Validity and Reliability of an Instrumented Leg-Extension Machine for Measuring Isometric Muscle Strength of the Knee Extensors

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Context: Isometric muscle strength of knee extensors has been assessed for estimating performance, evaluating progress during physical training, and investigating the relationship between isometric and dynamic/functional performance. Objective: To assess the validity and reliability of an adapted leg-extension machine for measuring isometric knee extensor force. Design: Validity (concurrent approach) and reliability (test and test–retest approach) study. Setting: University laboratory. Participants: 70 healthy men and women aged between 20 and 30 y (39 in the validity study and 31 in the reliability study). Main Outcome Measure: Intraclass correlation coefficient (ICC) values calculated for the maximum voluntary isometric torque of knee extensors at 30°, 60°, and 90°, measured with the prototype and with an isokinetic dynamometer (ICC2,1, validity study) and measured with the prototype in test and retest sessions, scheduled from 48 h to 72 h apart (ICC1,1, reliability study). Results: In the validity analysis, the prototype showed good agreement for measurements at 30° (ICC2,1 = .75, SEM = 18.2 Nm) and excellent agreement for measurements at 60° (ICC2,1 = .93, SEM = 9.6 Nm) and at 90° (ICC2,1 = .94, SEM = 8.9 Nm). Regarding the reliability analysis, between-days’ ICC1,1 were good to excellent, ranging from .88 to .93. Standard error of measurement and minimal detectable difference based on test-retest ranged from 11.7 Nm to 18.1 Nm and 32.5 Nm to 50.1 Nm, respectively, for the 3 analyzed knee angles. Conclusions: The analysis of validity and repeatability of the prototype for measuring isometric muscle strength has shown to be good or excellent, depending on the knee joint angle analyzed. The new instrument, which presents a relative low cost and easiness of transportation when compared with an isokinetic dynamometer, is valid and provides consistent data concerning isometric strength of knee extensors and, for this reason, can be used for practical, clinical, and research purposes.

Keywords: exercise testing, instrument development, peak torque
machine for measuring isometric muscle strength of knee extensors.

Methods

Design

To assess the validity and reliability of an instrumented leg-extension machine for measuring isometric muscle strength of knee extensors (hereafter referred to as prototype), the study was carried out in 2 phases. In the first phase (validity analysis), values of maximum isometric muscle strength at 30°, 60°, and 90° of knee flexion were measured with the prototype and compared with values measured with an isokinetic dynamometer in the isometric mode (considered as the criterion measure). In the second phase (reliability analysis), data on maximum isometric muscle strength at 30°, 60°, and 90° of knee flexion were obtained using the prototype through a test-retest approach, and values were compared between sessions. Data analysis was conducted through the use of the intraclass correlation coefficient (ICC) and additional information regarding the standard error of measurement was provided to help practitioners to use this parameter in the interpretation of test data, as suggested by Weir.8

Participants

Seventy healthy adults who volunteered in response to an advertisement were included in the study according to the following criteria: percentage of body fat (which should range from 12% to 16% for men and from 20% to 25% for women) and physical activity level (all subjects included were young recreational athletes, active in different sports such as swimming, soccer, volleyball, and track and field). Subjects were excluded if they had suffered any injury or undergone any surgery in the past 2 years. Thirty-nine subjects (20 women) participated in this study for the concurrent validation analysis and the other 31 subjects (15 women) participated for the reliability analysis. Mean (±1 SD) age, height, and mass for all subjects were 23.0 ± 4.0 years, 1.75 ± 0.08 m, and 64.6 ± 6.8 kg, respectively. Ethics approval was granted by the Institutional Committee for Ethics in Research and all participants gave written informed consent.

Equipment and Procedures

The prototype, which is not currently commercially available, consists of an adapted leg-extension machine with a ring-shaped load cell (sensitivity of 2 N; error lower than 1%) attached to the end of a lever arm. The device permits the measurement of isometric force at different angles of knee flexion (Figure 1), weighs approximately 15 kg, and can be disassembled into 3 light components. Subject position is seated with hands folded across the chest, and 3 seat belts are used for stabilization: 2 to strap the trunk to the back rest and 1 across the hip. For data acquisition (100 Hz) and processing the system ADS 2000-IP (Lynx Electronic Technology, Brazil) was used. To verify concurrent validity, an isokinetic dynamometer (CSMi Medical Solutions, Stoughton, MA) was used. The guidelines regarding isometric muscle evaluations, provided by the equipment manual, were carefully followed.

The concurrent validity was verified by comparing the data from the prototype with those measured using the

Figure 1 — Instrumented leg-extension machine used in the study (A) with subject positioned during test at 90° of knee flexion and position of device arm for tests at (B) 60° and (C) 30° of knee flexion.
isokinetic dynamometer (isometric mode). The order of angulations analyzed (30°, 60°, and 90° of knee flexion) and the order of instruments (isokinetic dynamometer and prototype) were randomly determined in a counterbalanced order.

The reliability of the prototype was analyzed through a test and retest approach, with an interval of 48 to 72 hours between measurements. The same time of day and angulation order were respected in both tests for each subject.

For both analyses, participants were given a familiarization period, which included 3 sets of submaximum muscle contraction for each angle analyzed. To restrict motion during the tests, straps across the trunk and hip were used with both pieces of equipment. For the isokinetic device, the lower leg was also strapped to the dynamometer arm. Three sets of maximum voluntary isometric force of right knee extensors were measured at 30°, 60°, and 90° of knee flexion. During the tests, subjects were verbally encouraged to extend their knee as strongly as possible. Each contraction lasted 5 seconds and a 2-minute rest interval occurred between each trial. Force data from the prototype, in newtons, were transformed to torque by multiplying the force value by the load cell lever arm length (0.50 m).

**Statistical Analyses**

The maximum torque value at each knee joint angle was considered for statistical analysis. The ICC was used for both validity (ICC$_{2,1}$) and reliability (ICC$_{1,1}$) analyses. ICC values were interpreted according to the following criteria$^9$: poor, $<.40$; fair, $.40$ to $.70$; good, $.70$ to $.90$; and excellent, $>.90$. A paired-sample $t$ test was used to compare the torque values between the devices at each joint angle ($\alpha = .05$). For the reliability analysis, the standard error of measurement (SEM) and the minimal detectable change (MDC) were also reported. MDC was estimated from SEM as follows$^8$:

$$MDC = SEM \times 1.96 \times \sqrt{2}$$

**Results**

Mean (± 1 SD) isometric torque of knee extensors at 30°, 60°, and 90° were 90.0 ± 35.0 Nm, 172.2 ± 59.6 Nm, and 204.5 ± 72.8 Nm for the isokinetic dynamometer, and 114.2 ± 34.0 Nm, 189.9 ± 63.8 Nm, and 174.8 ± 59.6 Nm for the prototype device. The average difference between the pieces of equipment were 24.1 ± 31.0 Nm, 17.7 ± 31.7 Nm, and 29.7 ± 31.3 Nm at 30°, 60°, and 90° of knee flexion, respectively. ICC values between devices varied from good (30° of knee flexion) to excellent (60° and 90° of knee flexion) (Table 1).

<table>
<thead>
<tr>
<th>n</th>
<th>Test Retest</th>
<th>ICC$_{2,1}$ (95% CI)</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>30°</td>
<td>39</td>
<td>90.0 ± 35.0$^a$</td>
<td>114.2 ± 34.0$^b$</td>
</tr>
<tr>
<td>60°</td>
<td>39</td>
<td>172.2 ± 59.6$^a$</td>
<td>189.9 ± 63.8$^b$</td>
</tr>
<tr>
<td>90°</td>
<td>39</td>
<td>204.5 ± 72.8$^a$</td>
<td>174.8 ± 59.6$^b$</td>
</tr>
</tbody>
</table>

Abbreviations: ICC, intraclass correlation coefficient; CI, confidence interval; SEM, standard error of measurement.

Table 1 Descriptive Information Comparing Peak Isometric Torque of Knee Extensors When Obtained From an Isokinetic Dynamometer and the Prototype Device

Note: Values are mean ± SD. Unit of Nm. Superscript letters (a,b) indicate statistically significant differences between devices at each joint angle.

<table>
<thead>
<tr>
<th>n</th>
<th>Test Retest</th>
<th>ICC$_{1,1}$ (95% CI)</th>
<th>SEM</th>
<th>MDC</th>
</tr>
</thead>
<tbody>
<tr>
<td>30°</td>
<td>31</td>
<td>123.1 ± 31.6</td>
<td>123.3 ± 36.5</td>
<td>.88 (.74–.94)</td>
</tr>
<tr>
<td>60°</td>
<td>31</td>
<td>196.7 ± 59.9</td>
<td>196.0 ± 68.6</td>
<td>.92 (.83–.96)</td>
</tr>
<tr>
<td>90°</td>
<td>31</td>
<td>182.0 ± 56.3</td>
<td>179.6 ± 57.8</td>
<td>.93 (.85–.96)</td>
</tr>
</tbody>
</table>

Abbreviations: ICC, intraclass correlation coefficient; CI, confidence interval; SEM, standard error of measurement; MDC, minimal detectable change.

Table 2 Descriptive Information Comparing the Consistency of Isometric Peak Torque of Knee Extensors Between Time 1 and Time 2

Note: Values are mean ± SD. Unit of Nm.
Discussion

Knee extensor isometric torque has widely been used as an estimate of knee joint strength. Values reported in this study for the new device are similar to knee isometric strength data found in the literature for healthy and nonathletic individuals.10

According to the results, we believe the prototype provides valid measures of isometric muscle strength of knee extensors. However, due to the difference between measures when comparing the devices, data obtained through the prototype should not be compared with a measure obtained through an isokinetic dynamometer. Regarding the analysis of reliability, the ICC values between test and retest can be considered excellent at 60° and 90°, and good at 30° of knee flexion.9 Therefore, we can affirm that the new instrument provides reliable data, which reinforces its use.

This study has some limitations that need to be considered when interpreting the findings. The results may not apply to subjects of all ages, as well as to those with knee dysfunction. In addition, higher levels of baseline disability tend to result in a larger MDC and, consequently, patients with knee dysfunction might need to experience a greater change to be confident that a true improvement in muscle strength has occurred.

Conclusion

When compared with the isokinetic dynamometer, although the prototype can be used only for evaluating knee-extension force, it presents some advantages such as a relatively low cost and ease of transportation. The new instrument is valid and provides consistent data concerning isometric strength of knee extensors and, for this reason, can be used for practical, clinical, and research purposes.

References


