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Comparison of surface electromyography and myotonometric measurements during voluntary isometric contractions

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Abstract

Objectives: Muscle stiffness increases during muscle contraction. The purpose of this study was to determine the strength of the correlation between myotonometric measurements of muscle stiffness and surface electromyography (sEMG) measurements during various levels of voluntary isometric contractions of the biceps brachii muscle. **Subjects:** Eight subjects (four female; four male), with mean age of 30.6 ± 8.23 years, volunteered to participate in this study. **Methods:** Myotonometer and sEMG measurements were taken simultaneously from the right biceps brachii muscle. Data were obtained: (1) at rest, (2) while the subject held a 15 lb (6.8 kg) weight isometrically and, (3) during a maximal voluntary isometric contraction. Myotonometer force–displacement curves (amount of tissue displacement to a given unit of force applied perpendicular to the muscle) were compared with sEMG measurements using Pearson's product–moment correlation coefficients. **Results:** Myotonometer and sEMG measurement correlations ranged from -0.70 to -0.90 . The strongest correlations to sEMG were from Myotonometer force measurements between 1.00 and 2.00 kg. **Conclusions:** Myotonometer and sEMG measurements were highly correlated. Tissue stiffness, as measured by the Myotonometer, appears capable of assessing changes in muscle activation levels.

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1. Introduction

Surface electromyography (sEMG) is a reliable and valid measure of muscle activity, relating directly to changes in torque production during isometric muscle activations [15,16]. sEMG, however, is time and labor-intensive and data interpretations can be difficult. Time and technical considerations have limited the use of sEMG. The methodology is not widely used in clinical settings, multi-center research studies and large patient population research studies.

The Myotonometer is a computerized, electronic tissue compliance meter that is capable of non-invasive assessment of muscle stiffness at rest and during muscle contraction. Muscle stiffness is typically defined as the

ratio of change in force to change in length along the long axis of a muscle. The change in stiffness to forces applied along the long axis of a muscle is proportional to changes in stiffness to forces applied perpendicular to muscle [9,17,22]. The Myotonometer measures stiffness by quantifying resistance (measured as millimeter of tissue displacement) per unit of a perpendicularly applied force. Muscle stiffness measurements obtained during muscle contraction provide an indirect but valid measure of muscle strength [2,3,7]. This is possible because a muscle fiber becomes stiffer when stimulated. Muscle stiffness increases linearly with force of contraction and with the same time course as muscle tension [9,11,22]. These results have been consistent across various experimental conditions including isolated muscle preparations [10], and during in vivo isometric [3,7], eccentric [17], and isokinetic [3] contractions.

Previous studies have reported on the validity of using compliance meters and the Myotonometer to

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assess tone (resistance to passive stretch while the individual maintains a relaxed state [21]) and strength differences of non-disabled individuals [5,14], individuals with upper motor neuron involvement [14], chronic pain patients [20], and following various exercise or therapeutic interventions [4,8,17].

Myotonometer use has several advantages when compared to sEMG, isokinetic testing and hand-held dynamometry. sEMG setup is time consuming and data interpretations can be difficult. Isokinetic and dynamometry testing can be influenced by muscle substitutions and only measure joint torque, not individual muscle contributions to joint torque. Myotonometer setup time is minimal and data can be acquired faster than other computerized testing procedures. Data acquisition and analysis procedures do not involve extensive user training. Further, intra- and inter-rater reliabilities are very high [1,13].

Previous studies have reported a correlation between muscle stiffness and isokinetic measurements of joint torque [2,7,9]. To our knowledge, studies have not examined whether or not a relationship exists between muscle stiffness as assessed by the Myotonometer and muscle activation as measured by sEMG. The purpose of this study was to assess the strength of the correlation between myotonometric measurements and sEMG during various levels of voluntary, isometric muscle contractions of the biceps brachii muscle. Some of the results reported here were published previously in abstract form [12].

2. Methods

2.1. Subjects

Eight healthy adult subjects (four female; four male), with a mean age of 30.6 ± 8.23 SD years (range = 22–41 years) were recruited from a sample of convenience of college students. The subjects were screened for orthopedic, pain-related, or other disorders that might influence muscle performance. An injury to either arm within six months prior to the start of the study was an exclusion criteria.

2.2. Procedures

All procedures received prior approval from The University of Montana Institutional Review Board for Use of Human Subjects and were conducted in accordance with The Declaration of Helsinki.

The right (dominant) biceps brachii muscle of each subject was tested. Each subject was tested while seated in a chair. The right arm was placed on a platform that was adjustable in height and padded for comfort. The elbow was held in a flexed position at 90° as determined by a standard hand-held goniometer. The distance

between the anterior axillary fold and the center of the antecubital fossa was measured and the midpoint determined. Two marks were placed on the skin—one at a point 2-cm proximal and the other 1-cm proximal to the midpoint. An sEMG electrode (6 cm, rectangular, bipolar, Ag–AgCl with onsite preamplifiers; 2 cm between active sites) was placed on the skin (following preparation that included shaving, cleansing with alcohol and mild skin abrasion) with its inferior border parallel to the upper mark. A reference electrode was placed on the antero-medial aspect of the left wrist. Recordings at a sampling rate of 2 kHz were amplified (2–5 K) and high pass filtered at 20 Hz (Therapeutics Unlimited multichannel EMG amplifier/filtration array; input impedance 15 M Ω at 100 Hz, noise < 2.0 microvolt RMS, common mode rejection 87 db at 60 Hz).

The Myotonometer (Neurogenic Technologies, Inc.) is a computerized, electronic device that quantifies tissue stiffness by measuring the amount of resistance encountered as a probe is pushed downward onto the muscle and underlying tissue. The amount of applied pressure (force) is recorded concomitant with the amount of tissue displacement (± 0.1 mm) caused by the pressure of the probe. As increasing probe pressure was applied, tissue displacement measurements were automatically obtained at eight force increments of probe pressure (0.25, 0.50, 0.75, 1.00, 1.25, 1.50, 1.75, 2.00 kg). Computational software generated force–displacement curves (millimeter tissue displacement per kilogram of probe force) from these data. The higher the resistance (stiffness), the less penetration of the probe and the less steep the slope of the force–displacement curve (Fig. 1).

The head of the Myotonometer probe was placed over the biceps brachii muscle on the distal mark, 1 cm below and centered along the distal edge of the sEMG electrode. Myotonometer data recordings of all eight force increments take approximately 1 s. Electromyographic data recording length, therefore, was set at 1 s to correspond to the time required for Myotonometer data acquisition. Myotonometer measurements do not interfere or influence sEMG recordings in any way. Fig. 2 shows the raw sEMG recording during a myotonometric measurement of the biceps brachii at rest. One examiner was responsible for sEMG data collection and another for Myotonometer data acquisition. Each examiner was blinded to the other's data collection.

Three sets of sEMG and Myotonometric data were obtained in the following order: (1) while subjects were at rest, (2) during an isometric contraction while holding a 15-lb (6.8 kg) barbell, and (3) during a maximal voluntary isometric contraction (MVC). The MVC condition involved having subjects maximally contract against a fixed steel cable. A weight was used instead of

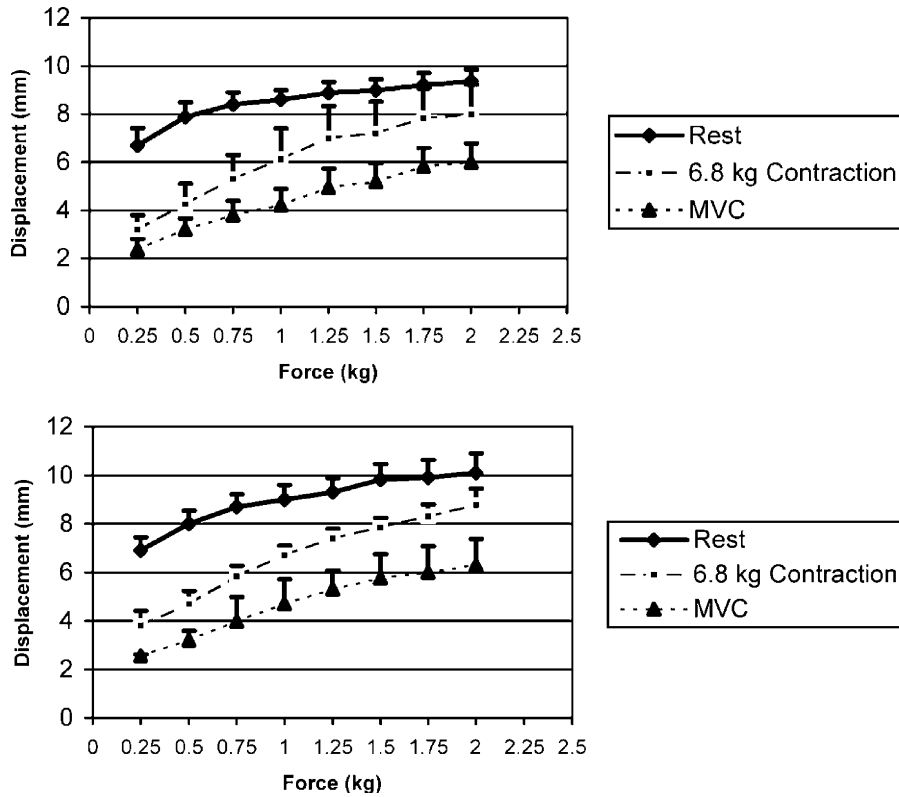


Fig. 1. Myotonometer muscle stiffness measurements (tissue displacement per unit of applied force) of grouped female and male data. Rest: measurements at rest; 6.8 kg contraction: measurements while subjects held a weight; MVC: maximal voluntary contraction. Note that the stiffness increases with increases in muscle activation. Error bars indicate standard deviations.

a set MVC percentage because this method provided a wider range of sEMG root mean square (RMS) values for correlation analysis. The elbow was positioned in 90° flexion, the wrist and shoulder in anatomical neutral, for MVC and barbell trials. Eight trials were performed for each of the three testing conditions. The

subjects were verbally cued to begin contraction prior to the start of EMG and Myotonometer data collection and were instructed to maintain the contraction for 1 s post data collection. Sufficient rest was given between each trial to help eliminate the effects of fatigue.

Surface EMG values were expressed in terms of the RMS of the amplitude for each 1-s trial. Myotonometer values were expressed in terms of millimeters of displacement per kilogram of applied force to the muscle. Mean values for the eight trials of each subject for each testing condition were calculated.

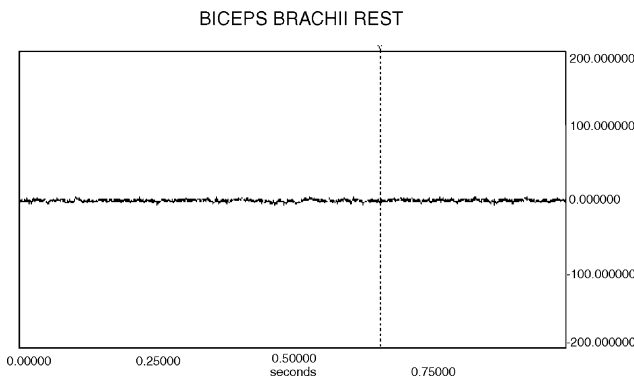


Fig. 2. A computer screen printout of one, 1-s trial with the biceps brachii at rest. The vertical dotted line corresponds to an audible tone emitted by the Myotonometer signaling a 2.0 kg probe force pressure has been obtained and the myotonometric measurement for the trial has been completed. Myotonometric measurements had no effect on sEMG recordings.

2.3. Statistical analysis

Myotonometer computational software calculated the area under the curve (AUC) for each force–displacement curve. The degree of relationship between biceps brachii muscle RMS and myotonometric measurements was determined using a Pearson’s product–moment correlation coefficient. Correlations between RMS and myotonometric measurements were calculated for all the eight subjects combined and with respect to gender. Correlations were calculated for the entire slope of female and male subjects’ force–dis-

placement curves and for each of the eight incremental Myotonometer force measurements (0.25–2.00 kg). These analyses permitted the determination of the relationship between the amount of tissue displacement to a perpendicularly applied force (stiffness) with changing sEMG levels for individual force increments (i.e. the level of correlation of each perpendicularly applied force increment with sEMG). Additionally, the strength of the relationship between the AUC of the slope generated by all eight force increment measurements (Fig. 1) and corresponding change in sEMG was determined. Probability values of less than 0.05 were considered significant.

3. Results

3.1. Female and male RMS and Myotonometer data correlations

Each Myotonometer measurement resulted in a force–displacement curve that reflected the amount of tissue displacement per unit force (Fig. 1). The AUC of these force–displacement curves was calculated for each subject for each condition (rest, 6.8 kg, MVC). Female and male grouped AUC data were correlated to RMS data. The mean MVC for males was 967.15 ± 368.41 microvolt (range = 837.78 – 1471.25 microvolt). The mean MVC for females was 436.93 ± 75.42 microvolt (range = 353.38 – 559.25 microvolt). The correlation between AUC and RMS data for females was -0.84 ($p = 0.001$). The correlation between AUC and RMS data for males was -0.85 ($p = 0.000$). Fig. 1 shows grouped female and male muscle stiffness values for each of the three muscle contraction conditions.

3.2. RMS and individual Myotonometer force data correlations

Table 1 summarizes results obtained from individual Myotonometer force measurements of female and male subjects. Correlation coefficients ranged from -0.70 to -0.86 for female subjects. Correlations for male subjects ranged from -0.71 to -0.90 . Significance was obtained for five of the eight Myotonometer force measurements. These five measurements represented the higher Myotonometer force levels (1.00 – 2.00 kg).

3.3. Combined group: RMS and Myotonometer data correlations

Table 2 summarizes results obtained for all the eight subjects. Correlations among RMS and Myotonometer measurements ranged from -0.57 to -0.70 . Significant relationships were documented for seven of the eight Myotonometer force measurements (0.25 and 0.75 to 2.00 kg).

Table 1

Correlation coefficients between sEMG-RMS and Myotonometer measurements

| Myotonometer force (kg) | Correlation EMG–Myotonometer (r) | Probability (p) |
|-------------------------|--------------------------------------|---------------------|
| <i>Female subjects</i> | | |
| 0.25 | -0.70 | 0.42 |
| 0.50 | -0.76 | 0.15 |
| 0.75 | -0.81 | 0.06 |
| 1.00 | -0.84 | 0.03 |
| 1.25 | -0.85 | 0.02 |
| 1.50 | -0.86 | 0.01 |
| 1.75 | -0.86 | 0.01 |
| 2.00 | -0.86 | 0.01 |
| <i>Male subjects</i> | | |
| 0.25 | -0.71 | 0.34 |
| 0.50 | -0.75 | 0.17 |
| 0.75 | -0.79 | 0.08 |
| 1.00 | -0.84 | 0.02 |
| 1.25 | -0.88 | 0.00 |
| 1.50 | -0.89 | 0.00 |
| 1.75 | -0.90 | 0.00 |
| 2.00 | -0.89 | 0.00 |

Table 2

Correlation coefficients between sEMG-RMS and Myotonometer measurements

| Myotonometer force (kg) | Correlation EMG–Myotonometer (r) | Probability (p) |
|---|--------------------------------------|---------------------|
| <i>Combined group (female and male)</i> | | |
| 0.25 | -0.57 | 0.01 |
| 0.50 | -0.60 | 0.06 |
| 0.75 | -0.64 | 0.03 |
| 1.00 | -0.67 | 0.01 |
| 1.25 | -0.70 | 0.01 |
| 1.50 | -0.70 | 0.01 |
| 1.75 | -0.70 | 0.01 |
| 2.00 | -0.67 | 0.01 |

4. Discussion

Results documented high to very high correlations among Myotonometer and RMS measurements when data were compared with respect to gender. The highest and most significant correlations among Myotonometer measurements and sEMG recordings occurred at the higher increments of Myotonometer application force. This is best explained by the fact that the Myotonometer probe must displace a certain amount of cutaneous and subcutaneous tissue before it begins to displace the targeted muscle tissue. Myotonometer measurements during the lower force recordings reflect, in part, displacement of non-contractile tissue and thus a weaker correlation to sEMG recordings when compared with measurements obtained at higher Myotonometer force recordings.

Correlation values between sEMG and myotonomeric measurements for the combined group would be considered in the moderate to good ranges. That combined group correlations were lower than when data were compared with respect to gender can be explained by an aggregation effect [19], explained as follows. Men and women possess inherent anatomical and physiological differences in subcutaneous tissues that can influence results when data are combined. The difference in RMS values for the MVC condition between females and males was very high (Fig. 3). When males and females were combined for statistical purposes, the high variance in the data decreased the strength of the correlation. When data for the female and male groups were separately analyzed, the variance decreased. Gender-specific correlation values represent a truer physiological picture.

A potential benefit of Myotonometer use in clinical settings is its ability to quantify changes in muscle activations quickly and easily. This is an improvement over manual muscle testing and other subjective assessment tools that only provide qualitative assessments of these changes. In addition, there are problems with manual muscle testing reliabilities especially in strength ranges above the fair range [6,18] and measurements are not sensitive enough to assess small or moderate changes in muscle strength [18]. Very high intra- and inter-rater reliabilities for both children and adults have been reported for myotonomeric measurements [1,13] and measurements are capable of detecting small changes [14]. Unlike measurements by computerized or hand-held dynamometers, Myotonometer measurements are not compromised by the possibility of muscle substitutions and can assess individual muscles and not just total joint torques. Because the Myotonometer is capable of assessing muscle tone changes at rest, it might be helpful in cases where joint movement or contraction causes pain. The Myotonometer is not influenced by atmospheric pressure changes and might be useful in assessing muscle health in microgravity environments. A considerable advantage is that Myotonometer setup and data acquisition and analysis requires

considerably less time than sEMG or other computerized testing. During testing procedures used for this study, eight trials of eight separate force measurements could be acquired in approximately 10 s.

Prior studies that have demonstrated the relationship between muscle stiffness and activation levels have used longitudinally applied torques to the muscle to measure stiffness. The present study is the first that we are aware of to demonstrate that a similar relationship exists between stiffness measurements obtained by a perpendicularly applied force to the muscle and muscle activation levels. Myotonometer operation and technical requirements are considerably easier than those of the various apparatuses that have been used to measure stiffness by applying a force longitudinal to the muscle.

The present study was conducted using a sample of healthy adult subjects. Pathological changes of muscle associated with various disabilities might demonstrate different correlation values. Further studies are needed to establish the effectiveness of the Myotonometer in assessing changes in a muscle's activation and torque generating ability in patient populations.

5. Conclusions

Myotonometer measurements of biceps brachii muscle stiffness are highly correlated to sEMG changes in healthy adult subjects. Myotonometer force-displacement measurements are sensitive to changes in muscle activation levels. The results of this study indicate that the Myotonometer can be used as an objective means to non-invasively and quickly assess changes in resting muscle stiffness and muscle activation.

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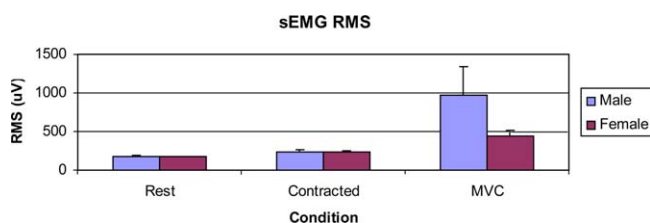


Fig. 3. Surface electromyography (sEMG) root mean square (RMS) data for female and male subjects. Rest: RMS of biceps brachii at rest; contracted: RMS of subjects while holding a 6.8 kg weight; MVC: RMS during a maximal voluntary contraction. Error bars indicate standard deviations.

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