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Comparison of spasticity measurements with surface electromyography in the affected and unaffected side of children with hemiparetic cerebral palsy

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ABSTRACT

Aims: Various methods are used in the evaluation of spasticity, which is common in Cerebral Palsy (CP). However, studies measuring upper extremity spasticity with Surface Electromyography (sEMG) were found to be insufficient in children with CP. In this study, the comparison of Modified Ashworth Scale (MAS) and sEMG measurements for bilateral upper extremity spasticity in children with Hemiparetic CP was aimed.

Methods: 33 (11.03 ± 3.82 years, 11F-2M) patients with hemiparetic CP and 32 healthy controls (10.31± 2.88 years, 16F-16M) with a similar mean age were included in the study.

Results: Upper extremity spasticities of both sides of the cases were evaluated with MAS and SEMG. Affected side MAS results were found to be higher than the unaffected side ($p<0.05$). The mean sEMG value of the wrist flexors was lower on the affected side during voluntary contraction and higher during voluntary relaxation ($p<0.05$). In addition, the maximum percentage of voluntary contraction was measured higher on the affected side ($p<0.05$).

Conclusion: Spasticity, as assessed by sEMG and MAS, was increased on the affected side. MAS and sEMG give consistent results. These results show us that the YEMG method can be used for spasticity measurements. It is considered that MAS would be a preferable method in evaluating spasticity owing to the fact that it is easy to use and it does not constitute extra costs.

Keywords: Cerebral palsy, muscle spasticity, surface electromyography

INTRODUCTION

Cerebral Palsy (CP) is a non-progressive developmental disorder that occurs as a result of brain damage during the prenatal, perinatal, or post-natal period and it is the most striking reason for disability in children. The most common type is the Spastic type, characterized by an increase in the muscle tonus.[1] As well as the motor functions of the patients, the sensory, cognitive, behavioral, perceptive, and communication skills of the patients are also affected severely.[2] Amongst the common problems observed along with Spasticity could be muscle shortness, involuntary contractions, and negligence of the affected side.[3,4]

When one half of the body is more affected than the other half, it is called hemiparetic CP. Although it may seem that only one side is affected in hemiparetic CP, both halves of the body are affected at different levels. This is defined by the transverse advancement of 90% of the corticospinal pathways whereas the rest advance ipsilateral.[5,7] It has been determined that there is a more distinctive impaction on the upper extremity, hands in particular, on 50% of the children with hemiplegic CP.[8] Observed in most of the patients, the hemiplegic hand, which is a spastic pattern where the forearm is in pronation, the elbow-wrist and fingers are in flexion and the thumb is in the palm, is an indicator of such impaction.[9-11]

Spasticity clinical manifestation, recognized as tonus increase, is characterized by decreased voluntary motor movement, increased reflex responses, and agonist-antagonist tone regulation disorder.[6,7] Since it is a multifaceted finding, its clinical evaluation is difficult. No measurement method can evaluate spasticity in all its aspects (speed dependence, frequency, severity, involuntary muscle contractions, phasic and tonic components, etc.).[12] The most frequent clinical evaluation of Spasticity is implemented using the Modified Ashworth Scale (MAS), in which resistance to passive movement is graded, as well as the Modified Tardieu, Fugyl Meyer, and Tonus Evaluation Scales.[13,14] Recent studies reveal that Surface Electromyography (sEMG) applications are also used in spasticity measurements.[15] Contrary to the aforementioned scales, the sEMG is a method that provides objective data and measures the electrical activity of skeletal muscles. sEMG, which is a non-invasive method, indicates the action potential values of the muscles during contraction and relaxation.[16] In the literature, studies measuring upper extremity spasticity using sEMG were found to be

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insufficient in children, unlike adult hemiplegia patients.[17-19] In this study, it was aimed to evaluate upper extremity spasticity in children with hemiparetic CP using sEMG and MAS and to compare the results of affected and unaffected extremities with each other and with healthy controls.

METHODS

Design

This was a cross-sectional study. In this study, children who were rehabilitated in Special Education and Rehabilitation Centres and diagnosed with Hemiparetic CP were evaluated.

Before initiating the study, ethical approval was obtained from the Hatay Mustafa Kemal University Tayfur Ata Sökmen Medical Faculty Clinical Researches Ethics Committee (Date: 08.04.2021, Decision No: 2021/35). All procedures were carried out in accordance with the ethical rules and the principles of the Declaration of Helsinki

After giving detailed information about the study to the patients and their relatives, patients who voluntarily agreed to participate in the study and signed the consent form were recruited. Patients 12 years of age and older gave their consent for the study. Parental consent was obtained for patients younger than 12 years of age.

The inclusion criteria:

- Patients diagnosed with Spastic Hemiparetic CP
- Clinically stable patients
- Patients in the age group of 5-17 years.

The exclusion criteria are:

- Patients with severe cognitive impairment
- Those with pulmonary, neurological, and orthopedic diseases that will affect functionality.
- Patients who have undergone Botox procedures in the last 6 months.
- Patients with a history of surgery in the upper extremity.
- Patients hospitalized due to acute infection or exacerbation.

Evaluation Methods

Patients' information such as age, height, weight, gender, disability, background, and family history were recorded via data recording and evaluation form.

In this study, MAS and sEMG were used for spasticity assessment. MAS is the most widely used clinical scale to evaluate spasticity. Despite its widespread clinical use, the reliability of the scale is questioned in some studies.[15,16]

During the MAS evaluation, the individual lies on the bed in a relaxed supine position and the upper extremity to be evaluated is manually moved by the physiotherapist quickly and repetitively. During this passive movement, an appropriate score from 0 to 4 (0,1,1+,2,3,4) is attributed to the spasticity level as per the resistance of the muscle to be evaluated.[17] The increase in the score indicates an increase in spasticity.

sEMG is a method in which electronic devices are used to measure the electrical activity of active skeletal muscles. This electrical energy is converted into a form that humans can perceive and is transferred to the computer screen as a graphic or sound. Electrodes are used non-invasively in sEMG. It is a painless, harmless, and objective method. It also provides the opportunity to document muscle activity. The higher the sEMG activation, the greater the force produced by the muscle. The EMG signal is the electrical appearance of the neuromuscular activation of the contracted muscle and is one of the most easily measurable signals.[18]

In this study, a four-channel Neurotrac Myoplus Pro 4 EMG Biofeedback device was used for sEMG Biofeedback measurements. The program of the sEMG Biofeedback device was installed on the laptop computer and the device was connected to the computer via Bluetooth. The sEMG measurements of the wrist extensor and flexor muscles of the patients were performed as per the action potentials during "work=voluntary contraction" and "rest=voluntary relaxation" (**Figure 1**).

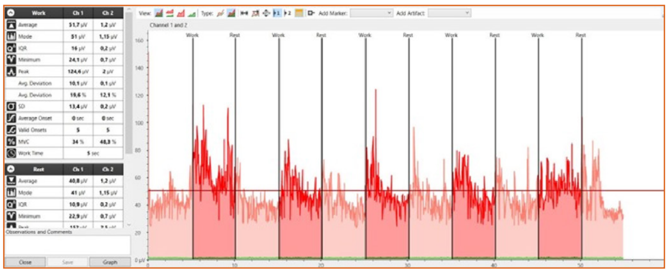

Figure 1. Affected Side sEMG result sample

When the individual to be tested was given "flex" and "relax" commands during flexor muscle activity, s/he contracted and relaxed the forearm flexor muscles. During the measurements which lasted 50 seconds, the measurement data were automatically recorded while the patient made voluntary muscle contractions and voluntary muscle relaxations five times. Mean contraction and mean relaxation activities, maximum contraction and relaxation activity percentages, mean deviation of relaxation, peak and minimum values, mean onset and release times were recorded with the device (**Figure 1**).

All evaluation measurements of the patients were conducted by the same physiotherapist.

Statistical Analysis of the Data

IBM SPSS 20.0 statistical program was used for statistical analysis. Descriptive statistics of the variables were calculated. In the comparison of affected and unaffected parties, the t-test was used in independent groups, and in the cases where the data did not comply with the normal distribution, the Mann Whitney-U test was used. The Spearman correlation analysis was used to evaluate the relationships.

In the interpretation of the correlation coefficient (r); Between 0.00-0.25 for a very weak correlation, 0.26-0.49 for a weak relationship, 0.50 and 0.69 for a moderate relationship, 0.70-0.89 for a high correlation, and between 0.90-1.0 for high correlation.[20] The probability of error in statistical analysis was determined as $p<0.05$ unless stated otherwise.

According to the G-Power (3.1.9.7) post hoc power analysis performed after the study, the effect size was calculated as=0.74, and the power of the study has been calculated as $(1-\beta)=0.91$ while $\alpha=0.05$.

RESULTS

33 patients and 32 healthy controls were included in the study (**Figure 2**). The sEMG values of the dominant sides of 32 healthy children [10 (8-13) years] who were in the same age range as the patients [12 (8-14) years] were used as the control group ($p=0.341$).

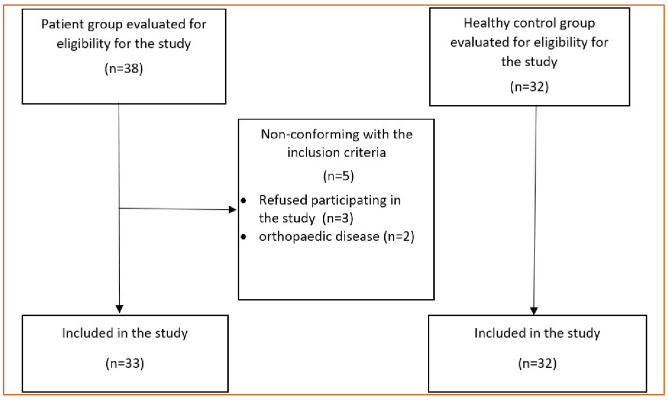

Figure 2. Workflow diagram

Age, height, weight, body mass index, gender, and demographic characteristics of the affected side of patients with CP and healthy controls are shown in **Table 1**. In Table 2, MAS measurement values for the pronator, wrist flexor, and elbow flexor muscles in children with CP are given for the affected and unaffected side and the MAS results on the affected side were found to be statistically and significantly higher than the unaffected side (p<0.05) (**Table 2**).

Table 1. Demographic characteristics of patients and healthy controls

Variables	CP X±CD M (IQR)	Control X±CD M (IQR)	p
Age (year)	12 (8-14)	10 (8-13)	0.314
Height (cm)	139.80±22.10	140.18±17.79	0.939
Weight (kg)	37 (23-50.50)	36.50 (26.25-55)	0.713
BMI (kg/m2)	17.63 (15.67-21.55)	19.26 (15.47-21.23)	0.865
	n/%		
Gender			0.213
Female	11 (33.3)	16 (50)	
Male	22 (66.7)	16 (50)	
Affected side			
Right	20 (61)		
Left	13 (39)		

X: mean, SD: Standard Deviation, M: Median, BMI: Body Mass Index.

Table 2. Comparison of sEMG and MAS measurement values on the affected and unaffected side in children with CP

Variables	AS X±SD M (IQR)	UAS X±SD M (IQR)	p
WFM Work			
AV (µV)	63.10 (45.05-77.45)	80.80 (56.50-111.90)	0.033*
MIN (µV)	4.7 (3.05-8.20)	3 (1.75-4.80)	0.022*
MVC (%)	30.89±14.10	26.14±9.38	0.112
WFM Rest			
AV (µV)	12.90 (7.20-17.95)	8.90 (4.55-13.95)	0.027*
MIN (µV)	2.60(1.10-5.50)	1.80(1.00-3.30)	0.172
MVC (%)	5.10(2.60-10.70)	2.70(1.20-4.25)	0.001*
WEM Work			
AV (µV)	67.90 (45-125.35)	95.10 (66.95-156.55)	0.081
MIN (µV)	5.60(2.85-9.85)	2.60(1.00-4.80)	0.005*
MVC (%)	34.76±11.09	31.29±10.42	0.195
WEM Rest			
AV (µV)	15.30 (10.60-23.25)	9.20 (5.95-14.15)	0.001*
MIN (µV)	4.20 (2.45-6.90)	1.80(1.00-3.30)	<0.001*
MVC (%)	7.60(4.30-11.25)	2.60 (1.55-4.60)	<0.001*
PS (MAS)	3 (2-3)	0(0-0.50)	<0.001*
WFS (MAS)	2 (2-3)	0 (0-0)	<0.001*
EFS (MAS)	2 (1-2)	0(0-0)	<0.001*

*p<0,05, X: mean, SD: Standard Deviation, M: Median, µV: Microvolt, AS: Affected Side, UAS: Unaffected Side, MVC: Maximum Voluntary Contraction Percentage, WFM: Wrist Flexor Muscles, WEM: Wrist Extensor Muscles, AV: Average EMG value, MIN: Minimum EMG value, MAS: Modified Ashworth Scale, PS: Pronator Spasticity, WFS: Wrist Flexor Spasticity, EFS: Elbow Flexor Spasticity.

The mean sEMG value during voluntary muscle contraction of the wrist flexor muscles on the affected side was statistically and significantly lower than the unaffected side, and the minimum sEMG value was higher (p<0.05). The mean sEMG and voluntary contraction percent MVC (%) values of the wrist flexor muscles during voluntary relaxation were also higher on the affected side (p<0.05). Maximum voluntary contraction percent MVC (%) values of wrist flexor muscles during voluntary muscle contraction were found to be similar on both sides (p>0.05) (**Table 2**).

The minimum sEMG value during voluntary muscle contraction of the wrist extensor muscles and the minimum sEMG and voluntary contraction percent MVC values during voluntary relaxation were higher on the affected side (p<0.05) (**Table 2**).

When the sEMG values of the unaffected side of the patients were compared with the healthy group; AV and MVC values of wrist extensors during voluntary contraction were lower on the unaffected side (p<0.05, **Table 3**). While there was no significant difference in the sEMG findings of the wrist flexors, it was found that the unaffected side was higher when the MAS data were examined (p=0.012).

Table 3. Comparison of sEMG values of the unaffected side and healthy controls in children with CP

Variables	UAS X±SD M (IQR)	CONTROL X±SD M (IQR)	p
WFM Work			
AV (µV)	80.80 (56.50-111.90)	98.40 (60.30-140.12)	0.325
MIN (µV)	3 (1.75-4.80)	3.30 (1.67-4.30)	0.979
MVC (%)	26.14±9.38	27.16±6.46	0.615
WFM Rest			
AV (µV)	8.90 (4.55-13.95)	7.45 (6.65-9.47)	0.783
MIN (µV)	1.80 (1.00-3.30)	2.40 (1.65-3.02)	0.318
MVC (%)	2.70 (1.20-4.25)	2.30 (1.50-3.27)	0.581
WEM Work			
AV (µV)	95.10 (66.95-156.55)	154.35 (108.85-195.35)	0.005
MIN (µV)	2.60 (1.00-4.80)	2.70 (1.45-4.37)	0.773
MVC (%)	31.29±10.42	38.18±5.41	0.001
WEM Rest			
AV (µV)	9.20 (5.95-14.15)	11.55 (5.67-13.02)	0.763
MIN (µV)	1.80 (1.00-3.30)	1.95 (1.17-3.80)	0.152
MVC (%)	2.60 (1.55-4.60)	2.80 (1.72-3.65)	0.665

*p<0,05, X: mean, SD: Standard Deviation, M: Median, µV: Microvolt, UAS: Unaffected Side, MVC: Maximum Voluntary Contraction Percentage, WFM: Wrist Flexor Muscles, WEM: Wrist Extensor Muscles, AV: Average EMG value, MIN: Minimum EMG value.

There was a weak positive correlation between the MAS on the affected side and the minimum sEMG (p=0,016 r=0,416) and MVC (p=0,021, r=0,401) values of the wrist flexor muscles during voluntary relaxation and a weak negative correlation between the mean sEMG value (p=0,030, r=-0,379) during voluntary contraction.

DISCUSSION

In this study, which aims to measure and compare spasticity values in children with hemiparetic SP using MAS and sEMG methods; [1] mean sEMG values of wrist flexor muscles during voluntary contraction are lower on the affected side; [2] mean FEMG values of wrist flexor muscles during voluntary relaxation are higher on the affected side; [3] sEMG values of the unaffected wrist extensors during voluntary contraction were lower compared to the healthy group; [4] There is no significant difference in sEMG findings of wrist flexors with healthy controls. When the MAS data is considered, it has been determined that spasticity on the unaffected side was higher; [5] it was ascertained that there is a positive correlation between the MAS of the wrist flexor muscles on the affected side and the minimum sEMG values during voluntary relaxation, and a negative one between the mean sEMG values during voluntary contraction.

Spasticity; It is an important complication that often accompanies CP and limits the mobility of the person.[21] Although it is easy to detect the presence of spasticity, it is not easy to quantify and grade. The degree of spasticity can vary from mild muscle stiffness to severe and sometimes painful muscle spasms.[22]

In the evaluation of spasticity, scales such as Ashworth Scale (AS), Modified Ashworth Scale (MAS), Modified Tardieu Scale (MTS), Fugyl Meyer Scale, Tonus Evaluation Scale are used in the clinic.[14,15,23]

MAS is frequently preferred in the clinic because it does not require any measuring device, it is easy and fast to apply.[24] However, the objectivity of MAS is questioned in current studies and it is emphasized that more studies are needed on this subject.[25-29]

Tederko et al.[30] evaluated the relationship between MAS and clinical examination results in 30 patients with spinal cord injury in a study they conducted and stated that MAS was insufficient to evaluate the tone of individual muscles, but it could indicate the increase in the muscle tonus in total. In addition, it was pointed out that it is difficult to repeat in young patients and that it is not a suitable method for evaluation in case of contracture. In a double-blind study of spinal cord injuries, the reliability of MAS was investigated among different evaluators. They reported that the MAS results were of poor reliability, both in the individual measurements of the evaluators and when compared with each other. In the same study, it was emphasized that the MAS was not psychometrically reliable and insufficient to measure rehabilitation effectiveness and it was argued that its use should be terminated.[31]

Alibioglu et al.[32] compared the MAS and neuromechanical measurement results of 34 stroke patients on both paretic and nonparetic lower and upper extremities. As a result, they found that there was no significant correlation between quantitative measurements of neural and muscle components of joint dynamic stiffness and MAS scores for neither the upper extremity nor the lower extremity. With these findings, they stated that Modified Ashworth scores were quite inconsistent with more objective spasticity measurements.

In their study comparing MAS and MTS measurements, Numanoğlu and Günel evaluated the lower and upper extremity muscles of 37 children with Spastic CP using both methods. As a result, it was determined that the reliability of MTS was better than MAS in each tested muscle. Although MAS is more advantageous than MTS in terms of applicability and time, it has been stated that it does not meet the requirements for clinical use because it depends on subjective decisions.[23] In our study, it was found that MAS can be used to detect the presence of spasticity and it is significantly higher on the affected side. Since the rehabilitation program was not applied to our patients and did not include follow-up results, the effect of determining the change in spasticity cannot be explained by the results of this study.

In addition to manual tests which are used to determine the severity of spasticity in the clinic, there are also biomechanical and electrophysiological methods that provide objective data.[24]

Electromyography and surface electromyography are among the evaluation methods that measure the electrical activity of active skeletal muscles with electronic devices.[18]

In a study conducted on spastic diplegic patients using EMG, it was shown that the mean EMG frequencies of the muscles in CP were higher than in the control group. In addition, it was also emphasized in the same study that dysfunction in the distal extremity muscles was more pronounced than in the proximal muscles.[33] In a study by Feltham et al.[24] on children with spastic hemiparetic CP, it was reported that sEMG values were higher in all muscles of the affected upper extremity and in the wrist and elbow flexor muscles of the unaffected side than in healthy controls. It was emphasized that this situation could be explained by the presence of systematic atrophy of type I muscle fibers in the heavily damaged (affected) arm.[24,34] Similarly, in our study, mean sEMG values of wrist flexor muscles during voluntary contraction were lower on the affected side; whereas the mean sEMG values of the wrist flexor muscles during voluntary relaxation were higher on the affected side. In the literature, it is suggested that the high-frequency components of the EMG spectrum are a reflection of the content of high-frequency action potentials produced by fast type II muscle fibers, while it is emphasized that slow type I muscle fibers produce low-frequency action potentials.[35,36]

When a muscle action potential is measured with sEMG in healthy individuals, it is expected that the muscle action potential will be high during maximum voluntary contraction and the muscle action potential will be at the lowest level during maximum voluntary relaxation.[37,38] Our results show that the muscle action potential value during maximum voluntary contraction may be lower than expected, and the muscle action potential value during maximum voluntary relaxation may be higher than expected in individuals with spasticity.

Unilateral brain injury causes changes in motor control not only of the contralateral body side but also of the ipsilateral side.[39,40] Staudt et al.[41] stated that in unilateral brain damage, there may be motor changes not only on the contralateral side but also on the ipsilateral side.

In our study, data from least affected parties were compared with healthy controls. Similar to the literature, sEMG values of the wrist extensors of the unaffected side during voluntary contraction were found to be lower compared to the healthy group.[24] While there was no significant difference between the FEMG findings of the wrist flexors and the healthy controls, it was observed that spasticity was higher on the unaffected side when the MAS data were examined.

In our study, the fact that MAS and sEMG revealed similar results when compared to both affected and unaffected extremities, as well as healthy controls, indicates that both measurement methods can be used in the evaluation of spasticity. When the correlation between MAS results and FEMG was examined, it was determined that there was a positive correlation between the MAS of the wrist flexor muscles on the affected side and the minimum sEMG values during voluntary relaxation, whereas there was a negative correlation between the mean sEMG values during voluntary contraction.

Validity and reliability studies for MAS will further clarify this study.

Limitations of the study

Because the study was conducted during the pandemic period, the high rate of absence of patients attending Special Education and Rehabilitation Canters as a precaution caused longer measurement times and problems in transportation to patients.

The results of future studies with more patients may differ and bring more clarity to the issue. The results can be generalized by conducting studies not only in a single city but also in other cities to be selected from different regions of Türkiye.

CONCLUSION

As a result, although sEMG is not as widely used as MAS in spasticity measurements in children with hemiparetic CP, the fact that the data obtained from sEMG have results based on numerical computerized measurement data may show that it can provide more objective data. In addition, our results show that MAS, which is widely used in clinic, gives results compatible with sEMG. These results show us that the YEMG method can be used for spasticity measurements. It is considered that MAS would be a preferable method in evaluating spasticity since it is easy to use and does not constitute extra costs. It is suggested that there is a need for validity and reliability studies in which the sEMG measurement method used in the evaluation of spasticity is investigated in detail.

ETHICAL DECLARATIONS

Ethics Committee Approval: The study was carried out with the permission of the Hatay Mustafa Kemal University Tayfur Ata Sökmen Medical Faculty Clinical Researches Ethics Committee (Date: 08.04.2021, Decision No: 2021/35).

Informed Consent: All patients signed the free and informed consent form.

Referee Evaluation Process: Externally peer-reviewed.

Conflict of Interest Statement: The authors have no conflicts of interest to declare.

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Author Contributions: All of the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved the final version.

REFERENCES

1. Cans C. Surveillance of cerebral palsy in Europe: a collaboration of cerebral palsy surveys and registers. Surveillance of Cerebral Palsy in Europe (SCPE). *Dev Med Child Neurol.* 2000;42(12):816-824. doi:10.1017/s0012162200001511
2. Beckung E, Hagberg G. Neuroimpairments, activity limitations, and participation restrictions in children with cerebral palsy. *Dev Med Child Neurol.* 2002;44(5):309-316. doi:10.1017/s0012162201002134
3. Sanger TD. Movement Disorders in Cerebral Palsy. *J Pediatr Neurol.* 2015; 13(04):198-207.
4. Pascual JM, Koenigsberger MR. Parálisis cerebral: factores de riesgo prenatales [Cerebral palsy: prenatal risk factors]. *Rev Neurol.* 2003;37(3):275-280.
5. Erol E, Elbasan B, Erol BÖ, et al. Pediatrik fizyoterapi rehabilitasyon ünitesine başvuran hastaların demografik özellikleri. *Gazi Sağlık Bilim Derg.* 2016; 1(1): 49-59.
6. Kutlay S. Spastik El, Türkiye Klinikleri. *J PM&R Special Topics.* 2008; 1:84-97.
7. Rosales RL, Chua-Yap AS. Evidence-based systematic review on the efficacy and safety of botulinum toxin-A therapy in post-stroke spasticity. *J Neural Transm (Vienna).* 2008;115(4):617-623. doi:10.1007/s00702-007-0869-3
8. McCall JV, Ludovice MC, Blaylock JA, Kamper DG. A Platform for Rehabilitation of Finger Individuation in Children with Hemiplegic Cerebral Palsy. *IEEE Int Conf Rehabil Robot.* 2019;2019:343-348. doi:10.1109/ICORR.2019.8779537
9. Shaw L, Rodgers H, Price C, et al. BoTULS: a multicentre randomised controlled trial to evaluate the clinical effectiveness and cost-effectiveness of treating upper limb spasticity due to stroke with botulinum toxin type A. *Health Technol Assess.* 2010;14(26):1-iv. doi:10.3310/hta14260
10. Unlu E, Çevikol A, Çakcı A. Spastik Elde Değerlendirme ve Tedavi Yontemleri. *FTR Bil Der.* 2011; 24(7):24-27.
11. Keklicek H, Uygur F, Yakut Y. Effects of taping the hand in children with cerebral palsy. *J Hand Ther.* 2015;28(1):27-33. doi:10.1016/j.jht.2014.09.007
12. Surkar SM, Hoffman RM, Willett S, Flegle J, Harbourne R, Kurz MJ. Hand-arm bimanual intensive therapy improves prefrontal cortex activation in children with hemiplegic cerebral palsy. *Pediatr Phys Ther.* 2018;30(2):93-100. doi:10.1097/PEP.0000000000000486
13. Rasool G, Afsharipour B, Suresh NL, Rymer WZ. Spatial Analysis of Multichannel Surface EMG in Hemiplegic Stroke. *IEEE Trans Neural Syst Rehabil Eng.* 2017;25(10):1802-1811. doi:10.1109/TNSRE.2017.2682298
14. Li Y, Zhang X, Gong Y, Cheng Y, Gao X, Chen X. Motor function evaluation of hemiplegic upper-extremities using data fusion from wearable inertial and surface EMG sensors. *Sensors (Basel).* 2017;17(3):582. doi:10.3390/s17030582
15. Alhusaini AA, Dean CM, Crosbie J, Shepherd RB, Lewis J. Evaluation of spasticity in children with cerebral palsy using Ashworth and Tardieu Scales compared with laboratory measures. *J Child Neurol.* 2010;25(10):1242-1247. doi:10.1177/0883073810362266
16. Alibiglou L, Rymer WZ, Harvey RL, Mirbagheri MM. The relation between Ashworth scores and neuromechanical measurements of spasticity following stroke. *J Neuroeng Rehabil.* 2008;5:18. doi:10.1186/1743-0003-5-18
17. Başarır M, Özek MM. Spastisite ve tedavisi. *Türk Nöroşir Derg.* 2013; 23:158-173.
18. Cerrah AO, Ertan H, Soylu AR. Spor bilimlerinde elektromiyografi kullanımı. *Spormetre Beden Eğitimi ve Spor Bilimleri Derg.* 2010; 8(2): 43-49.
19. Lei Wang, Xin Guo, Peng Fang, et al. A new EMG-based index towards the assessment of elbow spasticity for post-stroke patients. *Annu Int Conf IEEE Eng Med Biol Soc.* 2017;2017:3640-3643. doi:10.1109/EMBC.2017.8037646
20. Hayran M, Hayran M. Sağlık araştırmaları için temel istatistik, 1. baskı, Omega araştırma, Ankara, 2011.
21. Kaya Kara Ö, Türker D, Özal C, et al. Serebral Palsi'de güncel fizyoterapi ve rehabilitasyon yaklaşımları. *Ufkun Ötesi Bilim Derg.* 2010; 10(1-2): 5-22
22. Nielsen JB, Crone C, Hultborn H. The spinal pathophysiology of spasticity--from a basic science point of view. *Acta Physiol (Oxf).* 2007;189(2):171-180. doi:10.1111/j.1748-1716.2006.01652.x
23. Numanoğlu A, Günel MK. Intraobserver reliability of modified Ashworth scale and modified Tardieu scale in the assessment of spasticity in children with cerebral palsy. *Acta Orthop Traumatol Turc.* 2012;46(3):196-200. doi:10.3944/aott.2012.2697
24. Biering-Sørensen F, Nielsen JB, Klinge K. Spasticity-assessment: a review. *Spinal Cord.* 2006;44(12):708-722. doi:10.1038/sj.sc.3101928
25. Pandyan AD, Price CI, Barnes MP, Johnson GR. A biomechanical investigation into the validity of the modified Ashworth Scale as a measure of elbow spasticity. *Clin Rehabil.* 2003;17(3):290-293. doi:10.1191/0269215503cr610oa
26. Ansari NN, Naghdi S, Hasson S, Azarsa MH, Azarnia S. The Modified Tardieu Scale for the measurement of elbow flexor spasticity in adult patients with hemiplegia. *Brain Inj.* 2008;22(13-14):1007-1012. doi:10.1080/02699050802530557
27. Yam WK, Leung MS. Interrater reliability of Modified Ashworth Scale and Modified Tardieu Scale in children with spastic cerebral palsy. *J Child Neurol.* 2006;21(12):1031-1035. doi:10.1177/7010.2006.00222
28. Malhotra S, Pandyan AD, Day CR, Jones PW, Hermens H. Spasticity, an impairment that is poorly defined and poorly measured. *Clin Rehabil.* 2009;23(7):651-658. doi:10.1177/0269215508101747
29. Fleuren JF, Voerman GE, Erren-Wolters CV, et al. Stop using the Ashworth Scale for the assessment of spasticity. *J Neurol Neurosurg Psychiatry.* 2010;81(1):46-52. doi:10.1136/jnnp.2009.177071
30. Tederko P, Krasuski M, Czech J, Dargiel A, Garwacka-Jodzis I, Wojciechowska A. Reliability of clinical spasticity measurements in patients with cervical spinal cord injury. *Ortop Traumatol Rehabil.* 2007;9(5):467-483.

31. Craven BC, Morris AR. Modified Ashworth scale reliability for measurement of lower extremity spasticity among patients with SCI. *Spinal Cord.* 2010;48(3):207-213. doi:10.1038/sc.2009.107
32. Alibiglou L, Rymer WZ, Harvey RL, Mirbagheri MM. The relation between Ashworth scores and neuromechanical measurements of spasticity following stroke. *J Neuroeng Rehabil.* 2008;5:18. doi:10.1186/1743-0003-5-18.
33. Wakeling J, Delaney R, Dudkiewicz I. A method for quantifying dynamic muscle dysfunction in children and young adults with cerebral palsy. *Gait Posture.* 2007;25(4):580-589. doi:10.1016/j.gaitpost.2006.06.009
34. Lieber RL, Steinman S, Barash IA, Chambers H. Structural and functional changes in spastic skeletal muscle. *Muscle Nerve.* 2004;29(5):615-627. doi:10.1002/mus.20059
35. Kupa EJ, Roy SH, Kandarian SC, De Luca CJ. Effects of muscle fiber type and size on EMG median frequency and conduction velocity. *J Appl Physiol (1985).* 1995;79(1):23-32. doi:10.1152/jappl.1995.79.1.23
36. Wakeling JM, Rozitis AI. Spectral properties of myoelectric signals from different motor units in the leg extensor muscles. *J Exp Biol.* 2004;207(Pt 14):2519-2528. doi:10.1242/jeb.01042
37. Garciaa MAC, Vieiria TMM. Surface electromyography: Why, when and how to use it. *Rev Andal Med Deporte.* 2011; 4(1):17-28.
38. Cerrah AO, Ertan H, Soylu AR. Elektromiyografi ile kuvvetin değerlendirilmesi. *Türkiye Klinikleri J Neur.* 2010; 5(3):160-166.
39. Yarosh CA, Hoffman DS, Strick PL. Deficits in movements of the wrist ipsilateral to a stroke in hemiparetic subjects. *J Neurophysiol.* 2004;92(6):3276-3285. doi:10.1152/jn.00549.2004
40. Wiley ME, Damiano DL. Lower-extremity strength profiles in spastic cerebral palsy. *Dev Med Child Neurol.* 1998;40(2):100-107. doi:10.1111/j.1469-8749.1998.tb15369.x
41. Staudt M, Grodd W, Gerloff C, Erb M, Stitz J, Krägeloh-Mann I. Two types of ipsilateral reorganization in congenital hemiparesis: a TMS and fMRI study. *Brain.* 2002;125(Pt 10):2222-2237. doi:10.1093/brain/awf227