Low-Budget Instrumentation of a Conventional Leg Press to Measure Reliable Isometric-Strength Capacity

Heiner Baur, Alessia Severina Groppa, Regula Limacher, and Lorenz Radlinger

Maximum strength and rate of force development (RFD) are 2 important strength characteristics for everyday tasks and athletic performance. Measurements of both parameters must be reliable. Expensive isokinetic devices with isometric modes are often used. The possibility of cost-effective measurements in a practical setting would facilitate quality control. The purpose of this study was to assess the reliability of measurements of maximum isometric strength (Fmax) and RFD on a conventional leg press. Sixteen subjects (23 ± 2 y, 1.68 ± 0.05 m, 59 ± 5 kg) were tested twice within 1 session. After warm-up, subjects performed 2 times 5 trials eliciting maximum voluntary isometric contractions on an instrumented leg press (1- and 2-legged randomized). Fmax (N) and RFD (N/s) were extracted from force–time curves. Reliability was determined for Fmax and RFD by calculating the intraclass correlation coefficient (ICC), the test–retest variability (TRV), and the bias and limits of agreement. Reliability measures revealed good to excellent ICCs of .80–.93. TRV showed mean differences between measurement sessions of 0.4–6.9%. The systematic error was low compared with the absolute mean values (Fmax 5–6%, RFD 1–4%). The implementation of a force transducer into a conventional leg press provides a viable procedure to assess Fmax and RFD. Both performance parameters can be assessed with good to excellent reliability allowing quality control of interventions.

Keywords: muscle strength, muscle strength dynamometer, resistance training

Strength capacity can be measured on isokinetic devices. However, those devices are expensive and not available in every athletic training or rehabilitation setting. Cost-effective methods can possibly be implemented in regular training devices to measure strength capacity. This would allow widespread quality control of training or rehabilitation interventions.

Muscle strength, defined as the capability of the neuromuscular system to generate force, is required for daily life tasks and is essential for athletic performance. Evaluation of muscle strength must be reliable to appraise effects of training or rehabilitation. The measurement of maximal isometric strength and rate of force development (RFD: rise in contractile force at the onset of contraction) allows revealing differential effects of training or rehabilitation interventions. Aagaard et al. showed an increase in maximal isometric strength and RFD after 14 weeks of heavy resistance training. After 4 weeks of “ballistic” strength training with individual loads of less than 40% of 1-repetition maximum or a sensorimotor training program, both resulted in an increased RFD, whereas no changes in maximal strength were observed. Both aspects of strength capacity are therefore considered important and distinct characteristics of human performance.

Therefore, the purpose of this study was to assess intrasession retest reliability of maximal isometric-strength measurements and RFD on a conventional leg press that was newly instrumented with a force transducer. The hypothesis was that measurements of strength capacity would be reliable. Eventually a reliable low-cost method for leg press instrumentation could be suggested.

Methods

A test–retest design was used to assess intrasession reliability of isometric-strength capacity. Maximal isometric strength in Newtons and RFD in Newtons per second served as dependent variables.

Sixteen young and asymptomatic (no acute or chronic injury to the musculoskeletal system) female subjects (23 ± 2 y, 1.68 ± 0.05 m, 59 ± 5 kg, 4 ± 2 training sessions/wk) were tested twice within 1 measurement session. They all refrained from rigorous exercise 24 hours before testing. Subjects took part voluntarily and provided written informed consent. The ethics commission of the Canton of Bern approved the study (KEK Nr. Z007/12), which followed guidelines of Good Clinical Practice (EC-GCP Note of Guidance) and the Helsinki Declaration.
Participants performed a 5-minute warm-up on a cycle ergometer (Daum Elektronik Ergo Bike Professional, GTSM Magglingen AG, Zürich, Switzerland) at 70 W, after which 5 trials (1-min break between trials) eliciting maximal isometric voluntary contractions were measured on a conventional leg press (TechnoGym, Typ M051, Gambettola, Italy) with both legs, as well as 1-legged (right extremity). The order of tests was randomized, resulting in an overall trial number of 10 (5 trials 1-legged, 5 trials 2-legged). This protocol was repeated with a new randomized order after 20 minutes.

Subjects were positioned on the leg press supine with 90° hip flexion and 80° knee flexion. The leg press was equipped with a force transducer (strain gauge: S-Beam KM 1506 K, Art No 124 108, Megatron Elektronic AG, Putzbrunn, D, input voltage: ±5 V). The sensor was integrated in the pulling chain of the weights of the leg press (Figure 1). This resulted in a measurement of summed forces that are generated at the footplate of the leg press, transferred to the chain that is fixed to a moveable sledge where the subject is positioned and directed via 2 deflection rollers (1 eccentric, 1 symmetric pulley) to the weight plates of the leg press. The restriction of movement for isometric-force generation was realized by a simple bar attached to the frame of the leg press allowing only minimal movement of the weights and the sledge (Figure 1). This ensured direct force transfer to the transducer.

Subjects were instructed to perform each trial with maximal fast-force rise and maintaining maximal contraction for 5 seconds. Test trials with visual feedback preceded actual measurements without feedback, and detailed verbal instructions to perform with maximum effort were given continuously. Data from the force transducer were sampled at 1000 Hz, amplified with a gain of 1000 (UMVE; uk-laboratories, Kempen, Germany), and converted by a 12-bit analog-to-digital converter (Meilhaus ME-2600i; SisNova Engineering, Zug, Switzerland) for storage. Postprocessing consisted of signal filtering (low-pass 30 Hz, Butterworth, 12 dB/octave; software, analog/digital signal-analysis software ADS, uk-laboratories, Kempen, Germany). Maximal isometric voluntary contraction (Fmax) and RFD were extracted as outcome measures from force–time curves. Fmax was the absolute maximal value, and RFD corresponded to the maximal slope in the rise of the force–time curve. The 3 highest values of the measured 5 trials were averaged.

Intrasession retest reliability was determined for Fmax and for RFD by calculating the intraclass correlation coefficient (ICC2,1) and by determining the test–retest variability (TRV(%) = \[\frac{\sum_{i=1}^{7}(x_i - y_i)^2}{0.5(\sum_{i=1}^{7}x_i + y_i)}\] × 100, where \(x_i\) is the value of the outcome measure of test 1 and \(y_i\) is the value of the outcome measure of test 2 for subject \(i\)). Furthermore, a Bland-Altman analysis was calculated with bias and limits of agreement (LoA: ±1.96 SD), where the bias is a measure for the systematic error of the 2 measurements,

\[
\text{Bias} = \frac{1}{7}\sum_{i=1}^{7}(x_i - y_i),
\]

where \(x_i\) is the value of the outcome measure of test 1 and \(y_i\) is the value of the outcome measure of test 2 for subject \(i\)).

Data were evaluated descriptively with the presentation of means and standard deviations.

Results

Mean 1-legged Fmax was 840 (±230) N for measurement 1 (M1) and 790 (±238) N for measurement 2 (M2). The 2-legged trials resulted in higher values of 1370 (±326) N for M1 and 1297 (±344) N on M2. RFD in 1-legged mode showed a group mean of 9688 (±2870) N/s (M1) and 9615 (±2790) N/s (M2). Two-legged trials led to a higher RFD of 12,709 (±5240) N/s (M1) and 13,208 (±4975) N/s (M2).

Reliability-measure ICCs ranged from .80 to .93. TRV showed mean differences between M1 and M2 of 0.4% to 6.9%. The systematic error (bias) was low compared with the absolute mean values (Fmax 5–6%, RFD 1–4%). Table 1 depicts all values of reliability criteria for the measured outcomes and exercise modes.

<table>
<thead>
<tr>
<th></th>
<th>ICC2,1</th>
<th>TRV ± SD (%)</th>
<th>Bias ± LoA</th>
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</thead>
<tbody>
<tr>
<td>Fmax 1-legged</td>
<td>.92</td>
<td>6.4 ± 9.5</td>
<td>50 ± 79 N</td>
</tr>
<tr>
<td>Fmax 2-legged</td>
<td>.87</td>
<td>5.3 ± 11.0</td>
<td>73 ± 157 N</td>
</tr>
<tr>
<td>RFD 1-legged</td>
<td>.80</td>
<td>0.4 ± 17.1</td>
<td>73 ± 1736 N/s</td>
</tr>
<tr>
<td>RFD 2-legged</td>
<td>.93</td>
<td>6.9 ± 20.2</td>
<td>498 ± 1912 N/s</td>
</tr>
</tbody>
</table>

Abbreviations: TRV, test–retest variability; LoA, limits of agreement.
Discussion

The purpose of this brief report was to assess intrasession reliability of Fmax and RFD of the lower extremity on a newly instrumented leg press.

ICCs for maximum strength of .87 (2-legged) and .92 (1-legged) were comparable to reports in the literature. Callaghan et al.\(^4\) showed similar values for isometric and isokinetic measurements. This is also valid for the comparison of the current data with data of lower-extremity isokinetic assessments. The comparison of absolute values of maximum strength remains difficult because kinematics of force transmission can differ substantially between leg-press devices. Mean maximum-strength values of 1334 N in young healthy women show good validity compared with the values of Müller et al.\(^1\) and Spiering et al.\(^4\)

RFD can be expressed as in the case at hand with the maximum rate of force rise at the beginning of contraction, it can be depicted as the maximum or mean rate of force rise in different time windows starting at contraction onset,\(^2,6\) or it can be derived from a certain range of percentage of maximum strength during force rise (eg, 10–40% of measured maximum force).\(^10\) Since no clear consensus exists, comparison between protocols is impaired. Nevertheless, the current ICC results for RFD (.93) are in line with published 2-legged measurement (.94).\(^4\)

Takings the test–retest variability and the bias (and LoA) into account, percentage and absolute values might serve as an indication for interpretations of true intervention effects (Table 1).

There are limitations inherent in this investigation. First, only female subjects were tested. Reliability can differ depending on the studied cohort (gender, healthy, injured).\(^1\) It is therefore recommended to assess subject-specific reliability to judge measured effects. Moreover, it has to be pointed out that the focus was on the feasibility of reliable strength-capacity measurements on a newly instrumented device in an intrasession setup. Intersession reliability can therefore differ from the presented results. Nevertheless, it is important when intervention effects have to be appraised.

The implementation of a low-cost force transducer ($US200) and a movement-restriction bar inhibiting sledge movement of the leg-press seat in a conventional leg press offers a simple method to assess Fmax and RFD. The force transducer requires supply voltage and signal amplification, but it can be implemented in common signal-amplification systems.

The presented method of implementing a force transducer in a conventional leg press provides a feasible possibility to assess Fmax and RFD. Both functional-performance parameters can be assessed with good to excellent reliability in a practical setting, allowing quality control of training interventions.

References


