

Assessing the Spastic Condition of Individuals With Upper Motoneuron Involvement: Validity of the Myotonometer

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ABSTRACT. Leonard CT, Stephens JU, Stroppel SL. Assessing the spastic condition of individuals with upper motoneuron involvement: validity of the myotonometer. *Arch Phys Med Rehabil* 2001;82:1416-20.

Objectives: To examine the validity of a newly developed tissue compliance device to measure muscle tone and to quantify the level of severity of the spastic condition.

Design: Validity study.

Setting: Research laboratory.

Participants: Twenty subjects, 10 with upper motoneuron (UMN) disorders (spastic-type cerebral palsy or adult-onset cerebrovascular accident) who comprised the experimental group; and 10 nondisabled, age-equivalent subjects, who served as controls.

Interventions: Not applicable.

Main Outcome Measures: Muscle tone of the biceps brachii muscle was assessed with the Myotonometer™ and Modified Ashworth Scale (MAS). The Myotonometer was used to quantify the muscle's resistance to stretch in a relaxed state and during maximal voluntary isometric contractions. Analyses of variance determined differences among subjects. Correlations between Myotonometer measurements and MAS scores were calculated.

Results: Significant differences ($p < .05$) were observed between experimental and control groups and between the involved and uninvolved extremities of the experimental group with Myotonometer measurements. Correlations between MAS scores and Myotonometer measurements ranged from .64 to .81.

Conclusion: The Myotonometer effectively identified differences in the spastic condition of the biceps brachii muscle in subjects with UMN involvement. Correlations with the MAS were moderate to high.

Key Words: Cerebral palsy; Cerebrovascular accident; Muscle spasticity; Muscles; Myotonometer; Rehabilitation.

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PROPER EVALUATION OF SPASTICITY and the spastic condition is important in monitoring the progression of certain neurologic disorders, and for assessing therapeutic interventions.¹⁻³ Spasticity is defined clinically as velocity-de-

pendent resistance to passive stretch, accompanied by increased deep tendon reflexes.⁴⁻⁶ Positive and negative symptoms contribute to the spastic condition. Positive symptoms indicate a characteristic that is present or accentuated (eg, hyperactive stretch reflexes), whereas negative symptoms indicate a characteristic that has been lessened or is absent (eg, muscle paresis).^{5,7,8}

Changes in muscle tone and compliance contribute to the spastic condition. *Muscle tone* is defined as resistance to passive stretch that reflects the relative influences of mechanical-elastic characteristics and reflexive drive to the muscle.^{4,5} *Tissue compliance* is defined as the ratio of the change in muscle length to the change in muscle tension in the absence of change in the neural drive to the muscle. Soft tissue compliance contributes to the increased resistance to passive stretch of spastic muscles.⁹

Several devices and techniques have been developed to quantify spasticity and the spastic condition. The Modified Ashworth Scale (MAS) is the spasticity assessment tool used by many clinicians for most applications and has been the standard to which all newer spasticity measuring procedures have been compared.^{7,10-13} The MAS, however, is a subjective evaluation that can only be used to test the extremities. It has poor intertester reliability and has a tendency to cluster results (ie, it does not discriminate among moderate levels of spasticity).^{11,12} Although the MAS is the current clinical assessment tool of choice, it is clear that reliable, clinically applicable methods with which to assess spasticity are needed.

Recent methods used to assess spasticity include biomechanical and electrophysiologic techniques. Biomechanical methods include torque, ramp and hold, and pendulum (electrogoniometric) tests. Electrophysiologic tests include H-reflex, H:M ratio, electromyographic ratio to length change, and F-wave measurements.

To differentiate levels of spasticity, biomechanical assessment measures change in torque production (resistance) during passive limb movements. Pendulum tests, also known as drop tests, use an isokinetic dynamometer to act as an electronic goniometer. Various adaptations of the pendulum test have been successful in assessing therapeutic intervention effectiveness in reducing spasticity.^{14,15} Negative aspects of the test, however, include the need for complicated mathematical formulae that make use of questionable assumptions regarding muscle properties¹¹ and the fact that the test is not applicable for most muscle groups.^{11,16}

Ramp and hold tests assess spasticity by measuring the electromyographic activity and torque of the muscle as it is passively moved through its range of motion (ROM) at a constant velocity. This method requires extensive instrumentation as well as training to administer it. It is also a lengthy procedure. Another drawback to the ramp and hold test is that the results vary, based on an individual's limb size and biomechanical properties.¹⁶ And reflex stiffness appears to be normal in hypertonic muscles.¹¹

Electromyographic reflex thresholds (the angle at which electromyographic activity is first detected in a muscle that is passively lengthened) can also be computed. These threshold-

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Accepted in revised form November 28, 2000.

Supported, in part, by the MJ Murdock Charitable Trust Foundation. Charles Leonard is co-inventor of the Myotonometer™ (US patent 6063044) and is the president of Neurogenic Technologies, Inc.

An organization with which one or more of the authors is associated has received or will receive financial benefits from a commercial party having a direct financial interest in the results of the research supporting this article.

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0003-9993/01/8210-6441\$35.00/0

doi:10.1053/apmr.2001.26070

estimating techniques, however, are not readily available in most clinical settings and do not address tissue compliance changes that are often associated with the spastic condition.^{11,17} Despite these limitations, each of these methods has provided useful information about the mechanisms that contribute to the spastic condition. Realistically, however, they are not appropriate for repeated clinical use and are too complex to be applied to some individuals with disabilities.⁶ In addition, they have not correlated well with the clinical assessment of the severity of spasticity.^{11,18}

Tissue compliance meters are a relatively recent addition to the search for clinically applicable spasticity assessment instrumentation.^{13,19-21} These instruments consist of a probe that non-invasively pushes onto a muscle. Transducers within the probe measure the amount of underlying tissue displacement per unit of force applied to the muscle by the probe. Length-tension curves can be generated from these recordings that show the amount of stretch to the muscle per unit of applied force. Tissue compliance meters have been shown to be valid and reliable measures of muscle tone and compliance.^{13,19,20,22}

In this study, we used a patented,²³ computerized, electronic tissue compliance, meter-type device, the Myotonometer™.^a This study was undertaken to examine the construct validity of using Myotonometer measurements as a basis for quantifying differences in the level of severity of the spastic condition. Myotonometer measurements of a relaxed muscle provide valid and reliable measures of muscle tone and compliance.^{13,19,20,22} Measurements taken during muscle contraction correlate well to torque production within the muscle.²⁴ This experimental protocol included calculation of the percentage difference between force and displacement measurements of a muscle in a relaxed state and those obtained during a voluntary isometric contraction. We hypothesized that these values could be used to differentiate levels of severity of the spastic condition. Myotonometer measurements of the involved, spastic limb were compared with measurements of the uninvolved limb and with measurements from the nondisabled control subjects. With this method, we were able to determine whether Myotonometer measurements could differentiate among these 3 dissimilar groups. In addition, Myotonometer results were compared and correlated with results obtained from using the MAS.

METHODS

Subjects

Twenty subjects participated in this study. Ten subjects with upper motoneuron (UMN) involvement served as the experimental group, and 10 healthy, nondisabled, age-equivalent subjects served as the control group. All 20 were volunteers from the community, the Retired Senior Volunteer Program, and the University of Montana. Each gave written informed consent before being tested. All procedures were approved by the University of Montana Institutional Review Board and were conducted in accordance with the Declaration of Helsinki. Table 1 provides a summary of relevant subject characteristics. Persons in the experimental group had various levels of disability, but they all exhibited clinical signs of spasticity (resistance to passive stretch and accentuated deep tendon reflexes) in 1 or more extremity. The control subjects had no history of neurologic illness or injury. Persons with a recent history (<2yr) of an orthopedic condition (eg, musculotendinous sprain or bone fracture) were excluded from the study.

Data were grouped as follows: group 1 consisted of control subjects' dominant upper extremities, group 2 consisted of the involved upper extremities of individuals with UMN involve-

Table 1: Demographics of Study Sample

	Experimental Subjects		
	Women	Men	Combined
Subjects (n)	4	6	10
Age range (yr)	20-77	19-73	19-77
Mean age (yr)	44.8	49.3	47.5
Right CVA (n)	0	1	1
Left CVA (n)	2	3	5
CP diplegia (n)	2	1	3
CP quadriplegia (n)	0	1	1
Right-handed (n)	3	6	9
	Control Subjects		
	Women	Men	Combined
Subjects (n)	4	6	10
Age range (yr)	20-74	20-75	20-75
Mean age (yr)	50.8	48.0	48.3
Right-handed (n)	4	6	10

Abbreviations: CVA, cerebrovascular accident; CP, cerebral palsy.

ment, and group 3 consisted of the uninvolved upper extremities of individuals with UMN involvement.

Procedures

Each subject's tone and compliance was assessed with the Myotonometer and the MAS. The time of day of testing was similar for all subjects. In all cases the subject's tone was first assessed with the Myotonometer, followed immediately with the MAS. The reason for the testing order was that movements of the limb during Ashworth testing may affect background neural activity of the muscle and cause a change in muscle tone.⁵

Biceps brachii testing. Myotonometer tone and compliance measurements were taken while the subjects' muscles were relaxed, and during a maximal voluntary contraction (MVC) of the biceps brachii muscle. Five measurements were obtained for each condition (5 relaxed, 5 contracted). Subjects were given a 15- to 30-second rest between each trial.

The area over the flexor surface of the arm was tested with the subject in a sitting position. The elbow was flexed to 90° with the forearm supinated. The application area of the Myotonometer probe for the biceps was equidistant between the lateral aspect of the acromion process and the most inferior part of the olecranon. This point was marked with ink, and a horizontal line was drawn on the anterior aspect of the arm. Measurements were taken first with the muscle relaxed. For the contraction phase, subjects were instructed to perform a maximal isometric contraction of the elbow flexors. To ensure limited movement of the extremity, a strap was placed at the wrist for resistance. A hand-held force dynamometer, placed at the distal aspect of the forearm, was used to gauge the force of the isometric contraction of the upper extremity. Each subject was required to reproduce similar force output for each trial during MVC testing.

Myotonometer measurement procedures. The Myotonometer contains a linear array of transducers that measure the amount of tissue displacement per unit force applied by the Myotonometer probe as it is pushed onto the skin overlying the tested muscle. Measurements were taken every .25kg of force, up to 2.0kg. Associated computational software generates force and displacement curves for both relaxed and contracted conditions. The percentage difference at each .25kg of force between the relaxed and contracted conditions was computed. The smaller the difference in measurements between the 2 conditions, the more severe the spastic condition (figs 1-3).

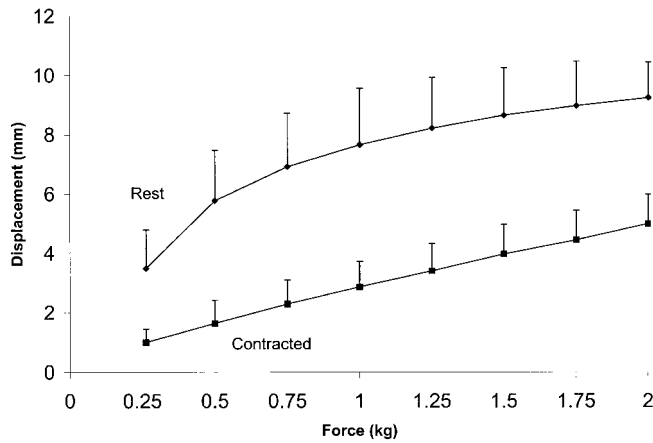


Fig 1. Control group (group 1) data of Myotonometer recordings of the biceps brachii muscle. Measurements were taken during resting condition and during biceps MVC (contracted) at force levels of .25, .50, .75, 1.00, 1.25, 1.50, 1.75, and 2.0kg. The y axis represents the amount of tissue displacement elicited by the Myotonometer probe. Error bars represent standard deviations.

MAS testing. The MAS uses an ordinal scale to assess the resistance of an extremity to passive stretch (table 2).^{7,16} Subjects sat during the MAS testing. A physical therapist/neuroscientist experienced in performing the MAS test examined the subject's spasticity. The resistance to elbow extension was evaluated. To minimize tester bias, the Myotonometer results were blinded to the examiner who performed the MAS testing.

Statistical Analysis

One-way analysis of variance (ANOVA) was used to compare the percentage differences between the relaxed and contracted conditions recorded by the Myotonometer for all 8 increments of force (.25–2.0kg) of the involved and uninvolved extremities of the individuals with spasticity, and the dominant extremity of the control group. A Tukey's honestly significant difference method was used as a post hoc test.

Cramer's V correlation was used to correlate MAS scores with the percentage differences of the Myotonometer results

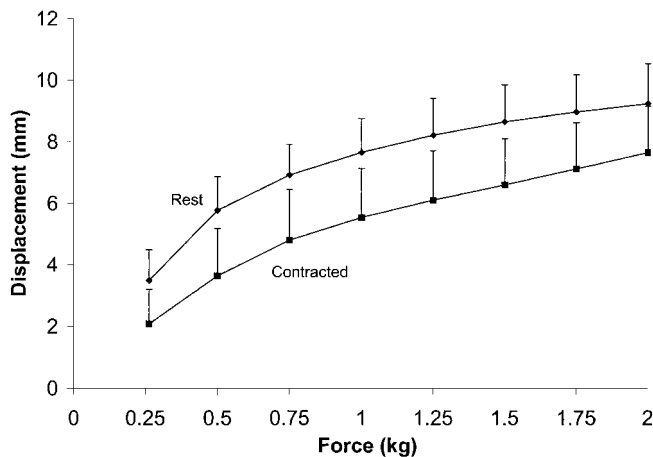


Fig 2. Involved extremity group data (group 2) of the biceps brachii muscle during rest and during biceps MVC (contracted) at force levels of .25, .50, .75, 1.00, 1.25, 1.50, 1.75, and 2.0kg. The y axis represents amount of tissue displacement elicited by the Myotonometer probe.

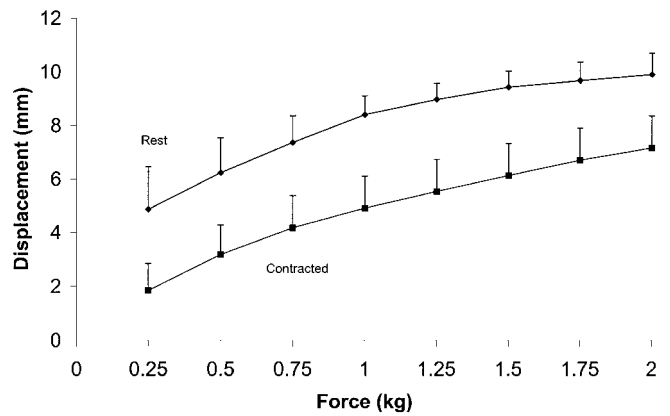


Fig 3. Uninvolved extremity group (group 3) data for the biceps brachii muscle during rest and during biceps MVC (contracted) at force levels of .25, .50, .75, 1.00, 1.25, 1.50, 1.75, and 2.0kg. The y axis represents amount of tissue displacement elicited by the Myotonometer probe.

(.25–2.0kg) of the involved extremity of the experimental group. A chi-square test was used to determine homogeneity of the data. To analyze the data using the Cramer's V correlation, Myotonometer percentage differences were converted from a real number scale to a nominal scale by assigning them into 3 groups. Group 1 consisted of percentage differences of less than or equal to 10%, group 2 of differences greater than 10% and less than or equal to 50%, and group 3 of differences greater than 50%. The Ashworth scores were also grouped for analysis. The reason for this was that, similar to previous reports,¹⁶ our testing revealed a clustering effect. Therefore, not all 6 categories of the MAS were represented. Correlation analysis is not possible with empty bins. The 6 MAS scores were condensed into 4 groups: group 1, subjects with MAS scores of 0; group 2, subjects with MAS scores of 1 and 1+; group 3, subjects with MAS scores of 2 and 3; and group 4, subjects with MAS scores of 4. Level of significance was set at *p* less than .05.

RESULTS

Percentage Difference Between Myotonometer Recordings Obtained During Muscle Relaxation and Contraction

There were significant differences (*p* < .05) for every force level (.25–2.0kg) between groups 1 (nondisabled controls) and

Table 2: MAS for Grading Spasticity

Grade	Description
0	No increase in muscle tone.
1	Slight increase in muscle tone, manifested by a catch and release, or by minimal resistance at the end ROM when the affected part(s) is moved in flexion or extension.
1+	Slight increase in muscle tone, manifested by a catch, followed by minimal resistance throughout the remainder (less than half) of the ROM.
2	More marked increase in muscle tone through most of the ROM, but affected part(s) move easily.
3	Considerable increase in muscle tone, passive movement difficult.
4	Affected part(s) rigid in flexion or extension.

Table 3: η Values Based on ANOVA Comparing Percentage Differences at Each Force Increment Between the Resting and Contracted Muscle in Biceps Brachii Testing

Force Level (kg)	Groups*		
	1 & 2	1 & 3	2 & 3
.25	.012	.295	.186
.50	.001	.083	.055
.75	.000	.077	.016
1.00	.000	.077	.010
1.25	.000	.107	.020
1.50	.000	.126	.028
1.75	.001	.131	.049
2.00	.001	.143	.034

* Group 1, nondisabled (controls); group 2, UMN involved extremity; group 3, UMN uninvolved extremity.

2 (involved extremity of experimental group). Significant differences were also found between groups 2 and 3 (uninvolved extremity of experimental group) at all levels of force, with the exception of .25 and .50kg. There were no significant differences at any level of force between groups 1 and 3. Table 3 summarizes these group statistics. Figures 1, 2, and 3 show the tissue displacement at each of the 8 force increments between the relaxed and contracted states for each group.

Biceps Brachii Resting Data

The resting values for groups 1 and 2 were similar (see figs 1, 2), indicating no difference among these groups in resting muscle tone and compliance (p values: range, .89 at .25kg of force to .62 at 2.0kg of force). In contrast, the resting muscle tone of group 3 (fig 3) was significantly less than that of controls (p values: range, .03-.05 for each force increment). The resting muscle tone of the uninvolved extremity was less than that of the involved extremity at every increment of force (figs 2, 3), but only the .25kg measurement achieved significance at p less than .05 (p values = .03, .40, .32, .10, .09, .08, .13, .18 [in ascending order from .25kg]).

Biceps Brachii Contraction Data

Data obtained during maximal voluntary muscle contraction (figs 1, 2) show that the amount of tissue displacement per unit force of group 2 (involved extremity) was significantly greater than that recorded for group 1 (controls) (p values: range, .01-.00 for each force increment). This indicates that there was less tone generated during muscle contraction (indicative of muscle paresis) of the involved extremity in comparison to the controls. The tone generated during muscle contraction of the uninvolved extremity was also significantly less than controls (p values: range, .03-.00). The tone generated during contraction by group 2 was slightly less than that of group 3 and did not achieve significance (p values: range, .39-.87).

Correlations Between MAS Scores and Myotonometer Recordings

Correlations comparing MAS scores with Myotonometer percentage differences (relaxed vs contracted muscle) for group 2 ranged from r values of .64 to .81. The highest correlations were found in the mid-force ranges. Table 4 summarizes these results.

DISCUSSION

The Myotonometer was successful in identifying differences in muscle tone and compliance and level of spasticity of the

biceps brachii muscle. Similar to results of other studies that used different laboratory methods,^{25,26} the resting tone of spastic muscles did not differ significantly from resting muscle tone of nonspastic muscles, as assessed by the Myotonometer. Impairment was detected, however, during muscle contraction. The increased probe penetration (indicating low tone and high compliance) during biceps MVC of the spastic muscle was the major contributing factor to the differences found between the involved extremity and the nondisabled, control group. This finding is indicative of muscle paresis.

Agonist paresis, a negative feature of the spastic condition, is a primary contributory factor to disability after a central nervous system (CNS) lesion.^{25,27,28} We found that muscle paresis, not excess resting muscle tone, was a contributory factor to our subjects' disabilities. Because homogeneity was lacking in our subjects, it cannot be said that this is a general feature of the UMN syndrome. Different CNS disorders might present with a different profile.

Based on Myotonometer measurements, the uninvolved upper extremity of individuals with an UMN lesion exhibited increased compliance during relaxed conditions, relative to that of individuals without an UMN lesion. One possible explanation for this finding is disuse phenomenon. A decrease in the activity and use of the uninvolved extremity after UMN damage would result in a decrease in resting tone. In contrast, resting muscle tone of the involved extremity was maintained because of spasticity and, possibly, a hyperactive reflex arc.

A moderate to high level of correlation between data obtained with the Myotonometer and the MAS was observed. This supports the validity of the Myotonometer in assessing muscle tone. In addition, the Myotonometer appears to be more discriminative in differentiating levels of muscle tone, it does not exhibit a clustering effect, and it can be used to measure postural or extremity musculature.

CONCLUSIONS

The Myotonometer is a useful clinical and research tool with which to identify muscle characteristic changes associated with spasticity of the biceps brachii due to an UMN lesion. The Myotonometer can provide clinicians and researchers with objective quantification of several aspects of the spastic condition without cumbersome, time-consuming, painful, or expensive procedures. This is an important development in the evaluation and treatment of neurologic disorders. The device appears to be useful in determining whether impairments of muscle tone or paresis contribute to an individual's disability. Devices such as the Myotonometer can provide quantitative data about the efficacy of various pharmacologic, surgical, and physical therapy interventions.

Table 4: Correlation of MAS and Myotonometer Results

Myotonometer Force (kg)	Correlation Coefficient
.25	.74
.50	.80
.75	.81
1.00	.81
1.25	.78
1.50	.76
1.75	.65
2.00	.64

Acknowledgments: We thank Pamela Diedrich and Tamaki Matsumoto for their technical assistance and Dr. Steven Fehrer for his review of this manuscript.

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