Reliability of one repetition maximum measurement for leg extension using an improved leg extension machine

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Abstract

Objectives: This study examined the reliability of one repetition maximum measurement (1RM) for leg extension using an improved leg extension machine through a comparison between before and after machine improvement.

Methods: Twenty-one healthy adult males were recruited. A ratchet was welded to the knee rotation axis of the leg extension machine to prevent counter rotation due to the free fall of weights. The 1RM measurement for knee extension was performed before and after machine improvement to observe changes in their reliability using the intra-class correlation coefficient (ICC).

Results: After machine improvement, an intra-rater reliability of ICC(1,1)=0.99 and inter-rater reliability of ICC(2,1)=0.99 were achieved. Reliability before and after machine improvement was also high, with ICC(2,1)=0.99.

Conclusions: The reliability of 1RM measurement for leg extension using an improved leg extension machine was high.

Keywords: Reliability, One repetition maximum measurement, Leg extension machine, Muscle force

Introduction

The muscle strength of individuals undergoing rehabilitation tends to be reduced as a factor associated with a decline in their activities of daily living. Resistance training is a method to strengthen weakened muscles.1 Such training aims to increase muscle strength by applying loading at or above a certain level to target muscles. When setting loads for resistance training, the maximal weight a subject can lift with 1 repetition maximum (1RM) is calculated to produce a relative rate of this value (%1RM).2 There are 2 methods to estimate 1RM: direct: examining a subject’s capacity to lift a certain weight with 1RM; and indirect or presumptive: measuring numbers of repetitions with maximum effort and loading to estimate 1RM.3 Both methods are reportedly effective to determine appropriate loading in individual cases.4-7 Conversely, 1RM measurement require considerable time and labor from the measurer, and load stress on a subject’s muscles and tendons, consequently increasing their risk of injury.8 Therefore, simple and safe 1RM test methods have yet to be developed.

In the case of knee extension, 1RM tends to be estimated based on the number of repetitions with maximum effort and loading.3 When measuring 1RM using a leg extension machine, the lower limb is pushed back in the direction toward knee flexion in response to the free fall of the weight after maximal knee extension. Therefore, it is necessary for subjects to return their lower limb slowly to its original position, with the knee extensors eccentrically contracting, while supporting the weight. Repeated eccentric contractions during measurement increase cumulative fatigue in subjects, resulting in an insufficient maximal voluntary concentric contraction of their knee extensors. Thus, the necessity of repeating eccentric contractions may reduce the reliability of 1RM measurement for knee extension. In addition, as a large number of subjects report pain due to executing eccentric contractions at a high velocity, these measurements have also been reported to be inappropriate in the clinical setting.9 These problems may be resolved by improving leg extension machines to avoid inducing eccentric contractions.

Therefore, in the present study, a leg extension machine was improved by attaching a ratchet to its knee rotation axis to prevent counter rotation due to the free fall of weights, and we verified the reliability of 1RM measurement for knee extension after such an improvement.

Methods

Subjects

We recruited 21 healthy adult males without orthopedic disorders of the knee joint (mean age: 27.7±5.4 years; height: 170.5±5.6 cm; body weight: 66.3±12.8 kg). The exclusion criteria were as follows: 1) individuals with movement restrictions by their family physicians; 2) those with difficulty in understanding the explanation of the motor tasks; 3) those with pain that may lead to the necessity of discontinuing the motor tasks; 4) those with a rapidly progressing progressive disease, acute disease, or unstable chronic disease; 5) those with a history of hypertension or tachycardia; 6) and those with an orthopedic disease of the knee joint.10,11 This study was approved by the ethics committees of the study corporative body (approval number: 16-005) and university (HM16-087). Furthermore, prior
to the experiment, the subjects were provided with written and oral explanations of the study objective to obtain their informed consent.

Procedure

Prior to 1RM measurement, a 10-min ergometer workout was performed for warm-up at an intensity level corresponding to the Borg Scale of Perceived Exertion: "Somewhat hard". For measurement, the left leg was used, while the right leg was kept hanging down. The chest, pelvis, proximal and distal parts of the thigh, and foot were immobilized using a belt. The initial position was adopted at a hip flexion angle of 70° and a knee flexion angle of 100°, with both upper limbs kept crossed in front of the chest. While limiting isotonic knee extension to maximum-effort concentric contraction, the measurements were performed at a knee angle of 90° to the final point of lifting (Figure 1).

The reliability of 1RM measurement for leg extension using an improved leg extension machine (NR-S; Senoh Corporation, Matsudo, Japan) was examined, adopting the method reported by Sugiura et al.10–12 The final point of lifting to determine the knee extension range of motion for 1RM measurement was measured using a stadiometer (seca213; seca Nihon Co., Ltd., Chiba, Japan). The first reliability of 1RM measurement for leg extension using an improved leg extension machine was between the first and second test occasion. The second was between test leader A and B.

Two independent raters measured 1RM to assess intra-rater reliability. On measurement, maximal voluntary knee extension without loading was repeated 5 times to adopt a mean (unit: cm; the values were rounded down to 1 decimal place) as the final point of lifting.10,11 Subsequently, to predict the weight that would be lifted initially, knee extension to the final point of lifting at a loading level corresponding to the Borg Scale of Perceived Effort: "Somewhat hard" was rehearsed. The loading level was adjusted at intervals of 0.5 kg until the maximum weight each subject could lift was determined. The value obtained at the final point of lifting with the maximum weight was adopted as the 1RM in each case. Measurement at the same loading level was not repeated more than twice, and "success" was defined as "lifting the weight at least once during any of the 3 measurement sessions." Between measurement sessions and load adjustments, 30-s and 3-min rests were inserted, respectively, and the value was determined before applying the 6th load. Measurement was repeated once at an interval of 24 h or more and less than 72 h in each case.

Improvement of the leg extension machine

To prevent the free fall of weights that induces counter rotation, a ratchet (R-160; Sanwa Conveyer Co., Ltd., Ono, Japan) was welded firmly to the knee rotation axis of the leg extension machine (Figure 2). A ratchet is a mechanical engineering-based mechanism that serves to limit motion to only one direction. A ratchet is composed of a gear with asymmetric teeth and a pawl sliding over these teeth. When the direction of motion is reversed, the pawl will come into contact with the steep slope of the gear tooth to impede motion. In the opposite case, it will slide over the steep slope of the gear tooth to allow rotary motion. In the present study, ratchet use aimed to prevent leg flexion (left-rotating gear) after knee extension (right-rotating gear). The ratchet turns "OFF" with right rotation and turns "ON" with left rotation. On measurement, the machine was used under 2 different conditions: the ratchet pawl was not used (lifted) to keep the machine unfixed during measurement ("before improvement"); and the ratchet pawl was used (set down) ("after improvement").

Analysis

The intra- and inter-rater reliability of 1RM measurement after improving the leg extension machine was verified by calculating the degree of agreement using the intra-class correlation coefficient (ICC). Furthermore, to verify the absolute reliability of 1RM measurement, systematic biases were examined through Bland-Altman analysis.13 When the 95% confidence interval for the mean difference between 2 measurement values did not include 0, a fixed bias was regarded as being present in a positive or negative direction. Similarly, when the Pearson product-moment correlation coefficient for the difference between 2 measurement values and their mean was significant at a significance level of 5%, a proportional bias was regarded as being present. Limits of agreement were calculated whenever a
fixed or proportional bias was identified. The standard error of measurement and minimal detectable change 95 were also calculated. For statistical analysis, IBM SPSS Statistics Ver. 21 was used, with the significance level set at 5%.

**Results**

After improving the leg extension machine (Test 1), an intra-rater reliability of ICC(1,1)=0.99 (first: 35.0±7.0 kg; and second: 34.9±6.9 kg) and inter-rater reliability of ICC(2,1)=0.99 (Rater A: 35.0±7.0 kg; and Rater B: 35.0±7.0 kg) were achieved. In Bland-Altman analysis, the 95% confidence interval for the mean difference between 2 measurement values was as follows: intra-rater 1RM: –0.05 to 0.15; and inter-rater 1RM: –0.09 to 0.13. The Pearson product-moment correlation coefficient for the difference between 2 measurement values and their mean was as follows: intra-rater 1RM: r=0.34 (p=0.13); and inter-rater 1RM: r=0.19 (p=0.39) (Table 1).

The reliability of 1RM measurement before and after machine improvement (Test 2) was ICC(1,1)=0.99 (1RM: 34.7±7.1 and 35.0±7.0 kg, respectively, with r<0.05). In Bland-Altman analysis, the 95% confidence interval for the mean difference between 2 measurement values ranged from –0.43 to –0.09 (Table 2).

**Discussion**

This study verified the reliability of 1RM measurement for knee extension after improving a leg extension machine using a ratchet and reliability before and after such an improvement, involving healthy adult males. High reliability was achieved after machine improvement, confirming the effectiveness of incorporating a ratchet mechanism into the leg extension machine to prevent eccentric contractions that increase the risk of causing pain. The results suggest the usefulness of this method for load-setting to increase muscle strength safely and appropriately.

After machine improvement, both the degrees of intra- and inter-rater agreement were high. Compared with the method used in a previous study to measure knee extensor strength by Tagesson and Kvist, achieving ICC(1,1)=0.90 and ICC(2,1)=0.96, the method used in the present study to measure 1RM may be highly reliable, although the device used varied between both studies. The reliability of 1RM measurement for leg extension using an improved leg extension machine was also similar to that of the method by Sugihara et al.10–12 (ICC(1,1)=0.96 and ICC(2,1)=0.95), supporting the usefulness of the former to enhance measurement safety without reducing its reliability. Shimizu and Tani16 emphasized the importance of clarifying the type and degree of bias/error, as well as the threshold of clinically allowable biases/errors, rather than simply confirming the absence of any difference in the measurement value among multiple methods/raters, when verifying the reliability or criterion-related validity of a new evaluation method. Bland-Altman analysis reportedly enables raters to examine the reliability and empirical validity of measurements, in order to confirm their clinical applicability based on the level of difference between 2 measurement values. In the present study, Bland-Altman analysis did not reveal any fixed or proportional bias in intra- or inter-rater reliability, confirming the high reliability of this method.

Although reliability between before and after machine improvement was high, with ICC(1,1)=0.99, there was a fixed bias, as the value after improvement was 0.5–1.0 kg higher in 8 of the 21 subjects. This indicates that their maximal voluntary contractions were only concentric as a result of ratchet use that omitted weight-supporting movement after knee extension. When focusing our attention, we are surrounded by diverse stimuli, but we extract only limited information from them. Being attracted or based on our own intentions, we selectively allocate our attention to specific stimuli.18 Franconeri et al.19 reported that attention is subject to the number of tasks being performed. As its amount is limited, attention is divided into multiple parts for use. As long as each part of divided attention meets the necessary requirements to process a task, the task can be accomplished. However, it has been reported that more difficult tasks require larger amounts of attention, resulting in insufficient amounts of attention allocated to other additional tasks.20 In the 1RM measurements for knee extension using weights for loading, their free fall due to the gravity tends to occur after knee extension. In the present study, the primary task was knee extension (concentric contraction), and the secondary task was

**Table 1** Intra- and inter-rater reliability of IRM measurement for leg extension after improvement of a leg extension machine

<table>
<thead>
<tr>
<th>Test</th>
<th>1RM (kg) (mean [SD])</th>
<th>Mean difference (mean [SD])</th>
<th>ICC(1,1)</th>
<th>Bland-Altman analysis</th>
<th>SEM</th>
<th>MDC95</th>
<th>LOA</th>
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<tr>
<td>a</td>
<td>35.0 (7.0)</td>
<td>0.09 (0.20)</td>
<td>0.99</td>
<td>−0.05−0.15</td>
<td>r=0.34</td>
<td>0.14</td>
<td>0.39</td>
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<tr>
<td>b</td>
<td>34.9 (7.0)</td>
<td></td>
<td></td>
<td></td>
<td>p=0.13</td>
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<tr>
<td>A</td>
<td>35.0 (7.0)</td>
<td>0.04 (0.26)</td>
<td>0.99</td>
<td>−0.09−0.13</td>
<td>r=0.19</td>
<td>0.19</td>
<td>0.52</td>
</tr>
<tr>
<td>B</td>
<td>34.7 (7.1)</td>
<td></td>
<td></td>
<td></td>
<td>p=0.39</td>
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**Table 2** Reliability of IRM measurement for leg extension after improvement of a leg extension machine

<table>
<thead>
<tr>
<th>Test</th>
<th>1RM (kg) (mean [SD])</th>
<th>Mean difference (mean [SD])</th>
<th>ICC(1,1)</th>
<th>Bland-Altman analysis</th>
<th>SEM</th>
<th>MDC95</th>
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<tr>
<td>Before 1RM</td>
<td>34.7 (7.1)</td>
<td>−0.26 (0.37)</td>
<td>0.99</td>
<td>−0.43−0.09</td>
<td>r=0.15</td>
<td>0.18</td>
<td>0.5</td>
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<tr>
<td>After 1RM</td>
<td>35.0 (7.0)</td>
<td></td>
<td></td>
<td></td>
<td>p=0.52</td>
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Before 1RM: 1RM before improvement. After improvement: 1RM after improvement. Mean difference: average and standard deviation of differences between 1RM before and after improvement. ICC: intraclass correlation coefficient. 95%CI: 95% confidence interval. Pearson: Pearson product-moment correlation coefficient. SEM: standard error of measurement. MDC95: minimal detectable change 95. LOA: limits of agreement.
weight-supporting movement after maximal leg extension (eccentric contraction). After the machine was improved to omit weight-supporting movement, attention allocation was limited to knee extension as the primary task. Consequently, only concentric contraction may have been measured as maximal voluntary contraction, increasing the measurement value.

Maximal muscle strength is determined by the cross-sectional area of the muscle as a structural factor and the excitement of motor units controlling each muscle as a functional factor. Maximal muscle strength depends on both the maximal excitation level of the muscle and the physiological cross-sectional area of the muscle.\(^{21,22}\) The former shows a certain value according to growth stage. In contrast, the value of the latter varies among individuals, and it is not necessarily certain at a given growth stage. It also shows diurnal variations, and noted that influences on muscle activity also change according to functional factors as a psychological limit.

Reliability of 1RM for improved machine

In short, on examining the reliability of 1RM measurement for knee extension after improving a leg extension machine to extract only concentric contractions and reliability before and after such an improvement, this method showed high reliability while ensuring safety.

**Conflicts of Interest**

The authors declare that they have no conflicts of interest.

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**References**


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