Postprint: Predictive Ability of Isokinetic Strength Testing for Knee Extension 1RM

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Abstract

Background Muscle strength training is an important component of rehabilitation. Scientific and rational strength training exercise prescriptions are typically established based on percentages of isotonic one-repetition maximum (1RM). However, accurate 1RM is difficult to obtain in practice, and patients often experience reduced efficiency of muscle strength training and delayed recovery of overall function due to the lack of appropriate resistance training prescriptions. Objective To investigate the predictive capability of isokinetic muscle strength testing for knee extension 1RM and to establish 1RM prediction equations based on isokinetic muscle strength testing results. Methods From March to June 2024, 61 healthy volunteers were recruited as the subject group through online platforms and promotional posters. Knee joint isokinetic muscle strength testing and knee extension 1RM testing were performed at an angular velocity of 60°/s to collect peak torque (PT), peak force (PF), and 1RM. Pearson correlation analysis was used to analyze the correlation between PT, PF, and 1RM, and simple linear regression was used to establish 1RM prediction equations. Bland-Altman plots were used to evaluate the agreement between predicted and measured values from the 1RM prediction equations. Results Among the 61 subjects, there were 23 males with a mean age of (25.6$\pm$6.0)$years and 38 females with a mean age of$(24.5±$5.3) years. Correlation analysis results showed that PT and PF values were positively correlated with 1RM in both males and females (P<0.05). The 1RM prediction equations based on PF values were y=0.07x+1.836, R2=0.514 for males and y=0.087x+0.858, R2=0.781 for females; the 1RM prediction equations based on PT values were y=0.177x+0.25, R2=0.386 for males and y=0.312x+0.464, R2=0.766 for females. Bland-Altman test results showed that the 95% limits of agreement (LOA) for the PT-based 1RM prediction equations were (-8.37~14.81) kg for males and (-4.47~9.33) kg for females; the 95% LOA for the PF-based 1RM prediction equations were (-5.29~10.82) kg for males and (-4.12~8.87) kg for females. The PF-based 1RM prediction equations demonstrated better agreement. Conclusion Both PT and PF values obtained from isokinetic muscle strength testing equipment can be used to predict knee extension 1RM values, with PF values demonstrating superior predictive capability for 1RM compared to PT values.

Full Text

Research on the Predictive Ability of Isokinetic Strength Testing for Knee Joint Extension 1RM

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Abstract

Background Muscle strength training is an important component of rehabilitation. Scientific and reasonable strength training exercise prescriptions are typically established based on percentages of the one-repetition maximum (1RM). However, accurate 1RM values are difficult to obtain in practice, and patients often lack appropriate resistance training prescriptions, which reduces the efficiency of muscle strength training and delays overall functional recovery.

Objective To investigate the predictive ability of isokinetic strength testing for knee extension 1RM and to establish a 1RM prediction equation based on isokinetic test results.

Methods From March to June 2024, 61 healthy volunteers were recruited as the test group through online platforms and promotional posters. Isokinetic knee strength testing and knee extension 1RM testing were performed at an angular velocity of 60°/s, collecting peak torque (PT), peak force (PF), and 1RM values. Pearson correlation analysis was used to examine the relationships between PT, PF, and 1RM, and simple linear regression was employed to establish 1RM prediction equations. Bland-Altman plots were constructed to evaluate agreement between predicted and measured 1RM values.

Results Among the 61 subjects, 23 were male with a mean age of (25.6±6.0) years, and 38 were female with a mean age of (24.5±5.3) years. Correlation analysis revealed that both P
0.05). The 1RM prediction equations based on PF values were: males $y = 0.07x + 1.836$, $R^{2} = 0.514$; females $y = 0.087x + 0.858$, $R^{2} = 0.781$. The equations based on PT values were: males $y = 0.177x + 0.25$, $R^{2} = 0.386$; females $y = 0.312x + 0.464$, $R^{2} = 0.766$. Bland-Altman analysis showed that the 95% limits of agreement (LOA) for PT-based equations were (-8.37~14.81) kg for males and (-4.47~9.33) kg for females, while for PF-based equations they were (-5.29~10.82) kg for males and (-4.12~8.87)

kg for females. The PF-based 1RM prediction equation demonstrated better agreement.

Conclusion Both PT and PF values obtained from isokinetic strength testing equipment can be used to predict knee extension 1RM values, with PF demonstrating superior predictive ability compared to PT.

Keywords Knee joint; Prediction equation; One-repetition maximum; Isokinetic motion; Peak torque; Peak force

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Quadriceps weakness is a common functional impairment following knee injury or surgery that significantly affects patient function and athletic performance. Scientific and reasonable resistance training programs are crucial for improving quadriceps weakness. Currently, resistance training exercise prescriptions are typically established based on percentages of isotonic one-repetition maximum (1RM), which provides excellent guidance for strength training. Although 1RM testing is considered one of the best methods for baseline measurement of maximal strength, practical limitations exist, including psychological apprehension about the test itself, fatigue from multiple testing sets before reaching 1RM, complex and time-consuming procedures, and high loads that place substantial stress on joints. These issues have limited the widespread clinical application of 1RM testing. Consequently, patients rarely undergo 1RM testing before resistance training and often lack appropriate resistance training prescriptions, which greatly affects the efficiency of strength training and overall functional recovery. Therefore, it is necessary to develop an accurate, time-efficient, and safe method for estimating 1RM.

Isokinetic strength testing is a widely used and accepted method for maximal strength assessment in clinical practice. With its excellent repeatability, precision, and safety, isokinetic testing is considered the "gold standard" for muscle strength evaluation. Isokinetic testing provides maximal accommodating resistance throughout the entire range of joint motion based on the subject' s actual strength, precisely quantifying muscle force without causing excessive load or injury. While isotonic 1RM testing provides the maximal load for a complete repetition of a given movement, isokinetic testing measures peak torque (PT) and peak force (PF)—the maximal torque and force produced by muscles during constant-velocity movement. Since 1RM, PT, and PF all reflect maximal muscle contraction capacity, this study compared knee extension 1RM test results with isokinetic knee extension PT and PF values to investigate the correlations between isokinetic PT and 1RM and to establish regression equations, thereby developing a safer and more efficient method for obtaining isotonic 1RM values to guide strength training.

1.1 Study Subjects

From March to June 2024, 61 healthy volunteers were recruited as the test group through online social platforms and promotional posters in Shanghai. Sample size calculation was performed using linear regression analysis, with sample size as the dependent variable and knee extension PT values or PF values as independent variables. According to the 10 EPV (events per variable) rule, a minimum sample size of 10 was required, resulting in final inclusion of 61 subjects (23 males, 38 females). Based on the same 10 EPV rule, an additional 40 healthy volunteers (20 males and 20 females) were recruited as a validation group for predictive equation validation.

Inclusion criteria: (1) Healthy adults; (2) Age 20-40 years.

Exclusion criteria: (1) History of severe neurological, endocrine, psychiatric, cardiopulmonary disease, or drug or alcohol abuse; (2) Recent muscle injury or surgery; (3) Participation in vigorous physical activity within one week before testing.

This study was approved by the Ethics Committee of Shanghai Sixth People' s Hospital (Approval No.: 2024-KY-138[K]), and all volunteers were informed of the study procedures and voluntarily signed informed consent forms.

1.2 Methods

1.2.1 General Data Collection Before strength testing, general information including sex, age, height, body mass, and lever arm length was collected. Height and body mass were measured using an SH-200G medical stadiometer (Zhengzhou Shanghe Electronic Technology Co., Ltd.). Lever arm length was measured using an NX A8-3 isokinetic dynamometer (Guangzhou Yikang Medical Equipment Industrial Co., Ltd.) as the length from the lateral femoral condyle to a point 1.5 cm above the line connecting the medial and lateral malleoli.

1.2.2 Isokinetic Knee Strength Testing Isokinetic strength testing of a randomly selected knee joint was performed using the NX A8-3 isokinetic dynamometer. Participants visited the testing site one week before the formal test to familiarize themselves with the testing procedures and experience the testing process. Before formal testing, subjects performed a 10-minute light-load warm-up on an Ergoselect 100P cycle ergometer (Shanghai Nuocheng Medical Technology Co., Ltd.).

During testing, subjects were seated on the isokinetic dynamometer with the hip flexed to 80°, the lateral femoral condyle aligned with the dynamometer axis, and the lower end of the lever arm fixed 1.5 cm above the line connecting the medial and lateral malleoli. The trunk, pelvis, tested-side thigh, and non-tested-side lower leg were securely stabilized. The knee joint range of motion was set from 10° to 90° of flexion, and gravity correction was performed to adjust for the influence of lower leg and lever arm weight on knee extension PT values. Before formal testing, four familiarization trials (including one maximal and three submaximal isokinetic contractions) were performed at the same angular velocity. Subjects performed five trials at an angular velocity of 60°/s. The PT value producing maximal knee extension was recorded throughout the testing process. PF values were calculated using the formula: Force = Torque / Lever Arm.

1.2.3 Knee Extension 1RM Testing The 1RM test for the same lower limb was performed using the isotonic mode of the NX A8-3 isokinetic dynamometer one week after the isokinetic strength test at the same time of day. The 1RM test was conducted according to methods described by TAGESSON et al. [?] and MACHT et al. [?]. Subjects first performed two warm-up sets at 20%-30% of body weight (10 repetitions per set with 3 minutes rest between sets). Subjects extended their knee from 90° flexion to 10° flexion, held the extended position for 1 second, then returned to 90° flexion in a controlled manner. After warm-up, weight was increased by 4-20 kg for the next repetition with 5 minutes rest between attempts. This procedure was repeated until subjects could complete only one repetition; the weight successfully lifted on the final attempt was considered the subject' s 1RM. The number of attempts should be within 3-5; if more than 5 attempts were required, subjects rested adequately before adjusting the load and retesting.

1.3 Statistical Analysis

Data analysis was performed using SPSS 20.0 software. Normally distributed continuous variables were expressed as ($\bar{x}$±s). The Shapiro-Wilk test was used to assess normal distribution of isokinetic knee extension PT values, PF values, and 1RM data. Pearson correlation analysis was used to examine relationships between PT values, PF values, and 1RM. Simple linear regression was used to establish 1RM prediction equations. GraphPad Prism 10.1 software was used to generate Bland-Altman plots to evaluate agreement between predicted and actual 1RM values. Statistical significance was set at $P<0.05$.

2.1 General Characteristics

The test group consisted of 61 subjects, including 23 males with a mean age of (25.6$±6.0)*years*, *meanbodymassof*(70.2±7.1)*kg*, *meanheightof*(175.9±6.7)*cm*, *andmeanleverarmlengthof*(3
cm.

2.2 PT, PF Values and 1RM Measurements in the Subject Group

In the male subjects, mean PT value was (185.8$±35.2)*N*·*m*, *PFvaluewas*(590.5±110.7)*N*, *and*1*RMvaluewas*(5
m, *PFvaluewas*(428.6±96.4)*N*, *and*1*RMvaluewas*(41.0±$9.5) kg.

2.3 Correlation Between Isokinetic Knee Extension PT, PF Values and 1RM

Correlation analysis revealed that isokinetic knee extension PT and PF values were positively correlated with 1RM in both males and females ($P<0.05$) .

Correlation analysis between PT and PF values of isokinetic knee extension and 1RM

2.4 1RM Prediction Equations

Simple linear regression analysis was performed with 1RM as the dependent variable and PT as the independent variable to establish 1RM prediction equations: males y=0.177x+0.25, R^2=0.386; females y=0.312x+0.464, R^2=0.766.

Simple linear regression analysis was performed with 1RM as the dependent variable and PF as the independent variable to establish 1RM prediction equations: males y=0.07x+1.836, R^2=0.514; females y=0.087x+0.858, R^2=0.781.

2.5 Agreement Analysis Between Measured and Predicted 1RM Values

Bland-Altman analysis showed that the 95% limits of agreement (LOA) for PT-based 1RM prediction equations were (-8.37~14.81) kg for males and (-4.47~9.33) kg for females. For PF-based 1RM prediction equations, the 95% LOA were (-5.29~10.82) kg for males and (-4.12~8.87) kg for females. The PF-based prediction equation demonstrated relatively smaller bias between predicted and measured 1RM values, indicating better agreement [Figure 1: see original paper].

[Figure 1: see original paper] Bland-Altman plot of measured and predicted values of 1RM prediction equation based on PT and PF values

The number of individuals with sports injuries is increasing, and selecting appropriate training loads based on 1RM is valuable for functional recovery of weakened muscles. This study predicted knee extension 1RM through isokinetic strength testing and established regression models for knee extension 1RM based on isokinetic PT and PF values, enabling safe 1RM estimation for individuals with knee injuries unsuitable for 1RM testing. This study provides prediction equations for isotonic knee 1RM based on isokinetic test results, facilitating clinical selection of appropriate resistance training loads for patients, improving strength training efficiency, and accelerating rehabilitation progress.

Previous studies have often overestimated 1RM values using prediction equations based on isokinetic or isometric test results [?]. Our findings showed that while measured and predicted 1RM values demonstrated good fit, the 1RM prediction equations based on isokinetic measurements tended to slightly underestimate individual 1RM values by approximately 2-3 kg on average. This discrepancy may be attributed to differences in 1RM testing methodology. Previous studies testing isotonic 1RM did not adequately stabilize the trunk and pelvis, whereas isokinetic or isometric testing fixed these positions to facilitate force production. This may have prevented subjects from generating maximal contractions during 1RM testing due to insufficient stability [?, ?]. In our study, identical stabilization was used for both isokinetic and isotonic testing, allowing subjects to achieve greater muscle contraction potential.

Furthermore, our results indicate that PF values predict knee extension 1RM more accurately than PT values, with lower mean errors. The PF-based prediction equations showed relatively smaller bias and narrower 95% confidence intervals compared to PT-based equations, with larger correlation coefficients. This may be because PT values are influenced not only by individual strength but also by lever arm length [?], whereas PF values exclude the effect of lever arm length and better reflect muscle force. Therefore, PF-based prediction equations provide more accurate 1RM predictions. Our study also found that females demonstrated better correlations between isokinetic measurements and isotonic 1RM, with more accurate prediction equations than males. This may be due to physiological differences in muscle composition between males and females [?, ?], which is the primary reason for establishing separate prediction equations for each sex.

Limitations

This study has several limitations. First, although determining an individual' s maximal strength can facilitate design of more individualized (1RM-based) rehabilitation protocols for strength gains, our participants were young, healthy individuals without recent knee injury, limiting generalizability to populations with knee injuries. Future studies should explore these prediction equations in patients with knee injuries (such as anterior cruciate ligament reconstruction) to establish more population-specific equations. Second, our subjects were aged 20-40 years; other age groups were not represented, limiting prediction accuracy for other age ranges. Third, to establish clinically practical prediction equations, we used only isokinetic measurements as independent variables. Other factors that may influence 1RM values, such as body fat percentage and BMI, were not included, which may limit prediction accuracy. Future research should focus on populations with knee injuries, adolescents, and elderly individuals, and incorporate additional factors such as body fat and BMI that could improve predictive ability during equation development.

Conclusion

Isokinetic strength testing equipment can be used to safely predict individual isotonic knee extension 1RM values, providing convenience for rehabilitation programs that use percentages of 1RM to determine exercise loads. Clinicians and coaches can use the prediction models generated in this study to estimate patient or athlete 1RM values and select appropriate resistance for training to help achieve muscle strengthening goals. Future studies should collect additional data to validate and further refine these prediction models.

Author Contributions: ZHAI Naisheng, HUANG Lihua, and ZHANG Ye conceptualized the research, designed the study proposal, and formulated the research questions. ZHANG Ye conducted the experiments and implemented the research process. ZHAI Naisheng collected data, performed data cleaning and statistical analysis, generated figures, and drafted the manuscript. ZHAI Naisheng and ZHANG Ye revised the final version and take responsibility for the manuscript.

Conflicts of Interest: None declared.

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Note: Figure translations are in progress. See original paper for figures.