500 831.6±820.4	50-2500 826.3±839	**0.025**	**0.024**
	MAS	0-0 0	0-0 0	1-4 2	1-4 2	**0.030**	**0.030**
	LOVETT	5-5 5	5-5 5	1-5 4	1-5 3	**0.045**	**0.038**
REC FEM	rsEMG Amplitude (μV)	15-25 17.4.6±1.3	15-25 17.8±1.4	10-50 27.1±11.3	10-100 40±24.4	**0.032**	**0.015**
	mcsEMG Amplitude (μV)	700-1600 1410.9±105.4	650-1600 1405.2±101.1	0-1500 328.9±443.6	0-1100 273.7±349	**0.009**	**0.009**
	MAS	0-0 0	0-0 0	1-3 2	1-4 2	**0.022**	**0.022**
	LOVETT	4-5 5	4-5 5	0-5 1	0-5 1	**0.007**	**0.006**

Abbreviations: rsEMG-resting electromyography; mcsEMG-maximal contraction electromyography; APB-abductor pollicis brevis muscle; REC FEM R- rectus femoris muscle; MAS - Modified Ashworth Scale (0, 1, 1+, 2, 3, 4); LOVETT- Lovett Scale (0-5)

Plots presented in Figure 2 A-F and the data in Table 3 provide the evidence on the detected positive correlations between MAS and rsEMG (r_s=0.701, p=0.008 in APB recordings; r_s=0.672, p=0.021 in REC FEM recordings), and Lovett and mcsEMG (r_s=0.525, p=0.008 in APB recordings; r_s=0.408, p=0.028 in REC FEM recordings) results, and negative correlations between rsEMG and mcsEMG scores (r_s=-0.581, p=0.008 in APB recordings; r_s=-0.487, p=0.032 in REC FEM recordings).

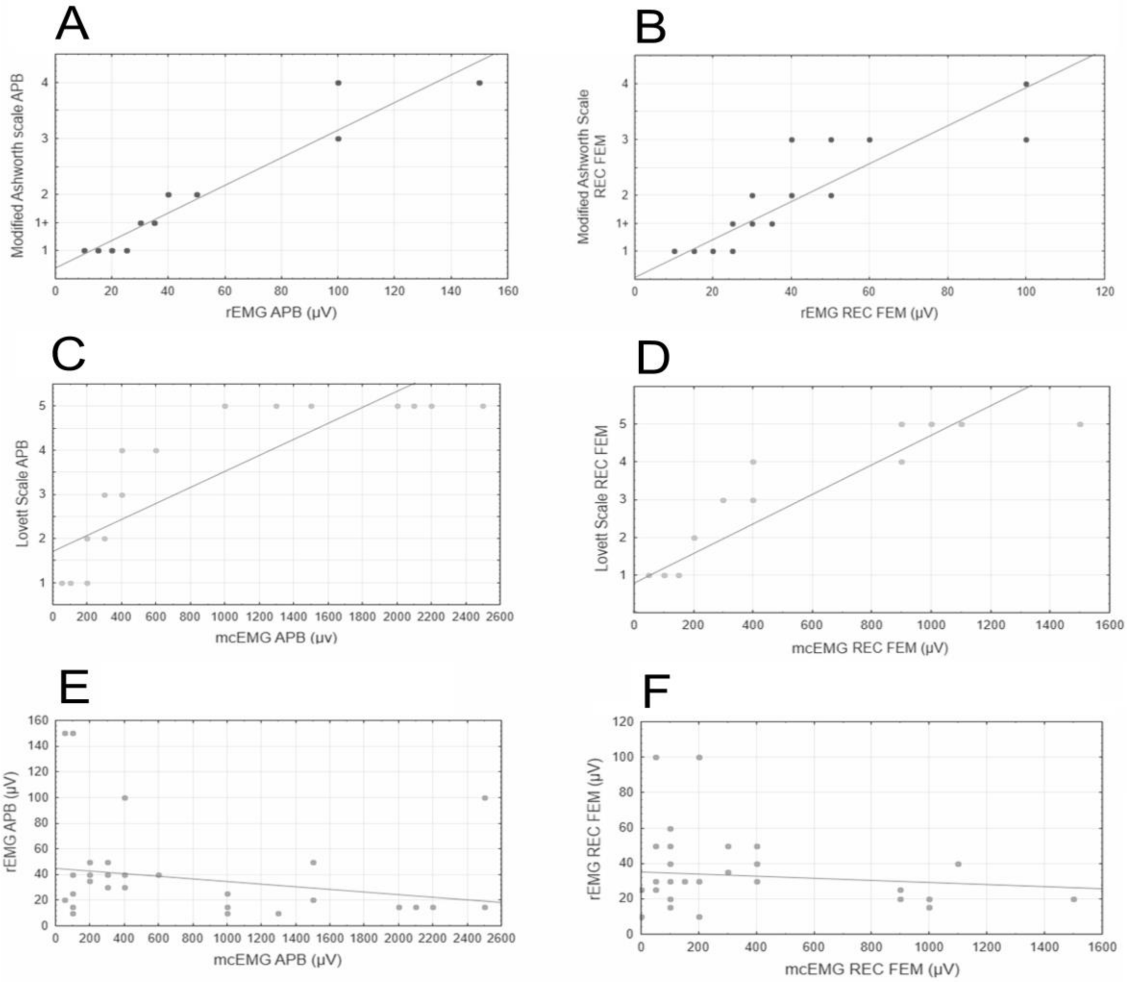

Figure 2. Plots of relationships between: A-MAS APB and rsEMG, B-MAS REC FEM and rsEMG, C- Lovett Scale APB and mcsEMG, D- Lovett Scale REC FEM and mcsEMG, E- rsEMG APB and mcs EMG, F- rsEMG REC FEM and mcsEMG.

Table 3. Spearman's rank correlation (r_s) calculated for the sEMG measurements and clinical study results in the groups of iSCI patients. Cumulative data from the right and left sides are presented. $p < 0.05$ was assumed as statistically significant for rank correlation.

sEMG test	r_s	p
	Modified Ashworth Scale	
rsEMG APB	0.701	0.008
rsEMG REC FEM	0.672	0.021
	Lovett Scale	
mcsEMG APB	0.525	0.008
mcsEMG REC FEM	0.408	0.028
	rsEMG	
mcsEMG APB	-0.581	0.008
mcsEMG REC FEM	-0.487	0.009

Discussion

The results presented in this paper reveal the correlation between sEMG recordings and clinical evaluation outcomes. It exposes that the decrease in contractile properties of muscle motor units is resulted by the increased muscle tension at rest. This dependence should be taken under consideration when planning the physiotherapy procedures of patients after cervical iSCI. This paper provides the first detailed presentation of such correlation recorded in patients after iSCI at C5-C8 levels. This pilot study shows that in iSCI patients by reducing the spasticity symptoms, following the kinesiotherapy practitioner therapy, or applying anti-spastic medications, there is a chance of positively influencing muscle function.

In iSCI patients, as a result of the disorder in the neural transmission of impulses from the supraspinal centers, the dysfunction of the lower motoneurone occurs, which is associated with increased muscle tension observed in the examined patients. This phenomenon also may explain explains why Huber et al. (2022) observed increased a spasticity and the reduced muscle strength in patients after ischemic stroke. The spontaneous generation of neuronal impulses from the lower motor neuron to the effector with a frequency of more than 5 Hz is caused by a loss of control of spinal motor centers over the excitatory and inhibitory influences from the cortico-spinal centers. This phenomenon contributes to the increase in the amplitude parameter above 25 μV in rsEMG recordings, which at the resting condition of the muscle is considered as increased muscle tension (Huber et al. 2013). The results of the current study seem to support this hypothesis.

The study included patients after iSCI with similar structural neuroimaging results, although the different degree of advancement of post-traumatic neurophysiological pathologies may be a limitation of this study. Another factor affecting the reliability of our study may be the ASIA score itself. As far as the risk resulting from the methodology of our study is concerned, it should be taken into account the patient's motivation factor to perform the tasks included in the clinical diagnostic tests. Therefore there were repeated the sEMG examination of each muscle three times, selecting the best result after consultation with another experienced neurophysiologist. We also adhered strictly to the protocol when assessing the results obtained with the MAS and Lovett clinical scales. We suggest that the assessment of patients after iSCI should not be limited to clinical tests. The methodology of the surface electromyography examination presented in this article is a repeatable, painless and constitutes the objective tool providing the reliable data to both the patient and the medical professionals. We recommend using neurophysiological tests not only in the early period after the spinal injury, but also later, which will allow for the creation of an individually tailored physiotherapy plan. It is worth emphasizing that sEMG allows for the objectivization of the subclinical changes, which may also have a positive impact on the patient's motivation and an engagement in the rehabilitation program.

The presented pilot study shows only the promising hypotheses, due to the fact that it includes only 19 patients with a spinal cord injury at the C5-C8 levels, and women constituted a small percentage of patients; a similar study on a larger population of iSCI subjects of both genders should be considered. Our study includes only the assessment of the sEMG amplitude parameter from APB and REC FEM muscles. We see the need to extend the evaluation of the sEMG signal acquisition with the frequency of the recruiting muscle motor units parameter as well as to examine more muscles, which is also underlined by other researchers (Balbinot *et al.* 2021).

Conclusions

The detected correlations between clinical assessments scales and scores and the results of sEMG recordings reveal the phenomenon of relationship between the increased muscle tension causing a decrease in contractile properties of muscle motor units. It should be taken into account when programming the kinesiotherapeutic strategies in the rehabilitation of patients after iSCI at the cervical level. sEMG studies allow for the more accurate functional decsription of muscle function, thus enabling the detection of even subclinical changes that could be unnoticed using other clinical diagnostics.

REFERENCES

Van Middendorp, J.J., Goss, B., Urquhart, S., Atresh, S., Williams, R.P., Schuetz, M. (2011). '*Diagnosis and Prognosis of Traumatic Spinal Cord Injury'*. Global Spine Journal, 1(1), pp.001–007. doi:https://doi.org/10.1055/s-0031-1296049.

Furlan, J.C., Noonan, V., Singh, A., Fehlings, M.G. (2011). '*Assessment of Impairment in Patients with Acute Traumatic Spinal Cord Injury: A Systematic Review of the Literature*.' Journal of Neurotrauma, 28(8), pp. 1445–1477. doi:https://doi.org/10.1089/neu.2009.1152.

Balbinot, G. (2022*) 'Surface EMG in Subacute and Chronic Care after Traumatic Spinal Cord Injuries.'* Trauma Care, 2(2), pp. 381–391. doi:https://doi.org/10.3390/traumacare2020031.

Harvey, L.A. (2016). *'Physiotherapy rehabilitation for people with spinal cord injuries.'* Journal of Physiotherapy, 62(1), pp. 4–11. doi:https://doi.org/10.1016/j.jphys.2015.11.004.

Biering-Sørensen, F., Nielsen, J.B., Klinge, K. (2006). *'Spasticity-assessment: a review.'* Spinal Cord, 44(12), pp.708–722. doi:https://doi.org/10.1038/sj.sc.3101928.

Peek, K., Pensuk, P. (2013). '*Muscle strength in adults with spinal cord injury: a systematic review protocol of manual muscle testing, isokinetic and hand held dynamometry clinimetrics.'* JBI Database of Systematic Reviews and Implementation Reports, 11(9), pp. 105–119. doi:https://doi.org/10.11124/jbisrir-2013-969.

Wu, Y., Martínez Ángeles, M., Orizaola Balaguer, P. (2013). '*Overview of the Application of EMG Recording in the Diagnosis and Approach of Neurological Disorders.'* Electrodiagnosis in New Frontiers of Clinical Research, doi:https://doi.org/10.5772/56030.

Cuthbert, S.C., Goodheart, G.J. (2007). *'On the reliability and validity of manual muscle testing: a literature review.'* Chiropractic & Osteopathy, 15(4). doi:https://doi.org/10.1186/1746-1340-15-4.

Huber, J., Leszczyńska, K., Wincek, A., Szymankiewicz-Szukała, A., Fortuna, W., Okurowski, S., Tabakow, P. (2021) *'The Role of Peripheral Nerve Electrotherapy in Functional Recovery of Muscle Motor Units in Patients after Incomplete Spinal Cord Injury.'* Applied Sciences, *11(20)*. doi: 10.3390/app11209764
Wincek, A., Huber, J., Leszczyńska, K., Fortuna, W., Okurowski, S., Chmielak, K., Tabakow, P. (2021) **'***The Long-Term Effect of Treatment Using the Transcranial Magnetic Stimulation rTMS in Patients after Incomplete Cervical or Thoracic Spinal Cord Injury.'* Journal of Clinical Medicine, *10(13)*, pp.2975. doi: 10.3390/jcm10132975
Kaczmarek, K., Huber, J., Leszczyńska, K., Daroszewski, P. (2022) *'Electroneurographic Evaluation of Neural Impulse Transmission in Patients after Ischemic Stroke Following Functional Electrical Stimulation of Antagonistic Muscles at Wrist and Ankle in Two-Month Follow-Up'.* Int. J. Environ. Res. Public Health, *19(2)*, pp.713. doi: 10.3390/ijerph19020713
Huber, J., Kaczmarek, K., Leszczyńska, K., Daroszewski, P. (2022) *'Post-Stroke Treatment with Neuromuscular Functional Electrostimulation of Antagonistic Muscles and Kinesiotherapy Evaluated with Electromyography and Clinical Studies in a Two-Month Follow-Up'.* Int. J. Environ. Res. Public Health, *19*(2), pp.964. doi: 10.3390/ijerph19020964
Kaczmarek, A.M., Huber, J., Leszczyńska, K., Wietrzak, P., Kaczmarek, K. (2022) *'Relationships between the Clinical Test Results and Neurophysiological Findings in Patients with Thoracic Outlet Syndrome.*' Bioengineering, *9(10)*, pp.598. doi: 10.3390/bioengineering9100598
Rajczewski, A., Daroszewski, P., Fabijański, A., Bogusławski, K., Kaźmierczak, M., Huber, J. (2023) *'Incidence of Carpal Tunnel Syndrome and Other Coexisting Brachial Plexus Neuropathies in Bullseye Shooters—A Pilot Retrospective Clinical and Neurophysiological Assessment.'* Appl. Sci., *13(14)*, pp.8020. doi: 10.3390/app13148020
Lovett, R.W. (1912) *'Clinical testing of the muscle function of the upper extremity.*' Arch. Neurol. Psychiatr., 3, pp. 543–550.
Balci, B.P., (2018). *'Spasticity measurement.'* Archives of Neuropsychiatry, 55(1). doi:https://doi.org/10.29399/npa.23339.
Cha, S., Yun, J.-H., Myong, Y., Shin, H.-I. (2018). *'Spasticity and preservation of skeletal muscle mass in people with spinal cord injury.'* Spinal Cord, 57(4), pp.317–323. doi:https://doi.org/10.1038/s41393-018-0228-2.
Huber, J., Lisiński, P., Polowczyk, A. (2013). *'Reinvestigation of the dysfunction in neck and shoulder girdle muscles as the reason of cervicogenic headache among office workers'.* Disability and Rehabilitation, 35(10), pp.793–802. doi:https://doi.org/10.3109/09638288.2012.709306.
Lisiński, P., Huber, J. (2017). *'Evolution of Muscles Dysfunction From Myofascial Pain Syndrome Through Cervical Disc-Root Conflict to Degenerative Spine Disease.' SPINE,* 42(3), pp.151–159. doi:https://doi.org/10.1097/brs.0000000000001691.
Campanini, I., Disselhorst-Klug, C., Rymer, W.Z., Merletti, R. (2020). '*Surface EMG in Clinical Assessment and Neurorehabilitation: Barriers Limiting Its Use.'* Frontiers in Neurology, 11. doi:https://doi.org/10.3389/fneur.2020.00934.
Bohannon, R.W., Smith, M.B. (1987) *'Interrater reliability of a modified Ashworth scale of muscle spasticity.*' Physical Therapy, 67(2), pp.206-207.
Buckup, K. (2004) *Clinical tests for the musculoskeletal system*. Stuttgart, New York: Thieme
Wesołek, A., Daroszewski, P., Huber, J. (2023) '*Neurophysiological Evaluation of the Functional State of Muscular and Nervous Systems in High-Maneuvering Jet Fighters.'* Appl. Sci., *13*(2), pp.1120. doi: 10.3390/app13021120
Balbinot, G., Li, G., Wiest, M.J., Pakosh, M., Furlan, J.C., Kalsi-Ryan, S., Zariffa, J. (2021). *'Properties of the surface electromyogram following traumatic spinal cord injury: a scoping review.'* Journal of NeuroEngineering and Rehabilitation, 18(1), pp.1-23. doi:https://doi.org/10.1186/s12984-021-00888-2.