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Research paper

Modified motor unit number index (MUNIX) algorithm for assessing excitability of alpha motor neuron in spasticity

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ABSTRACT

Objective: The understanding of the spasticity mechanism is still a problem in the literature, as its definition can be made on the basis of more than one parameter. Therefore, we studied alpha motor neuron excitability, dynamic changes based on force production, and patellar tendon (T) reflex in spasticity and healthy control groups.
Methods: Alpha motor neuron excitability, force production, and patellar T reflex were evaluated through three different test protocols. Motor Unit Number Index (MUNIX) measurement was applied for understanding motor neuron pool properties in the first protocol. Voluntary force production and patellar T reflex parameters were evaluated by voluntary force production and triggering patellar T reflex. Twenty spasticity and 20 healthy volunteers participated in the study.
Results: In the spasticity group, both MUNIX numbers and Motor Unit Size Index (MUSIX) numbers were lower than those in the control group. The results for the Ideal Case Motor Unit Count (ICMUC) parameter show that there is no significant difference between spasticity and healthy individuals for low-level contractions, whereas there is a significant difference for high-level contractions ($p < 0.05$). In the spasticity group, an increase was observed in the ratio of maximal voluntary force to the T reflex triggered force production (Tf/Vf).
Conclusion: Spasticity and healthy subjects can be distinguished easily and clearly by evaluating the changes in both kinesiological and electrophysiological findings and the decreasing threshold in the alpha motor neuron pool.
Significance: This study shows that such combined methods, which allow the evaluation of the alpha motor neuron pool, as well as kinesiological and electrophysiological parameters, are tools that cannot be overlooked in understanding spasticity.

1. Introduction

The characteristic features of the spasticity can be defined as increased stretching reflexes, hyperactivity in tendon (T) reflexes, and velocity-dependent increase in muscle tones (Burke et al., 1971; Burke et al., 1972; Lance, 1980). Although spasticity is a well-known phenomenon in clinical situations, these features present various difficulties in practice. Because there is more than one characteristic to evaluate the spasticity, there is difficulty in grading spasticity (Malhotra et al., 2009; Fleuren et al., 2010). One of the main problems evaluating the spasticity is due to changes while patients are in the dynamic or static state or when the patient makes active or passive motor movements (Sherwood et al., 2000).

Recent studies have shown that using only electrophysiological or clinical findings is insufficient to evaluate the spasticity (Burridge et al., 2005; Sunnerhagen, 2010; Gürbüz et al., 2015). For that reason, new studies focus on biomechanical assessment of spasticity in addition to clinical and electrophysiological findings (Kim, 2013; Bhadane et al., 2015; Lee et al., 2015). Unfortunately, these combined methods are still not enough to evaluate motor neuron pool quantitatively. It is not yet clear how the M response accompanying reflex responses changes because of the change in the excitability of the motor neuron pool (Ivanhoe and Reistetter, 2004; Floeter et al., 2005; Mukherjee and Chakravarty, 2010; Li et al., 2012; Stifani, 2014).

The main aim of this study is to investigate the possibility of evaluating the status of the motor neuron pool excitability through

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the MUNIX algorithm using patellar pendulum, which is triggered by patellar T reflex, and to evaluate the relation between voluntary force production and motor units that are included for this contraction.

2. Materials and methods

Twenty healthy volunteers with no neurological disorders and 12 patients with spasticity participated in this study. The spasticity group consisted of patients with cerebral spasticity. Patients with polyneuropathy, multiple sclerosis (MS), and spinal spasticity were excluded from the study. The study was reviewed by the local ethics committee and complied with the Helsinki Clinical Research Principles.

All measurements were recorded while the participants were sitting on a stretcher (90-cm above the ground) such that the leg was allowed to swing freely. Muscle activity of the rectus femoris muscle and biceps femoris muscle (short head) was recorded with surface electromyography (sEMG). Angle sensor was placed on the knee, and an accelerometer sensor was placed on the ankle.

3. Experimental protocol

Three different test protocols were applied to participants.

i) MUNIX and Motor Unit Size Index (MUSIX) measurements,
ii) Voluntary force production measurement, and
iii) Reflex evaluation.

i) Electrical stimulation was applied to the femoral nerve before starting the tests, and M responses were recorded. A Medelec Synergy EMG Device was used for electrical stimulation, and M responses were recorded. Stimulation intensity was adjusted according to the supramaximal M response and generally between 50 and 100 mA, and the duration was 1 ms. sEMG measurements were recorded with Medelec Synergy EMG and Biometrics DataLOG Type No. MWW8 Bluetooth® M550 MyoMeter devices. The lower frequency limit was 10 Hz and the upper frequency limit was 10 kHz, and the notching filter was activated. M response amplitudes were measured peak-to-peak of responses.

In the first test protocol, which was developed by Nandedkar et al., MUNIX and MUSIX were measured (Nandedkar et al., 2004; Nandedkar et al., 2010). The first step of the test protocol is to record the M response with supramaximal stimulation. After that, the sEMG activity was recorded in five different voluntary force production stages (10%, 25%, 50%, 75%, and 100%) with two repeated sets. These recordings called as Surface Interference Pattern (SIP). After completion of measurements, all the mathematical calculations and analyses were performed by using the MATLAB program.

The positive peak value of Compound Muscle Action Potential (CMAP) was determined in the developed software. For this operation, the DC offset value was subtracted from the signal. The start moment value, the moment of return at the start value, and the value of the highest amplitude were evaluated. The power and area of the positive part of the signal were calculated. The power and area values of the SIP recordings were also measured.

The Ideal Case Motor Unit Count (ICMUC), which refers to the lack of motor units in the contraction, parameter is obtained by multiplying CMAP ratio (CMAP Power divided by CMAP) and SIP ratio (Voluntary Contraction Area divided by Voluntary Contraction Power) (Eq. (1)).

$$ICMUC = \frac{CMAPPower * SIPArea}{CMAPArea * SIPPower} \quad (1)$$

By reconsidering Eq. (1), we observe that the CMAP power and area are constant values, and the ICMUC parameter changes depending on SIP area and power. When the level of contraction is increased, the power of the SIP decreases more than the area of the SIP. Therefore, the ICMUC value in the lower levels is higher than that in the higher levels.

Additionally, the relationship between ICMUC and SIP can be obtained by regression analysis. With regard to this, the coefficients A and α are obtained. MUNIX is defined by Nandedkar et al. as an ICMUC value corresponding to 20 mV $\times$ ms SIP area (Nandedkar et al., 2004).

For that reason, after calculating A and α values, MUNIX can be obtained by regression analysis (Eq. (2) and (3)).

Further, the MUNIX value was obtained, and by dividing the maximum M amplitudes by the MUNIX value, the MUSIX value was also obtained (Eq. (4)) (Nandedkar et al., 2004; Nandedkar et al., 2010; Neuwirth et al., 2011). Only patients with spasticity who could do voluntary muscle contraction were included in the MUNIX measurement ($n = 12$), as this protocol is based on voluntary muscle contraction.

$$ICMUC = A * SIPArea^{\alpha} \quad (2)$$

$$MUNIX = A * (20)^{\alpha} \quad (3)$$

$$MUSIX = CMAPamplitude/MUNIX \quad (4)$$

ii) A second assessment was also applied to the patients of the nonhemiplegic spasticity group and those in the healthy control group. In the protocol, participants were required to produce maximal voluntary contraction at 120° extension and flexion of leg and at 180° extension. The force produced by maximal voluntary contraction at 120° is defined as the maximal force (Vf). All force measurements were recorded by using a Biometrics DataLOG Type No. MWW8 Bluetooth® M550 MyoMeter. The MyoMeter was placed on the leg and fixed at a third of the distance between the knee and ankle. For calculation of the force at the patellar T during maximal voluntary contraction, we used the fundamental principle of leverage by measuring force using a dynamometer that is placed at two-third the length of the tibia. Sensor placements and dimension ratios are shown in Fig. 1.

The ratio of the patellar T to the tibia length for force measurement was calculated by taking measurements from cadavers. These measurements yielded a mean value of 0.09 for the ratio (data not shown). The force values produced by triggering the patellar T reflex were calculated using the acceleration sensor. For calculation of the force at the patellar T during patellar reflex that triggered force production, we used the fundamental principle of leverage along with acceleration sensor data. Tibia length and lower leg mass were determined according to the characteristics of those with Asian racial features; the ratio of tibia length to height is 0.057 for men and 0.061 for women, and the ratio of lower leg mass to body weight is 0.247 for men and 0.257 for women (Clauser et al., 1971). The force obtained by this measurement is defined as the reflexive force (Tf).

iii) The third evaluation was carried out for determining the patellar T reflex. Ten repetitive reflex measurements were obtained by tapping the patellar T with a reflex hammer.

All the measurements were recorded with Medelec Synergy EMG device and Biometrics DataLOG Type No. MWW8 Bluetooth® M550 MyoMeter. If EMG activity was a result of hitting the tendon with a hammer and at least three pendulum movements were observed, the measurement was classified as successful. However, EMG activity without hitting the tendon with a reflex hammer, voluntary muscle contractions after hitting the tendon, and a single pendulum with reflex movement were marked as unsuccessful trials, and these trials were removed from the study. Each

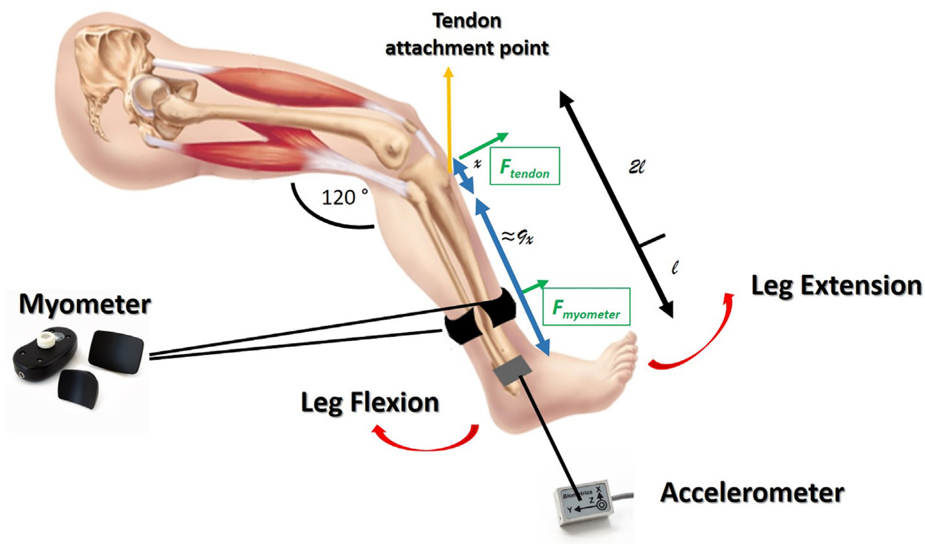

Fig. 1. Sensor placements and dimension ratios.

measurement was examined according to its achievement in the pendulum test. Patellar T reflex was also evaluated with the modified MUNIX (MUNIXT) algorithm.

3.1. Electrophysiological assessment

In the electrophysiological assessment, reflex responses and motor responses were evaluated with the parameter T_{max}/M_{max}. T_{max}/M_{max} was obtained by dividing the maximum EMG amplitude of the T response, which is triggered by applying a tapping force to the patellar T, by the maximum EMG amplitude of the M response, which is obtained by stimulating the femoral muscle nerve.

The spasticity group was compared amongst themselves (Ashworth 1, Ashworth 2) and with healthy participants. In addition, because EMG recording is done from the agonist–antagonist muscles (rectus femoris and biceps femoris, respectively), the responses particularly from the biceps femoris muscle were examined in cases of spasticity. Arc discharges were automatically detected using analytical software developed with MATLAB.

3.2. Statistical evaluation

Two different statistical evaluations were used in the study. The first statistical evaluation is regression analysis based on the algorithm developed by Nandedkar et al. Regression analysis is used to explain the relationship between two variables.

The second statistical method was used for group comparisons. The statistical analyses required for group comparisons were made using the SPSS 18.0 program. A value of $p < 0.05$ was accepted as a statistically significant difference. Mean values were expressed with standard deviations (sd) and min–max values. In the intergroup comparisons, the Kruskal–Wallis test was used to analyze the significance of differences between the electrophysiological and kinesiological parameters. The Mann–Whitney *U* test was used to define the group from which the significances originated.

4. Results

Our patient group consisted of 20 patients with spasticity caused by upper motor neuron lesions. Patients were aged between 19 and 65 years, with a mean age of 51.1 ± 16.79 years. The healthy control group consisted of 20 individuals with no neurological disorders. The healthy control group individuals were aged between 21 and 56 years, with a mean age of 40.64 ± 7.77 years. The mean height and weight were found to be 164.35 ± 11.01 cm and 77.38 ± 14.82 kg for the spasticity group and 176.72 ± 8.11 cm and 75.36 ± 12.2 kg for the healthy control group, respectively.

In the spasticity group, 13 individuals were male and 7 were female, and in the control group, 12 individuals were male and 8 were female. The Ashworth 1 group consisted of 10 patients, and the Ashworth 2 consisted of 10 patients.

We used Ashworth scale. We scaled as Ashworth 1 for a slight increase in tone giving a catch when the limb was moved in flexion or extension and as Ashworth 2 for an increase in muscle tone, manifested by a catch, followed by resistance throughout the reminder (less than half) of the range of movement (ROM).

4.1. Electrophysiological and muscle performance features of the healthy control group

The mean value of the M responses was 21.71 ± 4.24 mV for the healthy control group. The T/M ratio was calculated as 0.21 ± 0.14. Mean MUNIX and MUSIX values are 274.42 ± 55.33 and 43.28 ± 6.62 μV, respectively. Arc discharges or late responses of the biceps femoris muscle were not shown for the healthy control group.

The ratio of voluntary force production to reflexive force production was found to be 0.28 ± 0.08 for the healthy control group. All the results are shown in Table 1.

4.2. Electrophysiological and muscle performance features of the spasticity group

The mean M response of the spasticity group was 15.25 ± 4.67 mV, which was lower than the control group, and a statistically significant difference was observed between the groups. M responses were lower for the spasticity group, whereas T/M ratios were significantly higher for the spasticity group. T/M values were calculated as 0.57 ± 0.23 for the whole spasticity group. Among the groups, T/M was calculated as 0.60 ± 0.23 for Ashworth 1 and as 0.52 ± 0.24 for Ashworth 2. There was a statistically significant difference in the T/M ratios between the spasticity group and the healthy control group and between spasticity group (Ashworth 1–Ashworth 2) ($p < 0.01$ and $p < 0.05$, respectively).

Table 1
Electrophysiological and muscle performance features of all groups.

	Normal	Spasticity	Ashworth 1	Ashworth 2	p*	p**
M Response (mV)	21.71 ± 4.24	15.25 ± 4.67	15.43 ± 5.87	15.07 ± 3.40	<0.001	0.650
N	20	20	10	10		
Tmax/Mmax ratio	0.21 ± 0.14	0.57 ± 0.23	0.60 ± 0.23	0.52 ± 0.24	<0.001	0.038
Force Ratio (Tf/Vf)	0.28 ± 0.08	0.37 ± 0.06	0.31 ± 0.04	0.41 ± 0.03	0.033	0.011
MUNIX	274.42 ± 55.33	221.6 ± 54.42	193,33 ± 34,70	249,67 ± 42,96	0.018	0.065
MUSIX	43.28 ± 6.62	37.00 ± 6.49	37,67 ± 6,40	36,50 ± 6,02	0.032	0.589
MUNIXT	33.12 ± 15.25	130.64 ± 33.42	123,83 ± 36,23	137,50 ± 32,07	<0.001	0.520
N	12	12	6	6		

* Healthy control and spasticity.
** Ashworth Group.

MUNIX and MUSIX analyses were performed between the healthy control group and the spasticity group because only 12 participants from the spasticity group were able to perform the test, and the spasticity group could not have analyzed between Ashworth 1 and Ashworth 2.

Both MUNIX and MUSIX values in the spasticity group were lower than those in the healthy control group. The MUNIX average value was 221.6 ± 54.42, and the MUSIX average value was 37.00 ± 6.49 μV. There was a statistically significant difference between the groups ($p < 0.05$ and $p < 0.05$, respectively). All the results are shown in Table 1.

4.3. Modified MUNIX algorithm for assessing excitability of T reflex

Although the MUNIX algorithm provides insight into the quantitative features of the motor neuron pool, it does not give any knowledge about motor neuron pool excitability. For that reason, we decided to develop a modified algorithm. Considering that T response is a compound action potential of activated motor units triggered by patellar T reflex, we changed the area and power of CMAP with the area and power of T response. The response of the area and power value of the T response can give information about the number of motor units that are triggered by the ratio

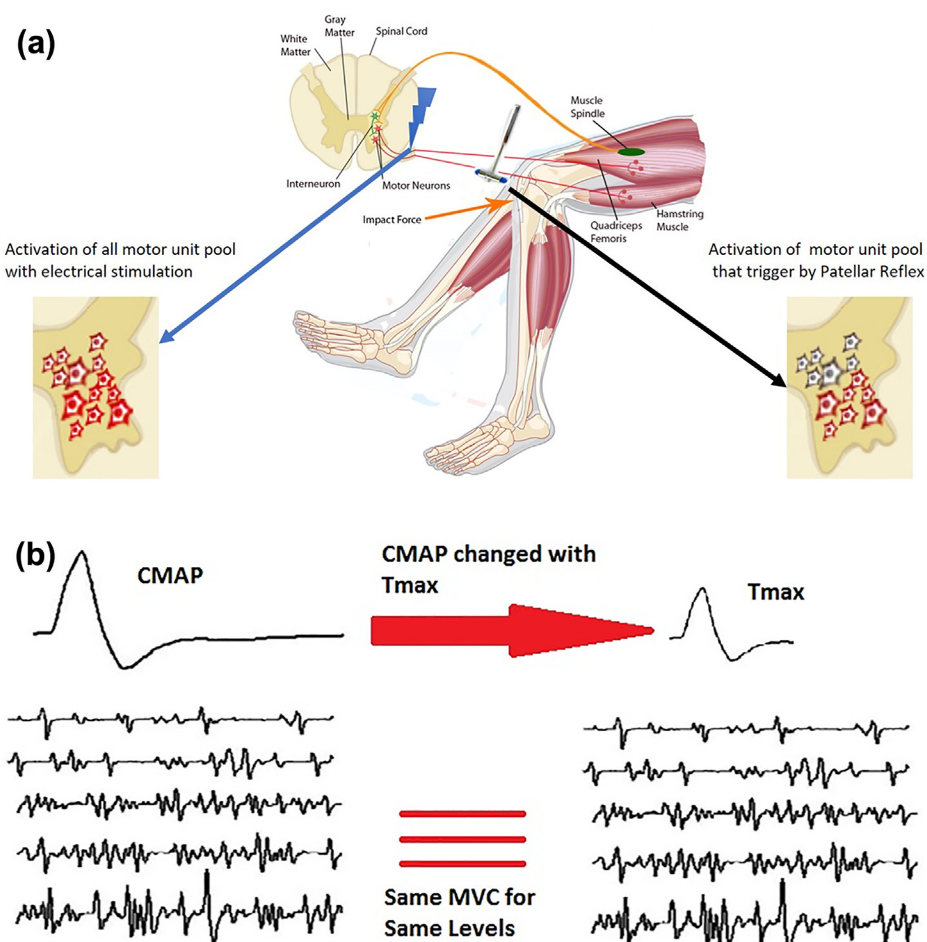

Fig. 2. Modified MUNIX algorithm. a) The CMAP signal selected as the reference point in the MUNIX algorithm is obtained by electrical stimulation. During reflex triggering, only a part of this motor unit pool can be triggered, and this triggered number of motor units is related to the excitability. We set the T Reflex response as the new reference point for evaluating this excitability. b) The reference point in the MUNIX algorithm was replaced by the T max response with the obtained maximal amplitude. In both algorithms, the same severe electrophysiological signal recordings were used for voluntary contractions.

of the area to power values of the voluntary contractions as described in Eqs. (5) and (6).

In this way, we try to obtain information about the activated motor neuron count through patellar reflex. We tried to observe excitability of the motor neuron pool with patellar reflex by comparing this count with total motor unit count in spasticity.

$$ICMUCT = A(SIP\,Area)^{\alpha} \tag{5}$$

$$MUNIXT = A20^{\alpha} \tag{6}$$

The results from the measurements show that the number of motor units (MUNIXT) triggered by the T response is higher in the spasticity group than in the healthy control group. We think that the ratio of MUNIXT to MUNIX values representing the total number of motor units reflects the excitability of the total motor unit pool for the respective muscle. This value (MUNIX/MUNIXT) was 56% ± 12% for the spasticity group and 14% ± 7% for the healthy control group. The basic principles of the modification algorithm are explained on the traces in Fig. 2.

Another parameter we use to compare the results is the ICMUC. The ICMUC value is defined as lack of MUP superimposition in the contraction and is related to force (Nandedkar et al., 2004). The results show that there is no significant difference between spasticity and healthy individuals for low-level contractions, whereas there is a significant difference for high-level contractions. The ICMUC values of the two groups at five different contraction levels are shown in Fig. 3. The ICMUC value is high in spasticity during high-level contractions. This may be interpreted as the lack of motor neurons involved as explained in an earlier study (Nandedkar et al., 2004).

The involuntary force generated from the patellar T by the reflex triggered is compared with the force that the patient can produce voluntarily. It is known that there is a loss of force production in spasticity, and studies have been conducted by different methods for monitoring this loss of strength (Zackowski et al., 2004; Ada et al., 2006; Pang et al., 2007). In our study, the Tf/Vf parameter was defined to monitor spasticity for the loss of force production.

In the spasticity group, an increase was observed in the ratio of maximal voluntary force to the T reflex triggered force production (Tf/Vf). There was a statistically significant difference among the spasticity group itself (Ashworth 1–Ashworth 2) and between the spasticity group and the healthy control group. The Tf/Vf mean value was 0.34 ± 0.04 for Ashworth 1 group and 0.41 ± 0.03 for Ashworth 2 group. When comparing the results of MUNIXT obtained from the modification algorithm, there was a significant difference in distribution between the spasticity group and the healthy control group. The Tf/Vf and MUNIXT distributions for the groups are shown in Fig. 4.

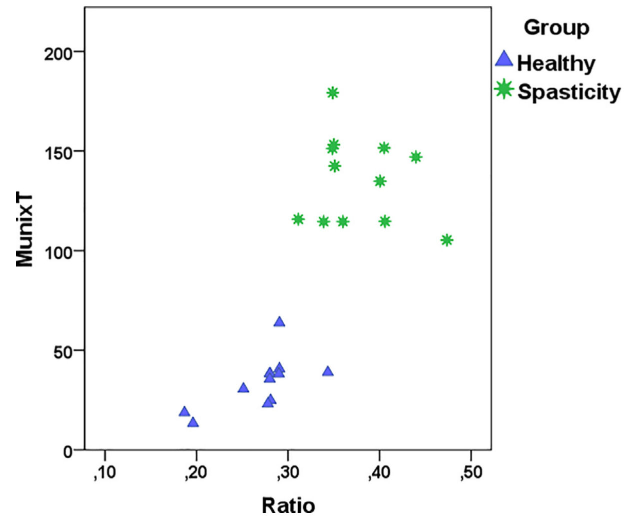

Fig. 4. Tf/Vf Ratio – MUNIXT distributions.

5. Discussion

One of the basic components of the classic definition of spasticity by Lance is the presence of increased deep tendon reflexes (DTRs). The Ashworth scale assessment does not include the assessment of DTRs, which are described as phasic stretching reflexes, although this is a clinical description. However, the presence of increased DTRs and pathological reflexes is one of the main findings in the detection of corticospinal lesions when examining patients.

The basic mechanism of increasing DTR because of upper motor neuron lesion cannot be explained only by the speed-dependent increase in stretch reflex, which is a correlation with tonus increase. The underlying pathology is an increase in the likelihood of the firing of neurons forming the alpha motor neuron pool of the relevant muscle. The increase in the amplitude of the H reflex or

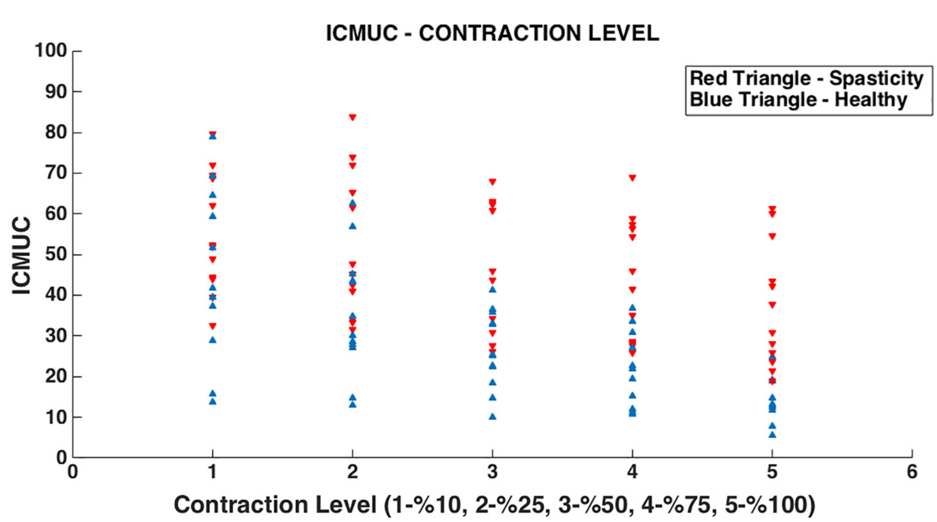

Fig. 3. ICMUC values of two groups at five different contraction levels.

the increase in the Hmax/Mmax ratio observed in the first electrophysiological studies on spasticity appears to result from the increased DTR (Calota and Levin, 2009; Burke, 2016).

The amplitude of the H reflex correlates with the number of alpha motor neurons fired by the Ia afferents; however, with the Ia afferents, the pool consisting primarily of small motor neurons can be ignited, and the H max/M max ratio is increased by the addition of new neurons because of the fire threshold falling on the changes due to the upper motor neuron lesion of the alpha motor neuron.

T reflex was used to evaluate the neuron pool that Ia afferents could fire similar to the H reflex. The Tmax/Mmax ratio is increased in spasticity. Therefore, it has been used as a tool to evaluate the phasic stretching reflex for many years (Milanov, 1992; Mullick et al., 2013; Thibaut et al., 2013).

The MUNIX method gives an opportunity for evaluating the number of axons that could innervate the related muscle, thus representing the alpha motor neuron pool (Nandedkar et al., 2004; Nandedkar et al., 2010; Neuwirth et al., 2011). The evaluation of MUNIX in spasticity has been used for limited study and we do not have enough knowledge with regard to this (Li et al., 2012; Marciniak et al., 2015). In these studies, the authors have reported a decrease in the MUNIX value and an increase in the MUSIX value in cerebral palsy and spinal cord lesions. As the tendency is same as those of previous works, the MUNIX value decreases but the MUSIX value is not different significantly in spasticity in our study. Different from this study, others calculated MUNIX values from distal muscles and tonus changes were not described clearly. In this study, the MUNIX value is calculated from the proximal muscle; hence, upper motor neuron effects by size index may not be prominent as much as those from distal muscles.

In addition, Amyotrophic Lateral Sclerosis (ALS) is also the most frequent study of MUNIX in diseases with upper motor neuron involvement. However, in these studies, motor unit loss and reinnervation have been evaluated in terms of being indicative. The upper motor neuron involvement has not been assessed in these studies (Escorcio-Bezerra et al., 2016; Fukada et al., 2016; Grimaldi et al., 2017; Neuwirth et al., 2017).

The superiority of the MUNIX method compared to other methods estimating motor unit numbers is that it allows studying the motor neuron pool of more muscle mass. In fact, the MUNIX method allows axons to be counted in the nerves of the distal muscles such as APB, ADM, AH, and EDB, as well as the motor neuron pool, which innervate proximal muscles such as biceps, deltoid, and triceps. However, the MUNIX value of the rectus femoris muscle from the proximal muscles of the lower limb has not been studied to date. The effector part of the patellar T reflex is the rectus femoris muscle from the quadriceps femoris and its components. In this study, the MUNIX value of the rectus femoris muscle was measured for the healthy control group and spasticity group. These values were compared between the groups. As reported earlier in the spasticity literature, MUNIX values have been observed to decline in the rectus femoris motor neuron pool.

An increased Tmax/Mmax ratio is reported in the spasticity literature. It is emphasized in the literature that the increase in Tmax/Mmax ratio could be related to an increase in the number of motor units that can fire by patellar reflex and the decrease in the threshold for motor unit firing. For this reason, the MUNIX algorithm presented by Nandedkar et al. is modified to observe the number of motor units triggered by T reflexes between the spasticity group and healthy control group. However, because of the increased Tmax value, the T reflex alternating the MUNIX value obtained in a modified form instead of the M response by using the T reflex was significantly higher in the spasticity than in the healthy control group. As shown in previous studies, T/M is increases in spasticity, and in our findings, the T/M ratio has increased markedly as shown in Table 1. The difference between Ashworth 1 and 2 groups was statistically significant but increased in both groups when compared to the healthy control group. We think that the difference between the two groups may be consistent with the saturation of the stimulus in the spinal pool. For the Ashworth 1 and Ashworth 2 groups, the statistical comparison was not significant. We think that statistically significant differences in these parameters can be observed with a higher number of participants.

We believe that the MUNIXT algorithm can be used as a marker for increasing the excitability of the alpha motor neuron pool in spasticity. The MUSIX is defined as motor unit size index in the algorithm developed by Nandedkar et al. We compared the MUSIX values in the MUNIXT algorithm with the MUSIX values in the MUNIX algorithm. A high correlation between MUSIX values was observed in both algorithms. We think that MUSIX values should be similar in both algorithms because we recorded these measurements from the same participants at the same time.

The MUNIXT algorithm developed in this study allows making a more comprehensive evaluation with the reasons explained in the following:

- Assessment of weakness and coordination (determination of levels) by involving voluntary force production in different levels,
- Evaluation of hyperactive reflexes by the involvement of T responses in evaluation,
- Enables you to obtain the percentage of excitability as a result of applying these mathematical operations to these parameters.

This allows the evaluation of alpha motor neuron excitability. In addition, the normalization of the percent excitability also reduces the error margin.

One benefit of the developed MUNIXT parameter to the clinic is that it can easily distinguish between spasticity and healthy individuals. We can see that it is difficult to distinguish with only MUNIX values, only Tmax/Mmax ratios, only Voluntary Force Production values, or only Reflex Force Production values. However, we can see that group separations can be done easily by adding MUNIXT value to these parameters.

With regard to the definition of MUNIX algorithm developed by Nandedkar et al., when we deal with a part with N (number) motor units, the CMAP response shows the sum of all motor units. The power and area of the CMAP signal represent the combination of the power and field of the N (number) motor units. SIP is the superimposed state of D (number) motor neurons discharging in different F frequencies. Therefore, comparing these two parameters allows us to obtain an index of the motor neuron pool (Nandedkar et al., 2004).

However, this method does not provide information about the excitability of the pool. The combination of the K (number) motor units triggered by the patellar T reflex generates the T response. Based on the T response in the MUNIXT algorithm, the ratio of the index to the MUNIX response obtained from the same SIP comparison result shows us a percentage of the excitability.

Another advantage provided by the MUNIX method is that it allows quantitative evaluation of the relationship between the numbers of motor units involved in the force generated by the ICMUC parameter. The ICMUC value is defined as the lack of MUP superimposition in the contraction and is related to force (Nandedkar et al., 2004). In our study, statistically significant differences were only obtained for the high-level contraction (75% and 100%) when the ICMUC parameter was compared between the spasticity group and healthy control group at all the five levels.

There are studies supporting that patellar T reflex-triggered patellar pendulum may be a useful method for the evaluation of spasticity. T reflex-triggered pendulum creates a composition that can be evaluated for both phasic and tonic stretch reflexes. It also includes the assessment of the phasic stretching reflex of the agonist muscle, as well as the impression that the notching sign in the pendulum caused by the triggering of the stretching reflex in the antagonist muscle can be regarded as a marker of spasticity.

Spasticity and healthy subjects can be distinguished easily and clearly by evaluating the changes in both kinesiological and electrophysiological findings and decreasing threshold in the alpha motor neuron pool. We believe that this study shows that such combined methods, which allow the evaluation of the alpha motor neuron pool, as well as the kinesiological and electrophysiological parameters, are tools that cannot be overlooked in understanding spasticity.

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Conflict of interest

The authors declare that they have no competing interests.

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