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Lecture

Assessing muscle compliance in stroke with the Myotonometer

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ABSTRACT

Background: This study explores changes of the intrinsic biomechanical property in the biceps brachii muscle after a hemispheric stroke using the Myotonometry technique.

Methods: Nineteen subjects with chronic hemiplegia participated in the study. Myotonometer was used to measure tissue displacement when compression force was applied at 8 levels from 2.45 N to 19.6 N. Muscle displacement and compliance were determined and averaged over multiple trials.

Findings: Statistical analysis indicated a significant decrease in muscle displacement and compliance in the spastic muscles compared with the contralateral side (muscle displacements: spastic: 4.51 (0.31) mm, contralateral: 5.74 (0.37) mm, $p < 0.005$; compliance: spastic: 0.17 (0.011) mm/N, contralateral: 0.22 (0.014) mm/N, $p < 0.005$). Correlation analysis, however, did not show any association between clinical assessments and myotonometric measurement ($p > 0.1$).

Interpretation: Alterations of muscle compliance in the spastic side reflect changes in the contractile or intrinsic mechanical properties after a stroke. Findings of the study have demonstrated high sensitivity and effectiveness of the Myotonometer in assessing muscle compliance changes.

1. Introduction

Spasticity or hypertonia, characterized by the velocity-dependent resistance to passive stretch, has been commonly observed in a number of neurological disorders including cerebral palsy, multiple sclerosis, spinal cord injury, and stroke (Burke, 1988; Lance, 1980; Leonard et al., 2001; Mirbagheri et al., 2001; Sanger et al., 2003; Sinkjaer et al., 1993). The origins of spasticity remain controversial, possibly from hyperactive stretch reflexes, abnormal intrinsic properties of the contractile apparatus, or mechanical (viscoelastic) properties of the passive tissues (Katz and Rymer, 1989; Mirbagheri et al., 2001; Sinkjaer and Magnussen, 1994).

Quantification of spasticity involves subjective and objective measurements which provide important information on the pathophysiological changes of nervous system and muscle tissues after an injury. The Modified Ashworth Scale (MAS) is frequently used in clinics, which consists of a 6-point ordinal scale to differentiate levels of spasticity (Bohannon and Smith, 1987). The scale of MAS, however, is subjective and tends to cluster in the lower ranges, leading to compromised interrater repeatability, accuracy and reliability (Aarrestad et al., 2004; Blackburn et al., 2002; Leonard et al., 2001). Objective evaluation of spasticity involves biomechanical and electrophysiological measurements which record joint torques, voluntary muscle activities, and muscle responses at rest or during contractions. H reflex, the ratio of H:M, and F wave are typical electrophysiological measures for assessing motoneuron excitability and spasticity (Argyriou et al., 2010; Huang et al., 2006; Pizzi et al., 2005).

Conventional biomechanical techniques utilize a servo-controlled motor to measure joint resistance torque with respect to angular displacement (Katz and Rymer, 1989; Mirbagheri et al., 2001; Rydahl and Brouwer, 2004; Toft et al., 1991). By stretching the muscle at a constant velocity within a preset range and inducing perturbations or electrical stimulations, it is possible to separate total mechanical stiffness into intrinsic and reflex components (Rydahl and Brouwer, 2004; Sinkjaer et al., 1988). Those components are interdependent and may individually contribute or co-contribute to muscle stiffness. Given that equipment setup and data collection are complicated the potential applications of the techniques in clinical facilities are restricted.

Myotonometry provides an alternative and more compact means to assess muscle stiffness or compliance (inverse of stiffness). Presently, there are two representative types of devices that quantify muscle compliance. One is Myoton, which applies a brief mechanical impulse to the skin and records the oscillations of muscle responses (Chuang et al., 2012). The other type is Myotonometer, which measures the

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amount of muscle deformation to a number of perpendicularly applied forces (Leonard, 1994; Leonard et al., 2001). Myotonometer is used to examine muscles in a relaxed position or under an isometric contraction (Bizzini and Mannion, 2003; Hung et al., 2010; Leonard et al., 2003; Marusiak et al., 2010). It requires minimal setup time and can achieve high intra- and inter-rater reliabilities (Aarrestad et al., 2004; Leonard et al., 2003). Therefore, it may have promising applications for evaluation of muscle conditions in the clinical setting.

Both myotonometric devices have been used to examine muscle compliance in spastic muscles in previous studies. The findings, however, are different (Chuang et al., 2012, 2013; Leonard et al., 2001; Rydahl and Brouwer, 2004). For example, substantial changes of the elasticity and stiffness in hand flexors were observed in stroke using the Myoton device (Chuang et al., 2012). On the other hand, no significant changes of compliance are reported between the spastic and healthy groups using the Myotonometer (Leonard et al., 2001; Rydahl and Brouwer, 2004). According to the literature, muscle displacement occurs after the full compression of subcutaneous layers (Rydahl and Brouwer, 2004). Previous studies focus on the overall tissue displacement without distinguishing subcutaneous and muscle displacements (Leonard et al., 2001).

In this study, we applied a two-layer spring model to evaluate the muscle displacement and the overall tissue displacement (Horikawa et al., 1993). We identified significant decrease of muscle compliance in the spastic side. The change of muscle compliance, however, was not correlated with the MAS.

2. Methods

2.1. Subjects

Nineteen subjects (10 Female, 9 Male) with chronic hemiplegia participated in the study. All subjects survived from one incidence of stroke at least 6 months prior to the study and were free of any other known neurological disorders. The average age was 62 (10) years (mean (standard deviation)) and the time course since stroke varied from 6 months to 13 years. All subjects signed consent approved by the Institutional Review Board of University of Texas Health Science Center at Houston prior to any experiments. The MAS test was performed on the spastic elbow flexors after the experiment. Clinical assessments and demographic information of subjects are presented in Table 1.

Table 1
Subjects' demographic and clinical data.

ID	Paretic	Age (year)	Gender	MAS	Duration (month)
1	L	58	F	1 +	6
2	L	77	M	0	16
3	L	58	F	1	88
4	L	71	M	0	76
5	R	61	F	1	91
6	R	53	M	1 +	52
7	L	65	M	0	51
8	R	52	F	1 +	86
9	R	69	M	1 +	75
10	R	63	F	1	41
11	R	79	M	1	64
12	L	62	F	0	164
13	R	67	F	1	101
14	R	37	F	2	88
15	L	65	M	1 +	24
16	L	71	M	1 +	60
17	R	49	F	3	17
18	L	55	F	2	82
19	R	67	M	3	21

MAS: Modified Ashworth Scale; Duration: months since stroke.

2.2. Experiments

Subjects were seated comfortably in a chair, and instructed to maintain an upright sitting posture during the experiment. In particular, the shoulder was slightly abducted and the elbow was laid on a height-adjustable table in 90-degree flexion. The Myotonometer (Neurogenic Technologies, Missoula, MT, USA) is a hand-held electronic device that consists of an inner metal probe, an outer plastic sleeve, and a linear array of force transducers. The probe and the plastic sleeve are on the same surface when no compressing force is applied. Prior to the test, the probe and the sleeve were placed over the muscle bulk perpendicular to the bone. During the experiment, the experimenter exerted continuous compression to the muscle until a sound was heard, which indicated the 19.6 N of force was met. The resistance that the muscle generated against probe penetration was sampled at 8 force levels from 2.45 N to 19.6 N at increments of 2.45 N. The corresponding tissue displacement was measured as the distance between the inner probe and the outer plastic sleeve. Each trial takes approximately 1 s and each muscle was tested 8 times in the experiment. The test was performed bilaterally over the biceps brachii muscles and all experiments were conducted by the same experimenter.

2.3. Data analysis

Offline analysis of the Myotonometer data was conducted in MATLAB® (MathWorks, Natick, MA). Results of the Myotonometer recording from a representative participant are presented in Fig. 1.

As seen in the figure, tissue displacement changes nonlinearly with force. For example, when compression force increases from 2.45 N to 5.51 N, tissue displacement changes from 8.54 mm to 10.5 mm in the spastic side. As compression force continues to increase from 5.51 N to 19.6 N, the second part of tissue displacement changes from 10.5 mm to 12.47 mm (Fig. 1). The different slopes of displacement-force may suggest two different types of tissues (i.e. subcutaneous tissue and muscle) (Horikawa et al., 1993; Sakai et al., 1995). Therefore, a two-segment model was used to approximate the nonlinear displacement-force relation. As illustrated, the turning point of the two segments occurs around 7.35 N or lower (Fig. 1).

Muscle displacement in this study was assumed to occur when resistance ranged from 9.8 N to 19.6 N. The area under the curve of the muscle (AUC_muscle) was defined as the sum of the muscle

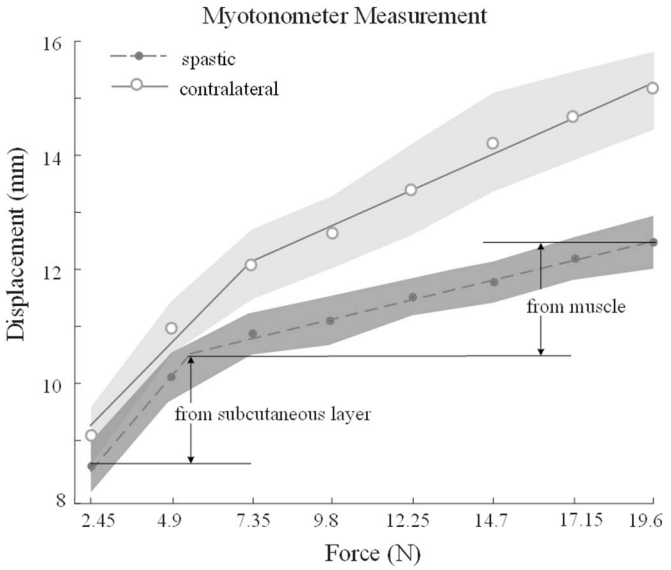

Fig. 1. Myotonometric measurement from a representative subject. Tissue displacement was averaged over eight trials and marked (dots: spastic, open circles: contralateral). The grey areas indicated the range of one standard deviation from the mean values.