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One-repetition maximum test and isokinetic leg extension and flexion: Correlations and predicted values

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Abstract. The most typical maximum tests for measuring leg muscle performance are the one-repetition maximum leg press test (1RMleg) and the isokinetic knee extension/flexion (IKEF) test. Nevertheless, their inter-correlations have not been well documented, mainly the predicted values of these evaluations. This correlational and regression analysis study involved 30 healthy young males aged 18–24y, who have performed both tests. Pearson's product moment correlation between 1RMleg and IKEF varied from 0.20 to 0.69 and the more exact predicted test was to 1RMleg ($R^2 = 0.71$). The study showed correlations between 1RMleg and IKEF although these tests are different (isotonic vs. isokinetic) and provided further support for cross determination of 1RMleg and IKEF by linear and multiple linear regression analysis.

Keywords: One-repetition maximum test, isokinetic dynamometer, correlation, regression analysis

1. Introduction

There are many different instruments and methods used to measure muscle performance. Among these instruments, the isokinetic dynamometer (ID) and the isotonic one-repetition maximum test (1RM) are reported as an instrument and a method gold standard, respectively [1–4]. Noteworthy whereas the first is known as a closed kinetic chain (CKC) type exertion, the second is known as open kinetic chain (OKC) although strictly speaking it is not (the lever arm of isokinetic dynamometer closes the chain). Thus a more accurate description would be multiple (isotonic) vs. single (isokinetic) joint exertion. It should be equally noted that whereas the resistive force in the isotonic effort changes its direction relative to the knee, in isokinetic efforts of the knee the resistive force remains substantially perpendicular to the shank [5,6].

The 1RM isotonic test is defined as the maximum load that a subject is able to lift only once when the technique of the given exercise is performed correctly. The test does not require a clinical environment or a laboratory and does not involve specific technical means. Generally, these tests utilize the same equipment used in subject's workout daily, such as leg press [3,4]. In ID the maximum performance is verified in the chosen muscle group too; the velocity of movement is always constant (isokinetic) and provides important information about muscle performance, typically to the Peak Torque (PT) [1,7–9].

The load of 1RM isotonic test or its percents obtained from maximum repetitions, and/or aligned to muscle

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performance ID evaluations are widely reported in the scientific literature [2,4,6,7,10–13]. These tests allow a specific muscle performance evaluation and both may quantify muscle functional capacity [14] and can direct rehabilitation programs of muscle groups that have suffered functional loss [7].

However, isotonic and isokinetic movements involve mechanical constraints which are likely to lead to specific and different neuromuscular responses [15]. Thus, some studies have examined the correlations between functional performance tests [16–19] and functional and isokinetic strength loss [20].

In the face of paucity of data relating to correlations between muscle performance in isotonic CKC and isokinetic OKC and cross prediction relationships [4] we undertook to explore these issues using linear and multiple linear regressions analysis.

2. Method

This study was based on 30 males aged 18–24 years (mean $\pm$ SD age, 21.0 $\pm$ 2.20 years; height 1.79 $\pm$ 0.05 m; body mass 76.70 $\pm$ 10.46 Kg; body mass index 23.83 $\pm$ 2.68). We recruited the subjects from the Federal University of São Carlos, Brazil. Inclusion criteria were as follow: (1) healthy males aged between 18 and 28 years; (2) have a body mass index lower than 26 Kg/m^2; (3) have a beginner and/or moderately trained pattern of physical activity, i.e., performed some physical activity with non-competitive aim between 1–3 times a week [10,21]. Subjects were excluded if they showed the following: (1) previous injury of femoral quadriceps or hamstring muscles (6 months prior to study); (2) osseous or articular disorder in lower limbs; (3) problems or any disease in cardiovascular system; (4) systemic disease, as diabetes mellitus; (5) being under medicine prescription or dietary supplement use (such as muscle mass builders).

All subjects were informed about the study purposes and procedures. Prior to participation, all subjects signed an informed consent approved by the Institutional Review Board at Federal University of São Carlos, Brazil.

2.1. Instruments

A Tanita body composition analyzer (model TBF-310 – Tokyo, JPN) was used to determine body mass (BM) and body mass index (BMI). A leg press with an incline of 45° (Reforce, São Paulo, BRA) was used for the 1RMleg test and a goniometer (ISP – Instituto São Paulo, São Paulo, BRA) was used to determine knee flexion angle in the 1RMleg test. In addition, a computerized isokinetic dynamometer (Biodex, Multi-Joint System III – New York, NY, USA) was used to register IKEF variables such as knee extensor and flexor torque.

2.2. Procedures

All evaluations took place at the Isokinetic Evaluation Laboratory and Physiology of Exercise Laboratory of the Federal University of São Carlos. Subjects were instructed not to change their normal physical routine and eating habits for the seven days prior the tests and not to drink alcoholic beverages.

IKEF evaluation was performed in the morning and recorded the knee peak torque extensor (PT.ext.), knee angle in peak torque extensor (A.PT.ext.) and knee peak torque flexor (PT.flex.). However, all variables derived from PT were considered. In the afternoon of the same day was conducted the 1RMleg test.

2.3. IKEF evaluation

A brief warm-up was carried out for 5 min on a cycle ergometer (*Ergo-FIT* – model Ergo 167 Cycle, Pirmasens, Germany) with 100 W load and speed between 60–70 rpm. Next, the subjects were positioned on the isokinetic dynamometer, which had been previously calibrated. The subjects stood properly aligned and stabilized with straps in order to avoid possible compensatory movements, in accordance with the guidelines of the device. The evaluation was performed only on the subject dominant lower limb, and alignment was made with the lateral epicondyle of the femur. The hip was in 80° flexion and the level arm of the equipment was set approximately 1cm above the tibial malleolus. Parameters such as chair height, backrest distance, seat level, and dynamometer base were adjusted for each subject.

Before the actual test familiarization took place in the form of 3 submaximal voluntary concentric muscle contractions along the full range of standardized and pre-programmed motion (90°–20°), with a constant angular velocity of 60°/s. After a 3-min rest, the test began with two sets (separated by a 3-minute interval) of five maximal voluntary concentric reciprocal femoral quadriceps and hamstring contractions (Fig. 1A). The subjects were encouraged verbally and visually to achieve maximum effort. Only those repetitions with a coefficient of variation of less than 10% were accepted [22].

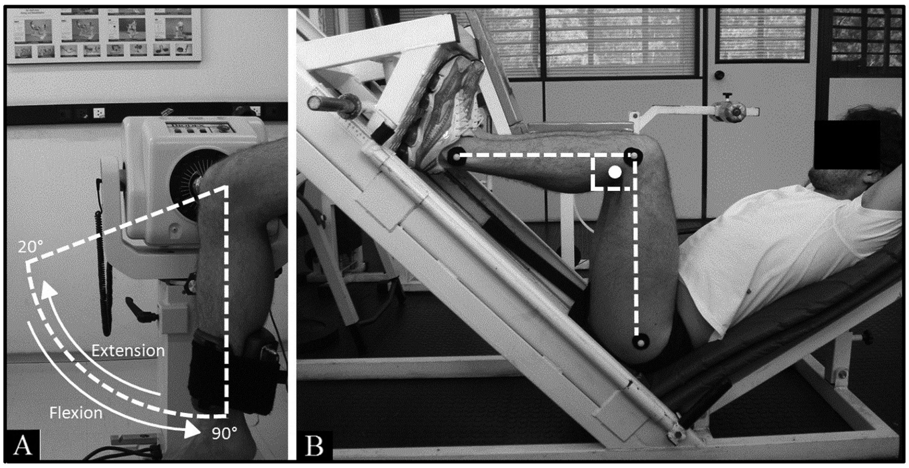

Fig. 1. A) Range of motion developed in the Isokinetic Dynamometer evaluation. B) Subjects positioning in the one-repetition maximum leg press test and knee angle flexion.

Table 1
Descriptive values of IKEF and 1RMleg of the subjects – Mean (SD)

Variable	Average ± SD	Range
1RMleg (Kg)	363.3 ± 75.2	260 to 470
PT.ext. (N.m)	253.5 ± 37.3	191.5 to 293.6
Avg.PT.ext. (N.m)	245.1 ± 37.6	186.4 to 287.6
Avg.TW.ext (J)	1,008.6 ± 161.4	800.9 to 1,119.6
Avg.TPow.ext. (W)	159.1 ± 22.7	126.3 to 179.1
A.PT.ext. (°)	63.0 ± 4.7	55 to 68.5
PT.flex. (N.m)	126.6 ± 18.0	104.6 to 158.9
Avg.PT.flex. (N.m)	124.3 ± 17.5	103.9 to 156.3
Avg.TW.flex. (J)	548.6 ± 72.2	476.6 to 688.0
Avg.TPow.flex. (W)	85.3 ± 10.3	76.2 to 105.2

Abbreviations. 1RMleg: one-repetition maximum leg press test; IKEF: isokinetic dynamometry test of knee extensor and flexor muscles; PT.ext.: knee peak torque extensor; Avg.PT.ext.: average of knee peak torque extensor; Avg.TW.ext.: average of knee total work extensor; Avg.TPow.ext.: average of knee total power extensor; A.PT.ext.: knee angle in peak torque extensor; PT.flex.: knee peak torque flexor; Avg.PT.flex.: average of knee peak torque flexor; Avg.TW.flex.: average of knee total work flexor; Avg.TPow.flex.: average of knee total power flexor; m: meter; Kg: kilogram; N.m: Newton.meter; J: Joule; W: Watts; °: degree.

2.4. 1RMleg evaluation

There was a brief warm-up period of five minutes on a cycle ergometer (*Ergo-FIT* – model Ergo 167 Cycle, Pirmasens, Germany) with 100W load and speed between 60–70 rpm. The test was standardized by defining the subject's lower limb extension identifying 90° knee flexion (using the goniometer) and marking the position (in centimeters) corresponding to this angle on the leg press machine. The proposed range of motion was 0° (full knee extension, start) to 90° (finish). The anatomical references for the identification of the desired angle were the greater trochanter and lateral epicondyle of the femur and the malleolus of the fibula of the same lower limb (Fig. 1B). Test familiarization consisted of 10 repetitions with a load estimated at less than 60% of 1RMleg. This hypothetical load was indentified in accordance with the level of physical effort by that subject during the familiarization period, following OMINI scale (0 equal extremely easy and 10 equal extremely hard) [23]. The loads increments for indentifying 1RMleg were added in terms of percentage of the load in the familiarization period, and depended on the subject's score on the OMNI scale. The load choices were limited to 5 attempts, separated by 5-min intervals to avoid metabolic disorders and the impairment of test quality. The subjects were encouraged verbally to achieve maximum effort.

We conducted a pilot study to establish the reliability of the 1RMleg test and IKEF. Six subjects were tested in two different moments separated by 5-day interval with procedures randomized. The $ICC_{3,1}$ was used to evaluate intra-evaluator reliability and the Standard Error of Measurement (SEM) in order to describe the measurement precision. The results expressed as ICC (SEM) were 0.89 (5.15 N.m) for PT.ext.; 0.83 ($< 1°$) for A.PT.ext; 0.85 (2.93 N.m) for PT.flex. and 0.99 ($<$1 Kg) for load of the 1RMleg.

2.5. Data analysis

Descriptive values (means, standard deviations) for each variable were first obtained. Next, data were analyzed with respect to their statistical distribution using the Shapiro Wilks W test. Pearson's product moment

Table 2
Pearson's product moment correlations between 1RMleg and IKEF

	IKEF (extensor)				
	PT.ext. (N.m)	Avg.PT.ext. (N.m)	Avg.TW.ext. (J)	Avg.TPow.ext.(W)	A.PT.ext. (°)
1Rmleg	0.58	0.65	0.44	0.51	0.58
	IKEF (flexor)				
	PT. flex. (N.m)	Avg.PT.flex. (N.m)	Avg.TW.flex. (J)	Avg.TPow.flex. (W)	
1RMleg	0.55	0.64	0.69	0.14	

Abbreviations. 1RMleg: one-repetition maximum leg press test; IKEF: isokinetic dynamometry test of knee extensor and flexor muscles; PT.ext.: knee peak torque extensor; Avg.PT.ext.: average of knee peak torque extensor; Avg.TW.ext.: average of knee total work extensor; Avg.TPow.ext.: average of knee total power extensor; A.PT.ext.: knee angle in peak torque extensor; PT.flex.: knee peak torque flexor; Avg.PT.flex.: average of knee peak torque flexor; Avg.TW.flex.: average of knee total work flexor; Avg.TPow.flex.: average of knee total power flexor; N.m: Newton.meter; J: Joule; W: Watts; °: degree.

correlation was used to determine the relationships between 1RMleg and IKEF variables.

In order to predict the 1RMleg and IKEF, mathematical models were proposed by multiple linear regression analysis using Pearson's product moment correlations. The assumptions were as follow: a) the independent variables (or predictors variables) correlate in a significant mode with the dependent variable (or response variable) to be predicted; b) the independent variables do not present collinearity when verified by the variance inflation factor (VIF) and statistical tolerance (1/VIF) tests [24]; c) the mathematical model do not present influent cases when verified by Cook's distance test [24]; d) the residuals do not present independent errors when verified by the Durbin-Watson test [24].

Using the residuals it was possible to calculate the mean confidence interval (CI) of the predicted values for the response variables (mean CI = mean of −95%CI and mean of +95%CI).

Each independent variable was then added hierarchically to the mathematical model according to its degree of correlation with response variable. For the accuracy of the mathematical models we considered the R^2 parameter. Pearson's product moment correlations indices and R^2 were considered as follows: $0.70 \leqslant r < 0.90$ equivalent to a strong relationship; $0.40 \leqslant r < 0.69$ equivalent to a moderate relationship and $0.20 \leqslant r < 0.39$ equivalent to a weak relationship [25]; with an alpha level of 0.05. All statistical analysis was conducted using Statistica software (version 7; StatSoft, Inc., Tulsa, OK, USA), and the SPSS software (version 17, SPSS, Inc., Chicago, IL, USA).

3. Results

Descriptive values for IKEF and 1RMleg are presented in Table 1. All statistically significant correlations were positive. The Pearson's product moment correlations between IKEF and 1RMleg were moderate (Table 2).

Table 3
Multiple linear regression analysis for the 1RMleg from the IKEF variables

Independent variable (s)	Parameter estimate	Standard error	P[d]
Step 1[a]			
Avg.TW.flex.	0.37	0.08	< 0.001
Step 2[b]			
Avg.TW.flex.	0.25	0.07	0.003
Avg.PT.ext.	0.81	0.25	0.003
Step 3[c]			
Avg.TW.flex.	0.19	0.07	0.011
Avg.PT.ext.	0.76	0.21	0.001
A.PT.ext.	5.24	0.54	0.002

Abbreviations. 1RMleg: one-repetition maximum leg press test; IKEF: isokinetic dynamometry test of knee extensor and flexor muscles; Avg.TW.flex.: average of knee total work extensor; Avg.PT.ext.: average of knee peak torque extensor; A.PT.ext.: knee angle in peak torque extensor.
a) R^2: 0.43, $p < 0.001$ (for model at this step);
b) R^2: 0.58, $p < 0.001$ (for model at this step);
c) R^2: 0.71, $p < 0.001$ (for model at this step);
d) For each variable at each step.

The mathematical models proposed using multiple linear regression analysis for 1RMleg (dependent variable) involved all independent IKEF variables with significant correlations. After identifying Avg.TW.flex., Avg.PT.ext. and A.PT.ext. as the independent variables with better correlation indices and free of collinearity, the regression mathematical model for 1RMleg was calculated: R = 0.84; $R^2 = 0.71$ [$(F_{3,26} = 21.61)$, $(p < 0.001)$], VIF = 1.13 (lower than 10) [24], 1/VIF = 0.88 (higher than 0.1) [24]. Residuals of this regression analysis were considered normal, non-correlated or did not present independent errors (Durbin-Watson = 1.93 – between 1.65 and 2.35) [24] and influential cases (maximum Cook's distance = 0.12 – lower than 1). The regression analysis steps (1–3) are shown in Table 3. The confidence intervals (CI) are shown in Table 4.

Table 4
Prediction of dependent variables by multiple linear regression analysis, accuracy of mathematical model (R^2) and Average Confidence Interval (CI) for each equation predicted

Predicted variable	Predicted equation	Accuracy (R^2)	Average CI
1RMleg (Kg)	[−252.35 + 0.75 * Avg.PT.ext. + 5.24* A.PT.ext. + 0.19 * Avg.TW.flex.]	0.71	336.82 to 381.83 (Kg)
PT.ext.(N.m)	[136.58 +0.29 * 1RMleg]	0.33	230.93 to 254.51 (N.m)
Avg.PT.ext.(N.m)	[96.01+ 0.35 * 1RMleg]	0.42	212.67 to 236.08 (N.m)
Avg.TW.ext. (J)	[549.76 + 1.19 * 1RMleg]	0.19	910.00 to 1047.72 (J)
Avg.TPow.ext.(W)	[82.81 +0.19 * 1RMleg]	0.25	144.92 to 164.10 (W)
A.PT.ext.(°)	[48.78 + 0.04 * 1RMleg]	0.34	62.35 to 65.67 (°)
PT.flex.(N.m)	[45.02 + 0.25 * 1RMleg]	0.29	123.50 to 145.94 (N.m)
Avg.PT.flex.(N.m)	[30.77 + 0.25 * 1RMleg]	0.35	113.64 to 133.13 (N.m)
Avg.TW.flex. (J)	[139.35 + 1.15 * 1RMleg]	0.43	517.07 to 592.17 (J)

Abbreviations. 1RMleg: load of one-repetition maximum leg press test; PT.ext.: knee peak torque extensor; Avg.PT.ext.: average of knee peak torque extensor; Avg.TW.ext.: average of knee total work extensor; Avg.TPow.ext.: average of knee total power extensor; A.PT.ext.: knee angle in peak torque extensor; PT.flex.: knee peak torque flexor; Avg.PT.flex.: average of knee peak torque flexor; Avg.TW.flex.: average of knee total work flexor; Kg: kilogram; N.m: Newton.meter; J: Joule; W: Watts; °: degree.

The predictions of IKEF variables based on independent variable (1RMleg) were performed such as process described earlier. Residuals of these regressions analysis were considered normal, non-correlated or did not present independent errors (Durbin-Watson varied from 1.50 to 2.30 – between 1.48 and 2.52) [24] and did not present influential cases (maximum Cook's distance varied from 0.02 to 0.03 – lower than 1) [24]. All mathematical models involved only one dependent variable (1RMleg) and thus there was no collinearity [24]. In addition, it was not possible to establish a significant mathematical model of linear regression analysis for the Avg.TPow.flex. based on 1RMleg.

The methodology for evaluating 1RMleg and IKEF involved two legs and one leg, respectively. The correlations between 1RMleg and IKEF (one leg or two legs) had the same values, i.e. the fitting curve had the same inclination, as illustrated in Fig. 2.

4. Discussion

The results obtained from the isokinetic knee extension/flexion tests agree with previous studies regarding angle of peak torque [7,9,26] as well as the PTs [4,7]. Regarding the 1RMleg evaluation, the present study demonstrated higher values than those reported previously [4,27] possibly because the current subjects were younger or due to the use of a different RoM: 0° (full knee extension – start) to 90° (knee flexion – finish).

The correlations between 1RMleg and knee extensor muscles were moderate, which partially agrees with Verdijk et al. [4] who have used a test velocity of 120°/s instead of the current 60°/s. In this study the confidence interval ranged 0.62–0.89.

The correlations between knee flexor muscles and 1RMleg were highest compared to knee extensor muscles. A possible explanation for this finding is related to co-contractions between the knee extensors and flexors. The hamstring may contribute in restraining hip flexion during the lowering of the load. In addition, other hip joint muscles (such as the gluteus maximus) may assist in extending the hip joint during the initial concentric phase of the 1RMleg test. Following this phase the hamstring can be more effective in extending the hip joint, offsetting the attenuated torque generated by shortening of the gluteus maximus (concentric phase of 1RMleg test) [28].

As for predicting 1RMleg and IKEF our results seem to be more accurate than those reported in previous studies [22,29]. The multiple linear regression analysis for 1RMleg involved Avg.PT.ext., A.PT.ext., and Avg.TW.flex. (independent variables). The A.PT.ext. and Avg.PT.ext. variables are justified by relationship to the best angle for development of higher torque of the femoral quadriceps [26].

The Avg.TW.flex. represents the amount of work produced by knee flexor muscles (hamstrings) during IKEF. This work is calculated by the area of torque curves vs. displacement [22,29]. Then, based on the above hypotheses concerning the hamstring and its relationship with 1RMleg, if Avg.TW.flex presents a high value, the 1RMleg will possibly present a high value too.

The mathematical models of all IKEF predictions varied from weak to moderate ($R^2 = 0.19$ to 0.43) using the 1RMleg such as only predictive variable. The moderate correlations between IKEF and 1RMleg may point out to an influence of the specificity of the exercise involving angle of execution, type of exercise

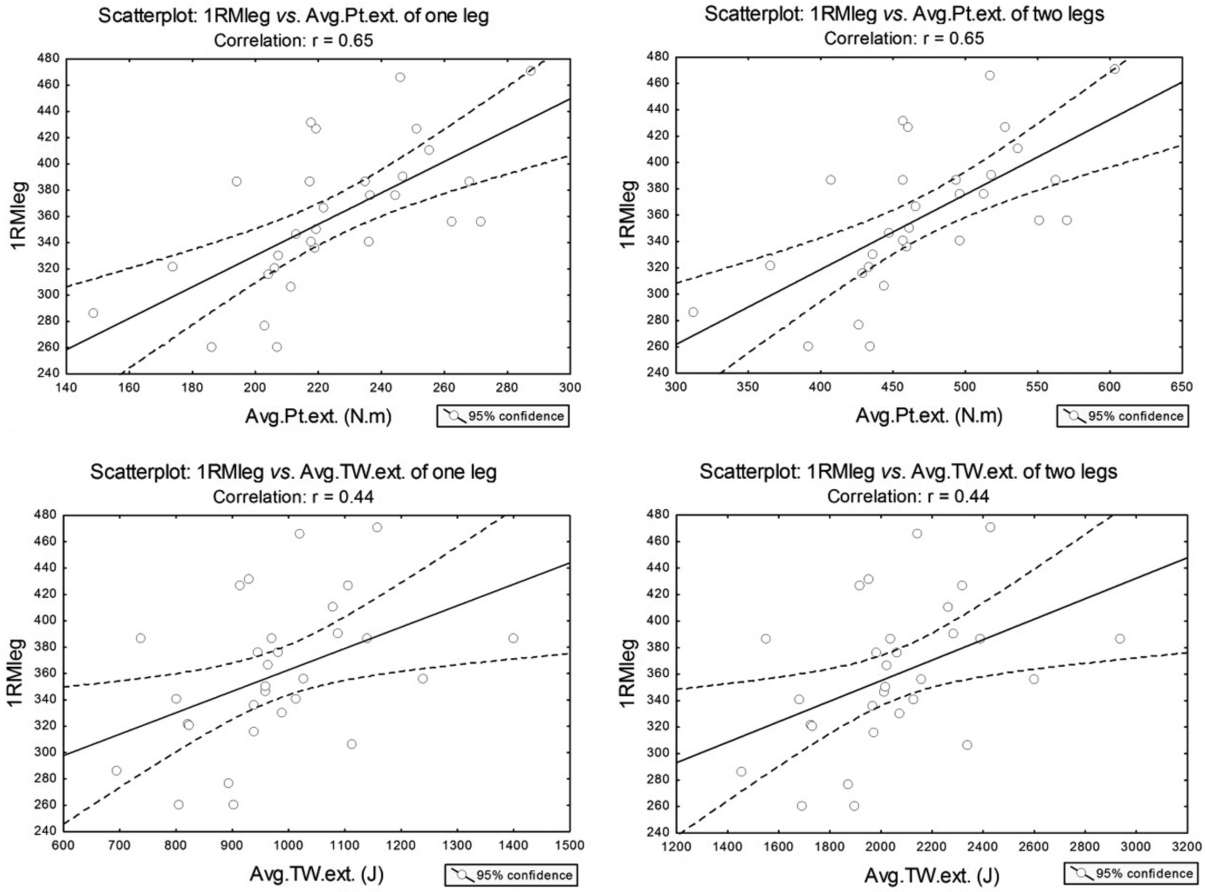

Fig. 2. Simulated Pearson's product moment correlations between 1RMleg (two legs) and IKEF for two legs (both lower limbs). Abbreviations. 1RMleg: load of one-repetition maximum leg press test; IKEF: isokinetic dynamometry test of knee extensor and flexor muscles; Avg.PT.ext.: average of knee peak torque extensor; Avg.TW.flex.: average of knee total work flexor.

performed (CKC vs. OKC) and the speed of movement (isotonic vs. isokinetic) [4,30,31].

Exercises conducted in CKC and OKC have different muscle recruitment patterns [32]. CKC has a greater EMG activity of vastus medialis and vastus lateralis in knee extension exercise than OKC knee extension exercises [32]. In addition, isotonic movement involves a variable angular velocity and it is supposed to induce a greater load on the neuromuscular system only at points of the range of motion that have biomechanical disadvantages, whereas other angles with biomechanical advantages do not require the maximal capacity of neuromuscular system [33]. In contrast, the isokinetic mode implies a maximal load throughout [33].

The weak to moderate correlations between IKEF (OKC) and 1RMleg (CKC) underlie the specificity of the effort [4,30,31,33–35]. In addition, these correlations may suggest a small transfer of muscle performance gains between isotonic CKC and isokinetic OKC exercises, or vice versa, such as demonstrated by Augustsson et al. [36].

A single knee test (IKEF evaluation) was sufficient to predict bilateral 1RMleg with high accuracy; the correlations between 1RMleg and IKEF (one or two legs) had the same values, since the fitted curve had the same inclination (Fig. 2). This result may potentially have a clinical implication as patients with e.g. selected lesion of the hips or ankles may be evaluated in indirect mode for 1RMleg.

4.1. Limitations

The study imitations are related to the sample size, the gender and age. Thereby these findings may not be valid for older populations or female subjects. Another limitation is the exclusion of isokinetic parameters reflecting gluteus maximus performance. This could potentially increase the mathematical model accuracy (higher R^2).

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