Comparison of EMG Activity Between Maximal Manual Muscle Testing and Cybex Maximal Isometric Testing of the Quadriceps Femoris

Hui-Ting Lin,1 Ar-Tyan Hsu,2 Jia-Hao Chang,3 Chi-Sheng Chien,4,5 Guan-Liang Chang4*

Two methods have been used to produce a maximal voluntary isometric contraction (MVIC) of the superficial quadriceps femoris muscles for normalization of electromyographic (EMG) data. The purposes of this study were to compare the myoelectric activity of MVIC of manual muscle testing (MMT) versus Cybex maximal isometric testing. Eighteen normal subjects were recruited. MMT and Cybex testing for MVIC of the dominant leg were performed. EMG activities of the vastus medialis, vastus lateralis and rectus femoris were recorded during MMT and Cybex trials. EMG amplitude and median frequency obtained from the two methods (MMT and Cybex testing) were used for statistical analysis of these three muscles. Statistically, the difference in the mean of the EMG signal amplitude and median frequency between MMT and Cybex testing were not significant. Considering cost and time, MMT for MVIC technique appears to be reliable and highly valuable. [J Formos Med Assoc 2008;107(2):175–180]

Key Words: Cybex maximal isometric testing, electromyography, manual muscle testing, quadriceps femoris

The primary function of the quadriceps femoris muscle is to generate knee extensor torque and to stabilize the patella.1 One method that has been used to promote better understanding of quadriceps muscle function is surface electromyography (EMG). Surface EMG is also reported to be a valid and reliable indicator of estimating muscle recruitment.2 For this reason, we were interested in EMG parameters such as EMG amplitude and medial frequency to understand the recruitment characteristics of quadriceps femoris in most research studies. EMG normalization is frequently used to improve reliability by decreasing variation within and between individuals in EMG studies. Maximal voluntary isometric contraction (MVIC) is a common method of normalization used as the standard reference for comparison between subjects, days, studies and muscles.3 There have been alternative methods used for EMG normalization in recent years, such as mean EMG value, peak EMG value, or EMG value obtained at the level less than MVIC during dynamic activity. Some researchers found better reliability by using EMG at submaximal contraction levels of the muscle for normalization.4,5 However, several researchers have reported that the MVIC method of normalization is the most reliable when compared with normalized EMG relative to the mean or the peak
amplitude of dynamic contraction. Several authors proposed that using mean dynamic method and peak dynamic method are not appropriate for EMG studies, as these two methods appear to remove the true biological variation within a group. Therefore, after some preliminary training, the use of MVIC for EMG normalization is recommended by most studies. 

The process of EMG normalization using MVIC requires expressing the electromyogram of the muscle of interest as a ratio to the maximal electromyogram of the same muscle during exercise. Standard measurement is available to measure maximal voluntary isometric muscle electromyogram using isokinetic dynamometer at a fixed angle. Manual muscle testing (MMT) is the current standard method for assessing strength in the clinical setting. The patient's strength is graded according to his/her ability to move against gravity and then to hold manual resistance with a static isometric contraction of the muscle being tested. MVIC with MMT is straightforward, whereas MVIC with Cybex testing is complicated and limited in clinical use because of its high cost and the time required for the subject's positioning and the related procedure. It is believed that one researcher performing MMT would provide consistency in subject positioning and in the resistance applied like MVIC with Cybex. The comparison between isokinetic muscle strength testing and normal grade MMT to assess muscle strength has been previously studied. Wilk and Andrew identified consistent differences of bilateral extremities in strength measured isokinetically in a group with normal grade MMT. Yet, Noreau and Vachon reported that similar results of muscle strength were observed when comparing MMT with Cybex for measuring the stronger side of subjects with spinal cord injury. However, to our knowledge, there are few studies that have demonstrated the difference in EMG parameters of MVIC obtained by maximal MMT and by maximal isometric Cybex testing. Very little EMG data are available to verify whether maximal EMG activity during maximal MMT is similar to maximal isometric Cybex testing for each muscle.

The purposes of this study were to compare EMG parameters for maximal isometric muscular strength from Cybex testing and from maximal MMT during knee extension, and to determine whether electromyograms obtained during maximal MMT can be used as a substitute for the basis of EMG normalization.

Methods

Subjects

Eighteen healthy subjects were recruited to participate in this study. The mean (± standard deviation) age, height and weight were 24.3 ± 1.7 years, 166.5 ± 6.5 cm and 59.4 ± 8.9 kg, respectively. They were all right leg dominant and had no history of musculoskeletal pathology or surgery. Before testing, oral informed consent was obtained from each subject. Informal written information was also provided.

Experimental procedures

Prior to testing, all subjects cycled for 3 minutes to warm up. Subjects were seated on the Cybex accessory chair and their trunk was fixed with a pelvic and chest belt. In order to reduce skin impedance, the skin area was shaved and cleaned with alcohol before placing the EMG electrodes. Because of the deep location of the vastus intermedius (VI) muscle, it is impossible to detect its electromyographic properties with superficial surface electrodes. Therefore, preamplified bipolar circular surface electrodes (Ag/AgCl), 1.25 cm in diameter (MA100; Motion Lab Systems Inc., Baton Rouge, LA, USA), were placed on three superficial quadriceps muscles, i.e. the vastus medialis (VM), vastus lateralis (VL) and rectus femoris (RF). For the VM, the electrode was placed on the VM muscle belly, approximately 4 cm proximal to the superomedial border of the patella. For the VL, the electrode was applied over the VL muscle belly, approximately 8 cm proximal to the lateral joint line of the knee. For the RF, the electrode was placed 50% of the distance from the anterior superior iliac spine to the superior pole of the patella.
The common mode rejection ratio of the current system was 100 dB at 60 Hz and the input impedance was greater than 100 MΩ at DC. The signal-to-noise ratio was 100 dB. The actual gain range used in this study was 20 K. Before EMG recording, each subject was instructed to practice each maximal MMT test and Cybex test. After resting for about 5 minutes, subjects performed the maximal MMT of the dominant side knee extensors at 45° of knee flexion measured with a goniometer by holding against the resistance of a male physical therapist (Figure). All subjects were given consistent verbal encouragement during the maximal excursion. The trial lasted for 5 seconds and was repeated three times with 3 minutes of rest between each MMT trial for EMG recording.

Following the MMT trial, subjects performed maximal isometric contraction with a CYBEX 340 Isokinetic Dynamometer (Cybex International Inc., Medway, MA, USA). For Cybex testing, the positioning and conditions such as resting time and verbal encouragement for maximal isometric actions in the subjects were the same as in the MMT trials. The order of different MVIC methods was random. All measurements of EMG activity were recorded simultaneously and stored in the computer for processing.

Data recording and signal processing
Raw EMG signals were collected at a rate of 1200 Hz. EMG signals were bandpass-filtered at 20–300 Hz. The data were stored in the computer and analyzed with Matlab version 6.0 (The MathWorks Inc., Natick, MA, USA). The middle 3 seconds of each trial where the EMG amplitude was the greatest was determined and processed through integration of the rectified calculation for amplitude analysis. The same 3-second window selected from each EMG signal was used for median frequency (F_{med}) analysis. A fast Fourier transform of 512 points (Hanning window processing) was performed on the 13 consecutive segments (512 ms), overlapping each other by half of their length (256 ms). F_{med} was determined from each of the 13 overlapping windows.\(^\text{13}\)

Analysis
We used the maximal EMG amplitude of Cybex trials as the baseline, expressing the maximal EMG amplitude of MMT trials as a ratio to that of the Cybex trials. Two-way ANOVA with repeated measures was performed to assess the main effects of test type (MMT and Cybex) and muscle (VM, VL, RF) on changes in EMG amplitude and F_{med}. Tukey’s post hoc analysis was performed for post comparisons. Post hoc power test for each effect was also assessed. In addition, one sample t test was then conducted to test the changes in EMG amplitude or F_{med} between the MMT test and Cybex test with the calculation of a 95% confidence interval (CI). The change in EMG amplitude or F_{med} for each muscle (VM, VL, RF) was calculated by subtracting the average amount of amplitude in the MMT test from the average amount of amplitude in the Cybex test. The alpha value was set at the level of 0.05. Intraclass correlation coefficients (ICC_{3,1}) were used to compute intrasession reliability.

Results
Same-day test–retest ICC_{3,1} among three MVICs during MMT or Cybex are presented in Table 1. The difference in EMG amplitude ratio and F_{med} between MMT and Cybex testing for MVIC were not statistically significant (p > 0.05). Table 2 shows
the results of EMG amplitude ratio to Cybex test and \( F_{\text{med}} \) of MVIC. The value of zero is contained within the 95% CI of the difference for \( F_{\text{med}} \) or EMG amplitude between MMT and Cybex for each muscle. Sample \( t \) test confirmed that the change in EMG amplitude and \( F_{\text{med}} \) between maximal MMT and Cybex maximal isometric testing did not differ from the value of zero (Table 3).

### Discussion

ICC is commonly used to assess test–retest reliability and reflects the relative reliability of a measurement. ICC > 0.75 is considered excellent, 0.40–0.75 is regarded as fair to good, and 0–0.4 as poor.\(^\text{14}\) The trial-to-trial estimates of \( F_{\text{med}} \) suggest that intrasession reliability of this quantified measurement is high. The use of a series of consecutive overlapping windows appears to be a valid method for determining \( F_{\text{med}} \), although greater variability is shown when using smaller sampling windows to analyze frequency spectrums. A large number of these windows should theoretically reduce sampling variance.\(^\text{15}\) In addition, the ICC scores were generally high for EMG amplitude. Therefore,

| Table 1. | Same-day intraclass correlation coefficient (ICC\(_{3,1}\)) of electromyographic amplitude (Amp) and median frequency (\( F_{\text{med}} \)) using manual muscle testing (MMT) and Cybex testing for maximal voluntary isometric contraction
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<tbody>
<tr>
<td></td>
<td>MMT</td>
<td>Cybex</td>
</tr>
<tr>
<td>Amp</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VM</td>
<td>0.94</td>
<td>0.98</td>
</tr>
<tr>
<td>VL</td>
<td>0.92</td>
<td>0.94</td>
</tr>
<tr>
<td>RF</td>
<td>0.93</td>
<td>0.90</td>
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<tr>
<td>( F_{\text{med}} )</td>
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<tr>
<td>VM</td>
<td>0.82</td>
<td>0.90</td>
</tr>
<tr>
<td>VL</td>
<td>0.97</td>
<td>0.93</td>
</tr>
<tr>
<td>RF</td>
<td>0.96</td>
<td>0.93</td>
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VM = vastus medialis; VL = vastus lateralis; RF = rectus femoris.

### Table 2. Electromyographic (EMG) amplitude ratio and median frequency of quadriceps muscle*

<table>
<thead>
<tr>
<th></th>
<th>MMT (% of Cybex)</th>
<th>Median frequency (Hz)</th>
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<tr>
<td></td>
<td>MMT</td>
<td>Cybex</td>
</tr>
<tr>
<td>Vastus medialis</td>
<td>1.07 ± 0.35</td>
<td>89.02 ± 7.47</td>
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<tr>
<td>Vastus lateralis</td>
<td>0.93 ± 0.20</td>
<td>92.64 ± 14.22</td>
</tr>
<tr>
<td>Rectus femoris</td>
<td>1.00 ± 0.30</td>
<td>83.90 ± 9.46</td>
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*Data are presented as mean ± standard deviation. MMT = maximal manual muscle testing.

### Table 3. Sample \( t \) test analysis of differences in electromyographic parameters between maximal manual muscle testing and Cybex maximal isometric testing

<table>
<thead>
<tr>
<th>Diff, df, Sig, Mean difference, 95% CI of difference</th>
<th>Lower</th>
<th>Upper</th>
</tr>
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<tbody>
<tr>
<td>Diff(_{\text{FmedVM}}), df = 17, ( t = 1.15 ), ( \text{Sig.} = 0.26 )</td>
<td>-1.70</td>
<td>5.87</td>
</tr>
<tr>
<td>Diff(_{\text{FmedVL}}), df = 17, ( t = 1.81 ), ( \text{Sig.} = 0.08 )</td>
<td>-0.87</td>
<td>11.81</td>
</tr>
<tr>
<td>Diff(_{\text{FmedRF}}), df = 17, ( t = 1.16 ), ( \text{Sig.} = 0.26 )</td>
<td>-1.16</td>
<td>4.02</td>
</tr>
<tr>
<td>Diff(_{\text{ampVM}}), df = 17, ( t = -0.48 ), ( \text{Sig.} = 0.63 )</td>
<td>-37.36</td>
<td>23.45</td>
</tr>
<tr>
<td>Diff(_{\text{ampVL}}), df = 17, ( t = -0.40 ), ( \text{Sig.} = 0.68 )</td>
<td>-70.71</td>
<td>47.75</td>
</tr>
<tr>
<td>Diff(_{\text{ampRF}}), df = 17, ( t = -0.63 ), ( \text{Sig.} = 0.53 )</td>
<td>-58.43</td>
<td>31.46</td>
</tr>
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</table>

Diff\(_{\text{FmedVM}}\), Diff\(_{\text{FmedVL}}\) and Diff\(_{\text{FmedRF}}\) = difference in medial frequency between maximal manual muscle testing (MMT) and maximal voluntary isometric contraction (MVIC) with Cybex testing for the vastus medialis, vastus lateralis and rectus femoris, respectively; Diff\(_{\text{ampVM}}\), Diff\(_{\text{ampVL}}\) and Diff\(_{\text{ampRF}}\) = difference in electromyographic amplitude between maximal MMT and MVIC with Cybex testing for the vastus medialis, vastus lateralis and rectus femoris, respectively.
this study indicated that MVIC is appropriate for normalization of EMG data in the superficial quadriceps muscle.

Normalized EMG is clinically most meaningful. The absolute value of the EMG signal depends on a variety of factors such as amplification rate and the position of the surface electrodes. Therefore, EMG normalization can provide a more quantitative measure and the most common method for EMG normalization is the MVIC method. In this study, we chose the intermediate angle of 45° of knee flexion according to Burden et al for the comparison of two methods of MVIC of the knee extensors. Although a 60° angle of flexion has been demonstrated to be the angle of maximal isometric force generation, the 45° of knee flexion was used for two reasons. First, it is close to 60° of knee flexion in which MVIC was produced, and second, MVIC is also easily detected and monitored when using the MMT method in the clinical setting. A simple and direct method for MVIC performed clinically by physical therapists is MMT with normal grade. Several studies also showed MMT to be highly reliable when performed by well-trained examiners. This applied technique of maximal manual isometric resistance is inexpensive and reliable between well-trained examiners. Isokinetic testing for MVIC has frequently been used as the standard procedure for EMG normalization. However, the procedure takes a long time and the instrument needed is expensive. The major finding of this study identified no statistical differences in the amplitude and mean Fmed of quadriceps electromyogram obtained during maximal MMT and MVIC with Cybex testing. It is well known that a resultant decrease of the spectral parameters of EMG signal such as Fmed or mean frequency could provide investigators with information on the electrophysiologic fatigue process of muscles. Therefore, the Fmed of maximal MMT being not different from that of MVIC with Cybex testing suggests that the myoelectric activity of each quadriceps muscle appears to be the same and no fatigue developed. In our study, the insignificant differences in EMG amplitude or Fmed between maximal MMT and MVIC with Cybex testing may have been due to low statistical power. Although power will increase as sample size increases, an alternative test by calculating CI was used to assess the difference in each EMG parameter between MMT and Cybex. The alternative approach has more validity than calculating power after the study has been completed. The 95% CI of the difference in Fmed or EMG amplitude between maximal MMT and Cybex maximal isometric test was employed. The value of zero being contained within the 95% CI of the difference in Fmed and EMG amplitude for each muscle suggests that there is no variation in EMG amplitude and Fmed between maximal MMT and Cybex maximal isometric testing.

To date, few studies have demonstrated the variability of EMG or other parameters for MVIC between MMT and Cybex tests. A study by Noreau and Vachon provided results for testing the differences in strength of spinal cord injured patients between Cybex dynamometry and clinical MMT maneuver. They reported a strong correlation between the strength values measured by the hand-held force sensor during MMT testing and dynamometry during Cybex testing. In addition, approximately the same recruitment behavior of quadriceps was observed between these two methods of MVIC. The level of patients’ stabilization might be almost the same for these two tests since the variation in EMG amplitude and EMG Fmed between these methods of MVIC is considerably small. From the results of the present study, we suggest that EMG obtained during maximal MMT, at least in the case of the superficial quadriceps femoris, can be used as the basis of EMG normalization and may be used as a substitute for Cybex maximal isometric testing.

Some limitations were noted in this study. The difference in EMG activity between maximal manual testing and Cybex maximal isometric testing was investigated only for the superficial quadriceps femoris. Integrated EMG amplitude and Fmed were used for comparison only at 45° of flexion. Hence, generalization of the results obtained from the present study should proceed...
with caution in test conditions when the knee joint is not constrained at 45° of flexion.

We suggest that EMG measurements obtained during maximal MMT could be used as the basis of EMG normalization and may be used as a substitute for Cybex maximal isometric testing.

Acknowledgments

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References