Influence of Knee Joint Position on Co-contractions of Agonist and Antagonist Muscles during Maximal Voluntary Isometric Contractions: Electromyography and Cybex Measurement

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Abstract: The purpose of this study was to investigate the influence of different angles of knee joint on the activation level of agonist and antagonist muscles from electromyographic activities and torque measurement during maximum isometric efforts. Electromyographic activities and isometric torque measurements were performed on 10 healthy subjects at 30°, 60° and 90° of knee joint flexion with the hip fixed at 80° of flexion. To quantify the antagonist muscle activity, we normalized its electromyographic value at each joint angle with respect to its electromyographic value at the same angle acting as an agonist at maximal effort. The results indicate that the greatest maximal voluntary isometric contraction torque of the quadriceps occurred during knee extension at 60° of knee flexion. Co-activation of quadriceps and hamstrings at certain angles can help to maintain the stability of the knee joint. However, no significant relationship of maximal voluntary isometric contraction electromyography and maximal voluntary isometric contraction torque of quadriceps were found in our study. Further investigation of the torque and electromyographic relationship using combinations of different hip and knee angles are suggested.

Key words: Knee joint angle, Co-activation, Maximal voluntary isometric contraction

INTRODUCTION

During sporting activities, the knee joints are susceptible to injury due to their anatomical position and complexity. Active knee stability during activities is maintained by the co-activation of agonist quadriceps (Quad) and antagonist hamstring (Hams) muscles1). Therefore, the contribution level of muscle activities around the knee is very important for controlling knee stability during movement or activity. Isometric quadriceps contraction at different joint angles with open kinetic chain (OKC) of the leg is often used to strengthen the knee extensor during rehabilitation therapy. Higher levels of co-activation of Quad and Hams during movement in anterior cruciate ligament (ACL)-deficient patients can provide active stabilization of the knee to compensate for the loss of the passive structure2). A previous study3) has found that the greatest knee extension torque was produced at 60° knee flexion with the hip fixed at 80° of flexion during maximal voluntary isometric knee extension. However, this study tested only angles of 15° and 60° of knee
A recent study indicated that the highest co-contraction level of Quad and Hams occurs at 80° extension of the knee joint during isometric contraction of knee extensor. In the above studies, the tested joint angle range was rather limited and the results did not show any influence of different knee joint angles on the activation levels of agonist and antagonist muscles during maximal isometric knee extensor contraction using electromyographic (EMG) activity and torque measurement.

Some of the previous studies had some limitations and few studies have investigated the co-activation activity during maximal voluntary isometric contraction (MVIC) using surface EMG, especially at different knee joint angles. It is likely that the difference in the joint angles is important for providing stability to the knee joint while doing various sports. However, the levels of the co-activation of the knee joint when doing an isometric contraction exercise of knee extensors at different joint angles remains controversial. Therefore, the purpose of this study was to investigate the influence of different knee joint angles on the activation levels of agonist (Quad) and antagonist (Hams) muscles during maximal isometric knee extensor contraction using EMG activity and torque measurement.

**METHODS**

**Subjects**
Four females and 6 males (age, 27.00 ± 4.42 y; height, 166.78 ± 7.36 cm; and weight, 59.44 ± 11.65 kg) with no current knee, hip, or lower back pathology participated in this study.

**Equipment**
The measuring system comprised an EMG system, Cybex Norm Isokinetic Testing & Rehabilitation System (Cybex International, INC., Ronkonkoma, New York) and some miscellaneous items: soap, sandpaper, 70% alcohol solution, electric conduction gel, a marking pen, tape measure, crepe bandage.

**EMG procedures**
Two surface electrodes were used to pick up the EMG activities from Quad and Hams. Figure 1 shows the EMG system in use. Each electrode site was shaved of hair, lightly abraded with fine sandpaper, and cleaned with alcohol to reduce the skin resistance. Both electrodes were placed at the midpoint of the muscles along the fiber direction. For Quad muscles, the electrodes were placed midway between the anterior superior iliac spine and the superior border of the patella. For Hams, the electrodes were placed at the point between the ischial tuberosity and the head of the fibula. Two ground electrodes were placed on the head of fibula and tibia tuberosity, respectively. The electrodes were covered with electrode gel to provide good electrical contact and then fixed with adhesive strips to ensure better contact with the skin and to eliminate motion artifact. Elastic wraps were also applied to maintain electrode placement. The electrodes sites were confirmed by observation and palpation of the subject’s muscles and applied resistance during isometric contractions of the knee. All tested sites were identified and prepared by the same researcher. The wires of the two circuits were held firmly on the skin with crepe bandage to minimize movement artifacts and connected to an amplifier with a band-pass filter of 5–300 Hz. The raw signals were then input to memory oscilloscope through the input box, and an A/D converter with a sampling rate of 1,000 Hz. After the EMG signals were digitized, they were input to a computer with the Global Lab software installed for the analysis.

**Torque-angle relationship**
The Cybex system was used to test the torque generation during maximal voluntary isometric contractions of the lower limb muscles. Subjects were seated with hip joint angle fixed at 80° with their arms folded across their chests. Restraining
straps were used at the hip, thigh and chest to prevent extraneous movement. The axis of rotation was aligned with the lateral condyle of the femur. The pad of the lever arm was positioned proximal to the malleoli. The tested leg was the dominant leg which was determined as the leg with which the subject preferred kicking a ball. Each subject was asked to perform three 5-s maximal voluntary isometric contractions (MVIC) of knee extension at 3 different knee joint angles (30°, 60°, 90°). The sequences of the tested angles were randomized for each subject in order to avoid any systematic effects. Contractions were performed consecutively at each of the three knee joint angles. A 1-min rest period between each contraction and a 2-min rest period between each trial was permitted to avoid the effects of fatigue. At each angle tested, the peak torque for each 5-s contraction was recorded and the mean of the three contractions were used as the performance measure.

**DATA ANALYSIS**

Reliability was determined using intra-class correlation coefficients (ICC 3,1) and standard error of measure for the torque and EMG data based on one-way repeated measures (ANOVA). The mean value of three repetitions for each knee flexion angle was selected for all data analysis. One-way ANOVA with post hoc comparisons using the Scheffe test was used to test for angle-dependent differences in normalized EMG and torque values.

Before analyzing the EMG recordings, the raw signals were full-wave rectified and smoothed. This approach was based on the finding that the amplitude of the rectified and smoothed EMG signals is qualitatively related to the amount of force developed by the muscles. The signals from 2–3 seconds of the contraction were analyzed. The full-wave rectified and smoothed signals were analyzed with the root-mean-square (RMS) processing technique.

All EMG and torque data were normalized. The normalization process for RMS EMG and torque data consisted of determining the largest mean value for each subject in all tested angles of the knee. This raw value was then assigned a value of 1.0, and all other values were expressed as a percentage of it.

**RESULTS**

Trial-to-trial reliability was assessed using data from the subjects. For the torque data, ICC values ranged from 0.98 to 0.99. For EMG data, ICC values ranged from 0.95–0.99 for Quad and 0.93–0.96 (Table 1) for Hams muscles, which indicated that the reliability of the measured EMG activities was high.

Table 1. Test-retest reliability (Intra-class correlation coefficients, ICC3, 1) and standard error of measurement (SEM) for the 10 subjects in 3 trial repetitions at each knee position

<table>
<thead>
<tr>
<th>Variables</th>
<th>Reliability</th>
<th>30°</th>
<th>60°</th>
<th>90°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force</td>
<td>ICC (95% CI)</td>
<td>0.98 (0.98–0.99)</td>
<td>0.99 (0.98–0.99)</td>
<td>0.99 (0.98–0.99)</td>
</tr>
<tr>
<td>SEM (Nm)</td>
<td>31.75</td>
<td>22.38</td>
<td>24.57</td>
<td></td>
</tr>
<tr>
<td>EMG (quad)</td>
<td>ICC (95% CI)</td>
<td>0.99 (0.98–0.99)</td>
<td>0.95 (0.84–0.98)</td>
<td>0.99 (0.98–0.99)</td>
</tr>
<tr>
<td>SEM (V)</td>
<td>0.063</td>
<td>0.037</td>
<td>0.073</td>
<td></td>
</tr>
<tr>
<td>EMG (hams)</td>
<td>ICC (95% CI)</td>
<td>0.95 (0.86–0.99)</td>
<td>0.93 (0.78–0.98)</td>
<td>0.96 (0.89–0.99)</td>
</tr>
<tr>
<td>SEM (V)</td>
<td>0.007</td>
<td>0.02</td>
<td>0.001</td>
<td></td>
</tr>
</tbody>
</table>
DISCUSSION

Reliability of torque and EMG measures

EMG has been accepted as a valid tool in the measurement of isometric muscle contraction\(^{11}\). Its advantage is that the researcher can easily and reliably\(^{12}\) monitor the myoelectric activity of a given muscle under a variety of conditions. If one is studying muscle function during isometric contraction, the EMG signal can be used as an indicator of the intensity of each contraction\(^{13}\). All data for each subject in the present study were collected in a single session in order to ensure that electrode placement was unchanged across the different testing positions. Previous studies have shown that the reproducibility of surface EMG recording for limb and respiratory muscles was
good if the electrode positions were not changed. In the present study, the knee was positioned in 3 flexion angles and this could have affected the muscle length of the quadriceps and hamstrings; but since the knee positions were analyzed separately, any difference in muscle length between 30°–90° knee flexion should not have affected the result. Moreover, the high ICC justifies the trial-to-trial reliability of the torque and EMG measures.

**MVIC-Torque of quadriceps**

The results revealed a significantly high MVIC-torque of the quadriceps occurred at a knee angle of 60° of extension. We may adopt knee extension training at 60° of knee flexion as the joint angle for isometric training with open kinetic chain (OKC) of leg to strengthen the knee extensor in clinical rehabilitation.

**MVIC-EMG and MVIC-torque of quad**

No significant relationship of MVIC-EMG and MVIC-torque of quadriceps was found in our study. EMG amplitude could theoretically result from changes in motor unit activity or changes related strictly to muscle length. MVIC-EMG is independent of joint angle because the motor unit activity in the muscle remains constant. Angle-dependent variations in joint torque were attributed solely to mechanical factors, such as changes in muscle length and moment arm.

The relationship between EMG activity and torque may vary according to the muscle fiber type and contraction status. During isometric voluntary contraction, this relationship depends on the particular muscle being examined. Muscles with predominantly uniform fiber compositions present with linear EMG/Torque relationships, while those with even fiber mix have non-linear relationships. Although the fiber composition of the vastus lateralis is indicated to be quite variable, a study demonstrated a linear EMG/torque relationship. On the contrary, a non-linear relationship of EMG/torque of quadriceps was observed in the present study. Besides the fiber composition, the EMG-torque relationship also depends on the level of contraction. If contraction is at a sub-maximal level, there will be a linear relationship. However, at higher levels of contractions, the relationship becomes non-linear, as in our present study.

**Implications for EMG normalization**

Normalization of data allows direct comparison of muscle activity between muscle and subjects, and has gained popularity in various EMG studies. According to Cerny, normalization of EMG data could eliminate the influence of location and size of the recording electrodes. Previous studies of EMG amplitude during voluntary contractions have demonstrated that even when motor unit activity is held constant, changes in muscle length could affect the EMG amplitude. Based on these significant joint angle-related effects on the MVIC-EMG, it is important to perform the normalizing procedure for EMG data at a joint angle that is as similar as possible.

**Limitations**

MVIC is not always achieved as we assumed. Twitch superimposition technique is needed to determine whether subjects instructed to perform MVIC were actually achieving maximal motor unit activity.

| Table 2. Means, SDs and ranges of knee extension parameters at 3 knee flexion positions |
|----------------------------------------|--------|--------|--------|------------------------------------------|
| dependent variables | 30° | 60° | 90° | Scheffe post hoc comparison |
| Torque ± SD | 60 ± 14.3 | 96.7 ± 8.6 | 84.7 ± 15.0 | 60°>30°, 90° |
| Range | 45–84 | 74–100 | 61–100 | |
| Quad EMG | 80.9 ± 14.5 | 84.16 ± 22.6 | 88.8 ± 12.4 | No significant difference, |
| Range | 61–100 | 42–100 | 71–100 | |
| HS EMG | 68.7 ± 25.1 | 69.1 ± 8.2 | 99.8 ± 6.0 | 90°>60°, 30° |
| Range | 26–100 | 58–86 | 98–100 | |

All data were normalized by expressing them as a percentage of the maximum value obtained for each subject at each of the knee flexion angles.
activation. Such an approach is difficult and impractical to perform given that the quadriceps and hamstrings were monitored simultaneously. Accordingly, we used EMG amplitude to make indirect inferences.

Cross-talk of EMG signals is the amount of signal generated by the contraction of adjacent muscles. It is a confounding variable that can never be completely eliminated in an EMG study. According to Winter et al.,21) the cross-talk estimated can be decreased to 6% or less if a spacing of more than 2.5 cm between electrode pairs is used on the tested muscle. In our present study, an inter-electrode distance of 1 cm and a large spacing between electrode pairs (at least 8 cm from Quad and Hams) kept cross-talk to a minimum.

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REFERENCES