Obtaining Reliable Measurements of Knee Extensor Torque Produced During Maximal Voluntary Contractions: An Experimental Investigation
Janet M Kues, Jules M Rothstein and Robert L Lamb

The purpose of this study was to develop and test a protocol that could be used to obtain reliable measurements of knee extensor torque produced during maximal voluntary contractions. On each of 3 days, 10 subjects performed six consecutive maximal voluntary contractions, in the same randomized order, for each of the following 10 conditions: concentric isokinetic contractions at velocities of 30°, 90°, 120°, and 180°/s; eccentric isokinetic contractions at velocities of 30°, 90°, 120°, and 180°/s; and isometric contractions at 40 and 60 degrees of knee flexion. The peak torques produced were examined to determine on which day and during which contraction subjects produced the greatest torques for each condition. This information was used to develop a practice protocol. Fifteen different subjects were tested following this protocol. Subjects participated in two practice sessions, a test session, and a retest session. Intraclass correlation coefficients (ICCs) were calculated to determine the degree of agreement between torques for the test and retest sessions. The ICCs ranged from .87 to .98. The protocol developed appears to be useful for obtaining reliable measurements of knee extensor torque.

Key Words: Lower extremity, knee; Motor learning; Muscle performance, lower extremity/measurement; Tests and measurements.

Physical therapists often assess the muscle performance of patients in order to decide whether to exercise specific muscles or muscle groups. Physical therapists may also assess the muscle performance of individuals during screening evaluations. Before any measurement of muscle performance can be useful, the reliability of the measurement should be determined. If reliability has not been established, the therapist cannot determine whether differences during repeated testing are due to measurement error or to actual changes in muscle performance.

Obtaining reliable measurements of muscle performance may be difficult if subjects are not allowed to practice the exercise protocol prior to testing. In 1965, Schenck and Forward reported that the forces produced by nondisabled subjects during maximal isometric contractions increased until the forces leveled off after the third day of testing. They measured muscle performance with a cable tensiometer.
and suggested that subjects practice prior to being tested with this device. Unfortunately, Schenck and Forward did not report the reliability of the force measurements they obtained.

Since the work of Schenck and Forward,1 a variety of instruments have been developed to measure muscle performance. Dynamometers that provide resistance during constant-velocity (isokinetic) movements are probably the instruments most commonly used by physical therapists to measure muscle performance. Because isokinetic movements are a novel task, several investigators2-6 have had their subjects practice prior to being tested on isokinetic devices. The details provided by these investigators regarding the practice sessions, however, were usually vague. For example, Knapik et al2 used a Cybex® II dynamometer* to measure the muscle performance of the knee flexor and knee extensor muscles of 16 military recruits. During testing, subjects were asked to perform maximal voluntary contractions. Knapik et al stated that the subjects performed “practice contractions” prior to being tested, but did not indicate how many contractions were performed or how much effort the subjects used. Their method for subject practice, therefore, is not replicable.

Some investigators who have examined the reliability of measurements obtained with isokinetic devices have included practice contractions in their testing protocols.7-10 The rationale for deciding on the number and types of practice contractions, however, was usually not stated. For example, Griffin7 reported that subjects practiced by performing five submaximal contractions and one maximal contraction prior to measuring elbow flexor torque with a Kin-Cord® dynamometer.1 She did not state her rationale for choosing this practice protocol. Griffin found that peak torque measurements obtained at the highest velocity of testing (210°/s) were not very reliable. The low reliability of peak torque measurements obtained at 210°/s may have been because subjects were not given an adequate amount or the appropriate type of practice prior to being tested at this velocity.

A study by Johnson and Siegel10 was the only one found in which a practice protocol was systematically developed. Johnson and Siegel tested 40 nondisabled, college-aged female subjects on a Cybex® II dynamometer. Subjects were tested on 3 consecutive days. On each day, subjects performed three submaximal and six maximal voluntary contractions of the quadriceps femoris muscles at a velocity of 180°/s. Johnson and Siegel found that concentric knee extensor peak torques produced during maximal voluntary contractions became stable after the third contraction on the first test day. Based on their results, they suggested that subjects practice by performing three submaximal and three maximal voluntary contractions prior to being tested.

One weakness of Johnson and Siegel’s study10 is that they did not operationally define the term “submaximal contraction.” Their protocol, therefore, is not replicable. Johnson and Siegel also did not state their rationale for having subjects perform submaximal contractions. Because the variable of interest was concentric knee extensor peak torque produced during a maximal voluntary contraction, maximal voluntary contractions would seem to be the most appropriate contractions to practice.

Allowing subjects to practice prior to measuring muscle performance would probably increase the chances of obtaining reliable measurements and would provide the examiner with measurements that better represent a muscle’s ability to produce force. Little research has been conducted to determine how practice affects the reliability of muscle performance measurements obtained with isokinetic devices. Physical therapists often use isokinetic devices to evaluate patients and nondisabled subjects. Isokinetic devices are also used by researchers who study normal muscle physiology.5-7,11,12 Testing protocols that have been demonstrated to optimize the reliability of measurements obtained with isokinetic devices would be useful for clinicians and researchers. The purpose of this study was to develop and test a protocol that could be used to obtain reliable measurements of knee extensor torque produced during maximal voluntary contractions.

Method

This study was conducted in two parts. The first part was conducted to develop a protocol that we believed could be used to obtain reliable measurements of knee extensor torque produced during maximal voluntary concentric, eccentric, and isometric contractions. Subjects were tested on 3 separate days, and the protocol was developed based on their performance. The second part of the study was conducted to test the protocol. A different group of subjects followed the protocol, and the reliability of the knee extensor torque measurements was determined.

Part 1

Subjects. The subjects in part 1 of this study were 10 female graduate students who (1) had no limitations in the range of motion (ROM) of their right hip or knee joint, (2) had no pain on resisted motion of their right hips and knees, (3) had never had surgery on their right knees, (4) had no known pathology of their right quadriceps femoris muscles or associated right knee structures, and (5) had never exercised on an isokinetic device. The subjects’ ages ranged from 23 to 33 years, with a mean age of 26 years (SD=3). Characteristics of the subjects are presented in Table 1. Subjects were asked to

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*Cybex, Div of Lumex Inc, 2100 Smithtown Ave, Ronkonkoma, NY 11779.
1Chattea Corp, 101 Memorial Dr, PO Box 4287, Chattanooga, TN 37405.
read and sign a consent form prior to testing.

**Instrumentation.** A Kin-Com® dynamometer (model #500-11, software version 3.01) was used to measure force during selected maximal voluntary concentric, eccentric, and isometric contractions of the right quadriceps femoris muscles. The Kin-Com® can be set in either an evaluation mode or a training mode. In this study, concentric and eccentric contractions were tested with the Kin-Com® in the evaluation mode. The control constant was set on speed. The acceleration ("turn point, acc.") and deceleration ("turn point, dec.") of the Kin-Com®’s lever arm was set on high. The high settings were used so that the subject’s limb accelerated to and decelerated from constant velocity in the shortest possible time period. These settings maximized the amount of time the subject’s limb moved at constant velocity. The force required to initiate motion of the lever arm ("init. force") was 150% of the weight of the subject’s limb. During preliminary testing on the Kin-Com®, we found that using 150% of the subject’s limb weight prevented sudden movements of the lever arm during testing and enabled the subject to generate some muscle tension before the lever arm began to move. Isometric contractions were tested with the Kin-Com® in the training mode. The time ("pause") for each isometric contraction was set for 3 seconds.

The Kin-Com®’s recording system samples the analog signals from the strain gauge (force signal), potentiometer (angle signal), and tachometer (velocity signal) at a rate of 100 Hz. Preliminary testing conducted in our laboratory indicated that during high-velocity testing a sampling rate of 500 Hz did not adequately represent the signals. The analog signals, therefore, were digitized by an external recording system (AMM1 Analog-to-Digital Board in a Keithley DAS Measurement and Control System®, series 500). Data acquisition was controlled using DADISP 1® software® (version 1). Signal acquisition was at a rate of 500 Hz for each channel.

The calibration of the Kin-Com®’s strain gauge and potentiometer was checked prior to and after testing all of the subjects using the external recording system. The results of the prestudy and poststudy calibration checks indicated that the strain gauge and potentiometer of the Kin-Com® remained in calibration during this study.

**Procedure for testing subjects.** Each subject was tested on 3 separate days with no less than 48 hours and no more than 96 hours between consecutive test sessions. Attempts were made to test each subject at approximately the same time of day during each session. For all of the subjects tested, the time of day for each test session was within 8 hours of the time of day for the other test sessions. The same examiner (MK) tested all of the subjects.

On the first test day, each subject’s limb was weighed by use of the Kin-Com®’s gravity-correction mode. The subject positioned herself in the supine position on the Kin-Com® table with her right leg next to the lever arm of the dynamometer. The axis of rotation of the lever arm was aligned with the axis of rotation of the subject’s right knee joint. The center of the right lateral femoral epicondyle was used as the reference for the axis of rotation of the knee joint. A thigh strap was then placed across the midportion of the subject’s right thigh, and the pad of the lever arm was placed just proximal to the medial malleolus. The distance from the pad to the axis of rotation of the lever arm was recorded. This value was recorded so that the pad of the lever arm was placed in the same position during subsequent test sessions. The distance from the pad to the axis of rotation of the lever arm was also used to convert a subject’s force measurements to torque measurements during data reduction.

With the subject still in a supine position, her knee was placed in 90 degrees of flexion. A universal goniometer was used to determine the position of the knee joint. This value was entered into the Kin-Com®’s computer so that the recording of the lever arm position corresponded to that of the knee joint position. The subject’s knee was then placed in 0 degrees of flexion and, with the subject relaxed, her leg was weighed by use of the Kin-Com®’s strain gauge and gravity-correction mode. The weight of the subject’s leg was used to determine the force required to initiate motion of the lever arm when performing concentric and eccentric contractions. The weight of the subject’s leg was also used during data reduction to correct torque measurements for the effect of gravity. During isokinetic testing, the torque required to move the limb against gravity is not measured. Winter et al. have shown that errors in torque measurements that are not corrected for gravity are substantial, especially if the torque values are low.

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1. Keithley Data Acquisition & Control Inc, 28775 Aurora Rd, Cleveland, OH 44139.
2. DSP Development Corp, 55 Cambridge Pkwy, Cambridge, MA 02142.
After the subject’s limb was weighed, she sat up on the Kin-Com® table with her hips in 80 degrees of flexion. The position of the subject’s hips was determined by visual estimation of the angle formed by her trunk and thighs. The seat back of the Kin-Com® was placed behind the subject to maintain this position. The location of the seat back was recorded so that the seat back was placed in the same position during subsequent test sessions. A strap was placed securely across the subject’s pelvis, and the axis of rotation of the lever arm was aligned with the axis of rotation of the subject’s right knee joint. This was done as described previously. The subject’s knee was then placed in 90 degrees of flexion. A universal goniometer was used to determine this position. This value was entered into the Kin-Com®’s computer so that the recording of the lever arm position corresponded to that of the knee joint position.

On subsequent test days, each subject went through a similar procedure. The only difference was that the subject’s limb was not weighed again. For gravity correction, the weight obtained during the initial session was used. The pad on the lever arm and the seat back were placed in the same position as on the first test day.

On each test day, subjects performed six consecutive maximal voluntary contractions of their right quadriceps femoris muscles for each of the following 10 conditions:

1. Isometric contraction at 40 degrees of knee flexion.
2. Isometric contraction at 60 degrees of knee flexion.
3. Concentric contraction at a velocity of 30°/s.
4. Eccentric contraction at a velocity of 30°/s.
5. Concentric contraction at a velocity of 90°/s.
6. Eccentric contraction at a velocity of 90°/s.
7. Concentric contraction at a velocity of 120°/s.
8. Eccentric contraction at a velocity of 120°/s.
9. Concentric contraction at a velocity of 180°/s.
10. Eccentric contraction at a velocity of 180°/s.

The order in which the conditions were tested was random for each subject and remained the same among test days. There was a 45-second rest period between consecutive contractions and a 2-minute rest period between conditions.

The conditions we tested were chosen because these conditions are often used when testing patients who have knee injuries or when conducting research with isokinetic devices. Because we tested 10 conditions, we decided that six contractions for each condition was the maximum number of contractions the subject could perform within a reasonable amount of time.

Prior to obtaining measurements during a condition, subjects were informed of which type of contraction they had to perform. Subjects were instructed to grasp the sides of the Kin-Com® seat and to “kick as hard as possible” during all contractions. The subjects began a contraction following the examiner’s verbal cue of “One, two, three, go!”

Isometric contractions were performed for 3 seconds. Concentric contractions were performed through a 75-degree arc of motion, starting at 90 degrees of knee flexion and ending at 15 degrees of knee flexion. Eccentric contractions were performed through the same arc of motion, starting at 15 degrees of knee flexion and ending at 90 degrees of knee flexion.

None of the subjects experienced pain during the testing.

The subjects did not view the Kin-Com®’s cathode ray tube (CRT) screen when performing the contractions. We felt that viewing the CRT screen would be distracting and would interfere with the subject’s ability to make a maximal effort. Schenck and Forward found that subjects who had knowledge of the force values they produced during maximal voluntary isometric contractions did not perform any differently than did subjects who did not know their force values.

Data reduction. The force, velocity, and angle data were analyzed using DADISP II® software (version 1.01). For each maximal voluntary contraction, the voltage signal from the strain gauge was converted to newtons, the voltage signal from the tachometer was converted to degrees per second, and the voltage signal from the potentiometer was converted to degrees. These conversions were computed by multiplying the voltage values by calibration factors that had been determined during preliminary testing of the Kin-Com® device used in this study (Thomas P Mayhew, personal communication, January 1989).

The calibrated force data for each subject were converted to torque values (in newton-meters) by multiplying the force values by the length of the subject’s lever arm. The calibrated torque data were then corrected for gravity.

The peak torque for each isometric torque data set was determined. The velocity data for each concentric and eccentric condition were then sampled. During isokinetic testing, the subject accelerates the limb and the lever arm of the machine at the beginning of the movement and decelerates the limb and the lever arm at the end of the movement. Because it is difficult to interpret forces produced during acceleration and deceleration of the limb, the concentric and eccentric torque data sets were only analyzed for the portion during which the limb velocity was constant.

Our method of analyzing the velocity data was chosen after performing a preliminary analysis of the velocity data. Our analysis showed that the arc...
percentage of the peak torque from the first contraction on the first test day. For example, for subject 1 all concentric peak torque values (at 30°/s) for day 1, day 2, and day 3 were divided by the concentric peak torque value (at 30°/s) for the first contraction on the first test day. These values were then multiplied by 100. This normalization procedure decreased the variability of the peak torque values for the subjects as a group and allowed us to compare changes in torque values across subjects and days. Because we were interested in how variability in peak torque changed with practice, we normalized the torque values to the most untrained contraction, the first contraction on the first test day. We therefore could examine how a subject's performance changed with practice and how the subject's performance compared with those of the rest of the group.

For each condition, on each test day, the greatest of the six normalized peak torque values were determined for each subject. These values were then graphed for each condition, with days on the x-axis and normalized peak torque on the y-axis. By normal-
were then visually examined to determine by which contraction the majority of subjects reached their greatest peak torque value for each condition. This visual examination was later confirmed by tallying the data to determine the actual number of subjects who reached their greatest peak torque value for each contraction.

We chose this form of data analysis because we did not want to group our data and possibly skew the results. We were also able to look for trends in the data and to recognize any outliers (ie, subjects who performed very differently than the rest of the group).

**Results.** Examination of the graphs depicting the relationships among the greatest peak torque values on day 1, day 2, and day 3 indicated that subjects generally reached their greatest peak torque on day 2 or day 3 for all conditions. The majority of subjects reached their greatest peak torque by day 2 for five of the conditions and by day 3 for the other five conditions (Tab. 2). The ICCs indicated that there was a greater degree of agreement between the greatest peak torque val-

Figure 3. *Normalized peak torque for eccentric contractions at 120°/s.*

Figure 4. *Normalized peak torque for each isometric contraction at 40 degrees of knee flexion on day 3 of the study.*
ues on day 2 and day 3 (ICC=.94), as compared with day 1 and day 2 (ICC=.89) and with day 1 and day 3 (ICC=.89). We therefore hypothesized that measurements became most stable sometime during day 2. Based on this finding and on the fact that most subjects reached their greatest peak torque on day 2 or 3, we decided it would be safest to conclude that subjects reached their greatest torque values by day 3.

Examination of the graphs depicting the relationship among peak torque values for consecutive contractions (on day 3) indicated that subjects generally reached their greatest peak torque values by the fourth contraction for all conditions. For two of the conditions, the majority of subjects reached their greatest peak torque values by the fifth or sixth contraction (Tab. 3).

Based on the results, we hypothesized that the following protocol could be used to obtain reliable measurements

<table>
<thead>
<tr>
<th>Condition</th>
<th>Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isometric (40°)</td>
<td>3</td>
</tr>
<tr>
<td>Isometric (60°)</td>
<td>2</td>
</tr>
<tr>
<td>Concentric (30°/s)</td>
<td>3</td>
</tr>
<tr>
<td>Eccentric (30°/s)</td>
<td>2</td>
</tr>
<tr>
<td>Concentric (90°/s)</td>
<td>3</td>
</tr>
<tr>
<td>Eccentric (90°/s)</td>
<td>2</td>
</tr>
<tr>
<td>Concentric (120°/s)</td>
<td>3</td>
</tr>
<tr>
<td>Eccentric (120°/s)</td>
<td>3</td>
</tr>
<tr>
<td>Concentric (180°/s)</td>
<td>2</td>
</tr>
<tr>
<td>Eccentric (180°/s)</td>
<td>2</td>
</tr>
</tbody>
</table>

<p>| Table 3. Contraction by Which Majority of Subjects Reached Their Greatest Torque Values on Day 3 |</p>
<table>
<thead>
<tr>
<th>Condition</th>
<th>Contraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isometric (40°)</td>
<td>4</td>
</tr>
<tr>
<td>Isometric (60°)</td>
<td>3</td>
</tr>
<tr>
<td>Concentric (30°/s)</td>
<td>2</td>
</tr>
<tr>
<td>Eccentric (30°/s)</td>
<td>3</td>
</tr>
<tr>
<td>Concentric (90°/s)</td>
<td>4</td>
</tr>
<tr>
<td>Eccentric (90°/s)</td>
<td>3</td>
</tr>
<tr>
<td>Concentric (120°/s)</td>
<td>5</td>
</tr>
<tr>
<td>Eccentric (120°/s)</td>
<td>4</td>
</tr>
<tr>
<td>Concentric (180°/s)</td>
<td>6</td>
</tr>
<tr>
<td>Eccentric (180°/s)</td>
<td>4</td>
</tr>
</tbody>
</table>
of knee extensor torque produced during maximal voluntary contractions. Subjects should be trained for 2 days before actual testing begins. On each training day, subjects should perform six consecutive contractions for each condition. On the day of testing, subjects should perform four consecutive contractions for each condition. The greatest of the four torque values should be used to represent the subject's maximum effort.

**Part 2**

The second part of our study was conducted to test our protocol.

**Subjects.** Fifteen female students who met the same criteria as the subjects in the first part of our study were our subjects. The ages of the subjects ranged from 23 to 33 years. The mean age of the subjects was 25 years (SD=3.5). Characteristics of the subjects are presented in Table 4.

**Instrumentation and procedure for testing subjects.** We used the same instrumentation and followed the procedure for testing that was used in the first part of this study. All subjects participated in four sessions: two practice sessions, one test session, and one retest session. The sessions were conducted on 4 separate days.

Table 4. Characteristics of Subjects

<table>
<thead>
<tr>
<th>Variable</th>
<th>N</th>
<th>X</th>
<th>SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age (y)</strong></td>
<td>15</td>
<td>25.0</td>
<td>3.5</td>
<td>21.0–33.0</td>
</tr>
<tr>
<td><strong>Height (cm)</strong></td>
<td>15</td>
<td>163.8</td>
<td>5.1</td>
<td>154.9–175.3</td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td>15</td>
<td>57.0</td>
<td>9.5</td>
<td>41.9–81.0</td>
</tr>
</tbody>
</table>

During the practice sessions, subjects performed six consecutive maximal voluntary contractions for each of the 10 conditions. During the test and retest sessions, subjects performed four consecutive maximal voluntary contractions for each of the conditions.

**Data reduction and data analysis.** We followed the procedure of data reduction that was used in the first part of this study. Only the data from the test and retest sessions were analyzed. Peak torque was determined for each isometric contraction. Peak torques and angle-specific torques (at 40° and 60° of knee flexion) were also determined for the concentric and eccentric contractions. Peak torques and angle-specific torques are common measurements obtained during isokinetic testing. We chose angle-specific torques at 40 and 60 degrees of knee flexion so that these values could be compared with the isometric values during future data analysis.

For each subject (for each session), the greatest of the four peak torque values for the concentric contractions at each velocity were determined. These values represented the subjects' concentric knee extensor peak torques (CKEPTs) during the isokinetic movements. The greatest of the four angle-specific torque values, at 40 and 60 degrees of knee flexion for each velocity, were also determined. These torque values represented the subjects' concentric knee extensor angle-specific torques (CKEAS) during the isokinetic movements. Eccentric knee extensor peak torques (EKEPTs) and eccentric knee extensor angle-specific torques (EKEAS) were also determined for each velocity tested. The greatest of the four peak torque values for the isometric contractions at each knee joint angle were determined for each subject and represented the subjects' isometric knee extensor torques (IKETs). Intra-class correlation coefficients (1,1) were calculated to determine the degree of agreement (reliability) among the repeated measurements for CKEPT, EKEPT, CKEAS, EKEAS, and IKET for the test and retest sessions.

**Results.** From the data obtained during the test and retest sessions, a total of 25 different torque measurements were determined for each subject. The EKEAS at 40 degrees of knee flexion during an isokinetic movement at 180°/s was not determined in this study. Analysis of the velocity data for this condition indicated that all subjects' legs were still accelerating at this point (ie, at 40° of knee flexion). Because interpretation of knee extensor torque values during acceleration of the leg is difficult, this measurement was not included in the results.

The ICCs estimating the reliability of the knee extensor torque measurements ranged from .87 to .98 (Tab. 5). The ICC value for CKEAS at 60 degrees of knee flexion during an isokinetic movement at 180°/s is based on data from 13 subjects. During the retest session for this condition, 2 subjects' legs were still accelerating at the 60-degree position of knee flexion. The CKEAS values for these 2 subjects, therefore, were not included in the data analysis.

**Discussion**

The ICCs indicate that the torque measurements obtained in the second part of this study were highly reliable. These results suggest that the protocol developed in this study can be used to obtain reliable measurements of knee extensor torque produced during maximal voluntary contractions. One trend, although small, is apparent in the ICC values estimating the reliability for the concentric and eccentric torque measurements (both peak and angle-specific). The ICC values increased as the velocity of the concentric or eccentric contractions increased. For example, the ICC value estimating the reliability of CKEPT at 30° was .94, and the ICC value estimating the reliability...
Treddinick and Duncan\(^8\) examined the reliability of knee extensor torque measurements obtained with a Kin-Com\(^8\) dynamometer. They tested 14 men between the ages of 23 and 32 years. Subjects participated in three sessions on 3 separate days. On the first day, subjects practiced by performing four submaximal and four maximal voluntary concentric and eccentric contractions at velocities of 60°, 120°, and 180°/s. Subjects were then retested 2 days later, following the same protocol. One week after the test session, subjects were retested.

Treddinick and Duncan\(^8\) averaged the peak torque values of the last three maximal contractions on the test day and compared these values with the average of the peak torque values of the last three maximal contractions on the retest day. The ICC (1,1) values describing the degree of agreement between the average peak torque values from the test and retest sessions ranged from .47 to .97. The ICC values reported by Treddinick and Duncan were generally lower than the ICC values obtained in our study.

Differences in the results may have been due to differences in the methods of the two studies. Treddinick and Duncan\(^8\) tested male subjects and did not test the same velocities that we tested. They also had subjects perform reciprocal contractions (ie, a concentric contraction followed by an eccentric contraction). More importantly, Treddinick and Duncan only had subjects practice for 1 day. Their measurements may have been more reliable if subjects had practiced more.

Although Treddinick and Duncan\(^8\) were more detailed than some investigators regarding their practice protocol, they did not state the rationale for their practice protocol. Too often investigators are vague about the practice sessions their subjects follow and appear to arbitrarily choose the number and types of practice contractions their subjects perform.

Few investigators testing with isokinetic devices have systematically developed practice protocols. Johnson and Siegel's study\(^10\) was the only one found in which a practice protocol was systematically developed. Johnson and Siegel tested 40 female subjects between the ages of 17 and 50 years on a Cybex\(^8\) II dynamometer. Subjects were tested at a velocity of 180°/s on 6 consecutive days. On each day, subjects performed three submaximal and six maximal voluntary contractions of their quadriceps femoris muscles. Johnson and Siegel found that concentric knee extensor peak torque measurements were most reliable if subjects practiced by performing three submaximal and three maximal voluntary contractions.

One weakness of Johnson and Siegel's study\(^10\) is that they did not operationally define "submaximal contraction." Their protocol, therefore, would be difficult to replicate. When developing the method of our study, we chose not to have subjects perform submaximal contractions for practice. We felt that operationally defining a submaximum contraction and determining a method of standardizing this type of contraction for each subject would be difficult. We also believed that because the subjects would be performing maximal voluntary contractions during testing, maximal voluntary contractions would be the most appropriate contractions to practice.

The results of Johnson and Siegel's study\(^10\) suggest that subjects do not need more than 1 day of practice to obtain reliable knee extensor torque measurements. The results of our study, however, suggest that subjects need more than 1 day of practice. Differences in the results may be due to differences in the methods of the two studies. Johnson and Siegel used a Cybex\(^8\) II dynamometer to measure muscle performance and had subjects
perform concentric contractions at a velocity of 180°/s. We used a Kin-Com® dynamometer to measure muscle performance and had subjects perform concentric and eccentric contractions at various velocities of movement and isometric contractions at different positions of knee joint flexion. Practice protocols may be specific to the number and types of contractions performed and to the type of dynamometer used.

Our results suggest that subjects without knee pathology need 2 days of practice in order to learn how to perform on an isokinetic device. Because our study was conducted on subjects without knee pathology, the results may not necessarily be generalizable to patient populations. Our protocol, however, can be used by clinicians who perform screening evaluations on nondisabled subjects. Our protocol can also be used in the laboratory setting by researchers who study normal muscle physiology.

Because of the lack of information on how practice affects patient performance on isokinetic devices, our results may also be useful for clinicians who test patients with isokinetic devices. Our results suggest that patients may need more than 1 day of practice in order to become consistent with their performance on an isokinetic device. Clinicians may choose to test our protocol on patients or to follow our protocol until more specific protocols are developed. At present, no such practice protocols exist for patient groups.

Our method can also be used by researchers and clinicians to develop their own practice protocols. We have provided the reader with a set of replicable procedures for obtaining reliable measurements of muscle performance.

This study was conducted on a small number of nondisabled female subjects using data-acquisition equipment that would not normally be used in a physical therapy clinic. Our sample size was small, and the reader should be cautious about generalizing the results of this study.

**Conclusions**

The results of this study suggest that the protocol we developed can be used to obtain reliable measurements of knee extensor torque from college-aged female subjects without knee pathology. Because of the lack of information on how practice affects subject performance on isokinetic devices, the results of this study provide the clinician and researcher with a useful protocol. The method of this study can also be used to develop practice protocols that are specific to the types of patients or subjects they test.

**Acknowledgment**

We thank the faculty of the Department of Physical Therapy at the Medical College of Virginia for their input during the development of this study and for their assistance with the review of the manuscript.

**References**


**Commentary**

The authors, Kues, Rothstein, and Lamb, are to be commended for investigating an issue of direct clinical relevance. Measurement of peak torque during maximal voluntary contractions is the basis of a wide range of clinical tests of muscle function. As stated by the authors, "Before any measurement of muscle performance can be useful, the reliability of the measurement should be determined." In this light, reliability of torque measurements, especially measurements of peak torque, which should occur during maximum voluntary contractions, is an essential factor in tests that measure muscle performance.
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