Comparison of hamstring/quadriceps ratio between isoinertial and isokinetic measurements

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Received 13 June 2012
Accepted 22 October 2012

Abstract.
OBJECTIVE: To determine the applicability and predictive accuracy of an isoinertial resistance machine for the assessment of hamstring/quadriceps conventional (concentric) ratio (CR).
METHOD: Thirty-two resistance trained young men (23.53 ± 3.2 yrs) were tested using dedicated instruments to obtain the peak torque (PT) of the right knee extensors and flexors as well as the corresponding one repetition maximum (1RM) values. All measurements were conducted in the concentric mode.
RESULTS: Significant (p < 0.05) correlations were indicated between knee extensor and flexor PT and 1RM values (r = 0.73 to 0.75), as well as between PT and 1RM CR values (r = 0.65). However the isoinertial CR values (0.42 ± 0.05) were significantly (p < 0.05) greater than their isokinetic counterparts (0.36 ± 0.04).
CONCLUSION: Caution should be used when comparing isoinertial CR with population-specific isokinetic normative scores.

Keywords: Muscle strength dynamometers, leg muscle strength, 1-repetition maximum test, muscle balance

1. Introduction

At a first glance, it would seem that issues concerning muscle strength, power and endurance are reserved primarily for athletes, since athletic performance is partially influenced by muscle action capability [1–3]. However, muscle strength is also an important aspect of health. Thus, reliable and accurate assessment of muscular function is essential for understanding the performance capacity and potential limitations of any individual. There are several methods that have been used to assess knee extensor and flexor muscle function; however isokinetic dynamometers and isoinertial resistance machines appear to be the most frequently used.

Commercially available isokinetic dynamometers have several clinical applications for injury rehabilitation, measurement of muscular torque, work, power or endurance [4]. In addition, whole-muscle function testing in human subjects is a widely used criterion measure to characterize and/or evaluate different populations. One of the most frequently assessed measurements with the isokinetic dynamometer is the ratio of antagonist/agonist peak torque (PT), as well as bilateral differences in muscular strength. These measurements are supported in the published literature as applicable variables associated with muscle balance [5–10]. Alternatively, one repetition maximum (1RM) testing is frequently used to design training programs and to assess muscle strength [11]. These assessments have been
primarily performed using free weights or isoinertial stacked plate resistance machines. Furthermore, studies have shown high reliability for isokinetic PT [12–14] and 1RM tests [15–17].

While the isokinetic dynamometer is a costly device, isoinertial free weights and stacked plate resistance machines are inexpensive and more accessible to the general population. As a result, the assessment of muscle balance by these low cost machines could be an important factor for the health professional as a significant approach to the measurement of muscle balance leading to injury prevention. Previous studies have reported a significant relationship between PT and 1RM values [18,19]; however, we are unaware of any published articles analyzing the relationship between isokinetic conventional ratio (CR) and 1RM antagonist/agonist ratio (1RM ratio). Thus, the purpose of this study was to determine the applicability and predictive accuracy of isoinertial resistance machines for assessment of the hamstring/quadriceps strength ratio using the isokinetic dynamometer as a reference method.

2. Method

2.1. Subjects

This study was approved by the Federal University of Rio Grande do Sul Institutional Review Board (protocol: 2008155). Thirty-two resistance trained (i.e., participation in resistance training during the prior 3 months) young men (23.53 ± 3.20 yrs; 178.78 ± 6.70 cm; 75.34 ± 11.22 kg) volunteered to participate. Subjects were informed of the purpose, procedures, possible discomforts, risks, and benefits of the study prior to signing a written informed consent. Participants were excluded from the study if they reported any history of cardiovascular disease, hypertension, or orthopedic disease. Subjects were instructed not to drink alcohol 48-h, or exercise 24-h, prior to testing.

2.2. Isokinetic tests

Subjects warmed-up on a cycle ergometer at 25–50 Watts for 5 minutes. Following the warm-up they performed light static stretching (15 seconds) of knee extensors and flexors. After stretching, subjects were seated on an isokinetic dynamometer and actively warmed-up the right leg muscles by performing 10–12 submaximal knee extension and flexion repetitions at 120°/s. For familiarization with isokinetic exercise, subjects performed 2 sets of 4 maximal repetitions at 60°/s with 1-min rest between sets. The familiarization session was performed 48 to 72-h before the first isokinetic test.

Isokinetic peak torque was measured on a Cybex Norm (Ronkonkoma, New York, USA) isokinetic dynamometer. Calibration of the dynamometer was performed according to manufacturer’s specifications before every testing session. Subjects sat upright with the axis of rotation of the dynamometer arm oriented with the lateral femoral condyle of their femur. Belts were used to secure the thigh, pelvis, and trunk to the dynamometer chair to prevent additional body movement. The chair and dynamometer settings were recorded to ensure the same positioning for all tests. The flexor torque produced by the relaxed segment was used for gravity correction. Subjects were instructed to fully extend and flex the knee and to work maximally during each set of exercise. The angular extension and flexion range of motion of the knee was 0° (full knee extension) to 90° (flexion). Seated hip angle was 85° (0° full extension).

The testing protocol consisted of one set of five reciprocal repetitions of concentric knee extension and flexion at 60°/s. Verbal encouragement was given throughout the testing session. The conventional ratio (CR) consisted of knee flexor concentric PT divided by knee extensor concentric PT [6,8]. All testing procedures were measured on the right leg. The procedures were administered to all subjects by the same investigator.

2.3. One repetition maximum (1RM) strength test

A 1RM knee extension and flexion test was conducted on an isoinertial stacked plate resistance machine to determine maximal knee extension and flexion strength. The test protocol recommended by Baechle and Earle [20] was adopted as follows: 1) a warm-up involved 5–10 repetitions at 40–60% of the estimated 1RM, 2) one minute rest with light static stretching (15 seconds) of knee extensors and flexors followed by 3–5 repetitions at 60–80% of the estimated 1RM, and 3) three to five attempts to reach the 1RM with 3 to 5-min rest intervals between each new lift. The maximum weight that was successfully lifted was recorded. Before the 1RM test, the 1RM values were estimated through the number of repetitions performed according to the Lombardi table [21]. 1RM testing was assessed unilaterally with a total range of motion of 90° (flexion of 0° until 90°, where 0° is complete knee extension). The exercise order was randomized and
the movement velocity was controlled by a metronome (Wittner, Quartz) (1.5 seconds concentric and 1.5 seconds eccentric actions). The data were analysed after correction of the 1RM value for the lever arm length of the knee extension isoinertial machine (1RM values in kg multiplied by the length of the lever in m). The 1RM ratio consisted of the corrected 1RM knee flexor value divided by the corrected 1RM knee extensor value. The tests were repeated on all subjects, 48 hours after the first 1RM test, to estimate day-to-day reliability.

2.4. Statistical analyses

The normality of all values, as well as the residual scores normality were verified by the Shapiro Wilk statistic. The Pearson correlation test \( r \) was used to verify the relationship between variables. Dependent \( t \)-tests were used to evaluate any differences between the mean isokinetic CR and the mean 1RM ratio. Also, the Bland and Altman [22] method was used to analyze the individual residual scores for each method. The limits of agreement between isokinetic and isoinertial were identified using 95% confidence intervals. Linear regression modeling was subsequently employed to identify adjustments for comparison between isokinetic CR and 1RM ratio and also to develop an equation to estimate CR from the 1RM test. In addition, test/re-test reliability was assessed for all variables and data were analyzed by intraclass correlation coefficient (ICC). All statistical procedures were performed with the Statistical Package for Social Sciences (SPSS) version 17.0 (SPSS Inc., Chicago, IL). Significance was set at \( p \leq 0.05 \).

3. Results

The test/re-test reliability was assessed for all variables and the results ranged 0.75–1.00. The mean hamstring and quadriceps muscle strength from the refer-

| 1RM ratio | 0.42 (± 0.05)* |
| Conventional ratio | 0.36 (±0.04) |

\*Pearson correlation: statistical significance. PT: peak torque; IRM: one repetition maximum.

Fig. 1. Correlation between CR and 1RM ratio. \( r = 0.65; p < 0.001 \). 1RM: one repetition maximum, CR: conventional ratio.

The relationship between peak torque (PT) values assessed by the isokinetic dynamometer and 1RM strength values of the isoinertial equipment are presented in Table 2. The correlation coefficients ranged 0.73–0.75 \( (p < 0.05) \).

The relationship between CR from the reference method and 1RM ratio for the knee extensors and flexors from the right leg are presented in Fig. 1. The correlation coefficient was 0.65 \( (p < 0.05) \). Residual scores were also calculated for each participant by subtracting the 1RM ratio from the respective CR reference measure. The residuals were analyzed using the Bland and Altman [22] method to determine the percentage of participants whose CR was correctly estimated within \( \pm 2 \) Standard Deviations (Fig. 2). The correlations between residual scores and average of both methods were not significant \( (r_{y, res} = 0.153, p > 0.05) \).

The results of the regression analyses demonstrated that an equation using the 1RM ratio explained 50% of the variance observed \( (F = 28.83; p < 0.001) \) in the isokinetic CR. Thus, further modeling analysis indicated the use of a regression equation adjustment \( Yi = \)

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(β_0 + β_1 \times X_i + \varepsilon_i) \) to estimate CR by using the β constant and the β_1 1RM ratio values. The following equation was derived:

\[
\text{Conventional ratio} = [0.17 + (0.44 \times \text{1RM ratio}) + 0.03]
\]

4. Discussion

The purpose of this study was to determine the applicability and predictive accuracy of an isoinertial resistance method for assessment of knee extensor and flexor strength and the hamstring/quadriceps conventional ratio (CR) using isokinetic dynamometry as a reference method. We found a good relationship between isoinertial 1RM strength and isokinetic PT. However, it appears that the isoinertial method significantly overestimated (0.42) the isokinetic reference CR values (0.36) in this sample. This overestimation could be related to either knee flexors sub-estimation or knee extensors overestimation on the isoinertial machine. These results could also be related to joint torque capability differences provided by the variable-cam isoinertial knee extensor and knee flexor machines. Folland and Morris [23] reported that the angle-torque relationship of different training machines was highly variable, but consistently less curvilinear and significantly different from knee extensor capabilities, with changes in torque varying from 2.5 to 22.2% (ascending limb) and 37.6 to 20.5% (descending limb).

The relationship between isokinetic and 1RM muscle strength has been the subject of a few studies. Gulick et al. [18] compared knee extensor isokinetic PT with 1RM strength using the isotonic mode on a Cybex isokinetic dynamometer. They compared PT, total work, and work from the best repetition with 1RM, but found that only 1RM correlated with PT \((r = 0.67)\). Their results are in agreement with the present study, although we found slightly higher correlations with the knee extensors \((r = 0.75)\). Another and more recent study that investigated the correlation between knee extension 1RM and isokinetic PT was Verdijk et al. [19]. They also assessed the validity of specific knee extension 1RM testing by comparison with isokinetic dynamometry in a heterogeneous population (elderly and young subjects of both genders). Similar to the present study, all participants performed 1RM tests on an isotonic leg extension machine. Additionally, isometric and isokinetic knee extension PT was determined at along a velocity spectrum. Akin to the present results, 1RM strength correlated strongly with the dynamometric results. Although our results were similar, we tested PT at 60°/s and they tested at higher velocities (> 120°/s). We used 60°/s because this is the most used velocity to assess maximum PT production during an isokinetic protocol [6,9,24–28]. In addition, Gulick et al. [18] and Verdijk et al. [19] only examined correlations of the knee extensors. The present study also reported a strong correlation \((r > 0.70)\) between isokinetic knee flexion PT and 1RM strength. Thus, it appears that the
isoinertial 1RM test is a good measure of strength for both knee extensors and flexors.

Furthermore, the higher correlations in the present study may be due to the control of movement velocity during the 1RM test. The movement velocity in the present study for both 1RM isoinertial tests was controlled by a metronome (1.5 s concentric and 1.5 s eccentric). This velocity was selected to correspond to the duration of each repetition at 60°/s. It is well established that 1RM strength is dependent on movement velocity [11,29,30]. Sakamoto and Sinclair [11] investigated the effect of movement velocity on the relationship between loading intensity and the number of repetitions during a bench press. Subjects performed bench presses on a Smith machine at 5 different intensities (40–80% 1RM), repeated for 4 velocity conditions. Velocity significantly changed the relationship between intensity (%1RM) and the number of reps performed, with faster velocities producing a greater number of repetitions. The superior number of repetitions suggests that the benefit of using the stretch-shortening cycle during faster movements outweighs the associated disadvantages of the force/velocity relationship.

Hatfield et al. [30] investigated the impact of a very slow velocity and a self-selected volitional velocity at varying intensities on number of repetitions, peak force, peak power, and total volume in the squat and shoulder press exercises. Subjects performed significantly fewer repetitions in the very slow exercise while peak force and power were significantly higher at the volitional velocity. Also, the volitional velocity elicited higher total volume than the very slow velocity. Thus, it was concluded that a very slow velocity may not elicit appropriate levels of force. Recently, González-Badillo and Sánchez-Medina [29] examined the possibility of using movement velocity as an indicator of relative load in the bench press exercise. They reported a very close relationship between mean propulsive velocity and 1RM load (R² = 0.98). Mean velocity attained with 1RM was the same, independent of individual changes in 1RM strength. Thus, it was concluded that the movement velocity during 1RM and muscular endurance tests was also an important variable to be controlled [11, 29, 30]. In addition, the control of movement velocity can decrease the inter-individual differences during isoinertial resistance tests.

A number of studies have investigated the CR as an important variable when assessing muscle balance [5, 9, 24–28, 31] and risk of injury [5,6,8]. The relationship between CR and 1RM ratio in the present study was significant (r > 0.60). These results point out to the possibility of using the isoinertial machine to assess the muscle balance of concentric knee flexors and extensors. However, the isoinertial method significantly overestimated the isokinetic reference CR values in this sample. Thus, using isoinertial ratio values when comparing population-specific isokinetic normative scores could lead to misinterpretation. To minimize this error and to render the results of the present study more applicable, we developed a regression equation to correct the 1RM ratio values. For example, a 0.45 right leg 1RM ratio, is analogous to 0.39. This corrected CR value, compared to the normative scores, suggests lower balance between knee extensors and flexors [6].

Some authors do not consider the CR a functional method to assess muscle balance [5,7,25]. They assume that imbalances between the agonist and antagonist muscles of the knee should be assessed by the DCR: Hecc/Qcon. However, although Magalhães et al. [31] suggested that the CR was also an important parameter to evaluate risk of injury, the fact that eccentric knee flexion was not assessed in the present study could be considered a limitation. Therefore, we suggest that eccentric isokinetic and 1RM functional ratios should be assessed in future studies.

5. Conclusions

The results of this study demonstrate that muscle strength and muscle balance can be measured by a controlled movement velocity 1RM isoinertial testing procedure. This is important to exercise and health professionals since lower cost equipment such as isoinertial machines may be reliably used to assess and monitor changes in muscle function, while the method may be a good screening tool in sports medicine and sports training environments. However, the derived ratio should be handled with care given the deviation from the isokinetically derived findings.

References


