Correlation between the 8-repetition maximum test and isokinetic dynamometry in the measurement of muscle strength of the knee extensors: A concurrent validity study

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ABSTRACT

The 8-repetition maximum test has the potential to be a feasible, cost-effective method of measuring muscle strength for clinicians. The purpose of this study was to investigate the concurrent validity of the 8-repetition maximum test in the measurement of muscle strength by comparing the 8-repetition maximum test to the gold standard of isokinetic dynamometry. Thirty participants (15 males and 15 females, mean age = 23.2 years [standard deviation = 1.0]) underwent 8-repetition maximum testing and isokinetic dynamometry testing of the knee extensors (at 60, 120, and 240 degrees per second) on two separate sessions with 2–3 days between each mode of testing. Linear regression was used to assess the validity by comparing the findings between 8-repetition maximum test and isokinetic dynamometry testing. Significant correlations were found between the 8-repetition maximum and isokinetic dynamometry peak torque at each testing velocity ($r = 0.71–0.85$). The highest correlations were between the 8-repetition maximum and isokinetic dynamometry peak torques at 60 ($r = 0.85$) and 120 ($r = 0.85$) degrees per second. The findings of this study provide supportive evidence for the use of 8-repetition maximum testing as a valid, alternative method for measuring muscle strength.

INTRODUCTION

Muscle strength is defined as the amount of force that a muscle or muscle group can produce during contraction. The assessment of muscle strength is a common component of the physical examination when the clinician is evaluating a patient for impairments and physical disabilities (American Physical Therapy Association, 2001). The findings of previous research studies indicate that muscle strength is directly associated with meaningful outcomes such as physical function and athletic performance (den Ouden, Schuurmans, Arts, and van der Schouw, 2011; Manty et al, 2012; Wisloff et al, 2004). Furthermore, improvement in muscle strength has been correlated to an increase in physical function (Liu and Latham, 2009). Thus, valid procedures for measuring muscle strength are important.

A number of methods for assessing muscle strength exist. One technique for evaluating muscle strength is isokinetic dynamometry testing. During isokinetic dynamometry testing, a person performs one or more contractions of an isolated muscle group while the dynamometer provides precise resistance to control the velocity of contractions so that each contraction is performed at a specific velocity. The measurement of muscle strength using isokinetic dynamometry is often expressed as peak torque at a specific velocity of contraction. Isokinetic dynamometry has high reliability, validity, and is considered the “gold standard” for measuring muscle strength (American College of Sports Medicine, 2006; Drouin et al, 2004; Hartmann, Knols, Murer, and deBruin, 2009). However, a practical limitation to the utilization of isokinetic dynamometry in a clinical setting is the financial cost of the equipment (approximately $40,000).

An alternative method for measuring muscle strength is repetition maximum testing, such as the
The 1-repetition maximum test has been described as the “gold standard” for isotonic muscle strength measurement (American College of Sports Medicine, 2006). The results of previous studies indicated that the 1-repetition maximum test is a reliable and valid means of evaluating muscle strength and has been correlated to isokinetic dynamometry (Levinger et al, 2009; Schroeder et al, 2007; Verdijk, van Loon, Meijer, and Savelberg, 2009). To conduct the 1-repetition maximum test, an individual performs a repetition of an exercise while the resistance is progressively increased until a resistance is determined that will allow only one repetition. The 1-repetition maximum is defined as the maximum amount of resistance that can be performed for only one repetition. Some clinicians and researchers have expressed the preference for potentially safer methods of measuring muscle strength that do not require an individual to attempt a repetition using a maximum resistance (Verrill and Bonzheim, 1999). Although the findings of previous studies indicate that 1-repetition maximum testing can be performed safely in numerous populations (Kaelin et al, 1999; Levinger et al, 2009; Schroeder et al, 2007), other research have reported rare occurrence of injuries during 1-repetition maximum testing (Shaw, McCully, and Posner, 1995). Professional organizations have suggested multiple-repetition maximum testing as an alternative to 1-repetition maximum testing, an example of which is the 8-repetition maximum test (American College of Sports Medicine, 2009; Marwick et al, 2009; Williams et al, 2007).

The 8-repetition maximum test is a multiple-repetition maximum test during which a person performs eight repetitions of an exercise as the resistance is gradually increased until a resistance is determined where only eight repetitions can be performed. In contrast to the 1-repetition maximum test, the 8-repetition maximum test does not require a person to attempt a repetition using a maximum resistance. The results of the study by Taylor and Fletcher (2012) indicate that the 8-repetition maximum test is reliable (intraclass correlation coefficient ≥0.90). The 8-repetition maximum test has also been used in intervention studies to simultaneously measure changes in muscle strength and prescribe a resistance training intensity, based on the 8-repetition maximum (Larose et al, 2010; Swank et al, 2010). Yet, data related to the correlation between the 8-repetition maximum test and the gold standard of isokinetic dynamometry have not been published. In fact, the validity of the 8-repetition maximum test in assessing muscle strength may be negatively influenced by the muscle fatigue effect of such a test if adequate recovery time during testing is not provided, meaning the increase in muscle work required for the test would likely require greater energy expenditure (Scott, Leary, and Tenbraak, 2011).

The 8-repetition maximum test may serve as a feasible and cost-effective option for clinicians to concurrently determine an intensity for resistance training and measure muscle strength. However, 8-repetition maximum testing has not been compared to isokinetic dynamometry so that appropriate concurrent validity can be determined. The purpose of this study was to investigate the concurrent validity of the 8-repetition maximum test in the measurement of muscle strength by evaluating the correlation between the findings of the 8-repetition maximum test and isokinetic dynamometry testing.

METHODS

Study design

This investigation used a concurrent validity research design to examine the validity of the 8-repetition maximum test in the evaluation of muscle strength. To investigate the concurrent validity, each participant underwent 8-repetition maximum testing and isokinetic dynamometry testing with 2–3 days (48–72 hours) between each mode of testing. For all participants, isokinetic dynamometry testing was conducted during the first testing session, and 8-repetition maximum testing was conducted during the second testing session. The variable of the 8-repetition maximum was compared to peak torque outcomes from isokinetic dynamometry testing.

Study setting and participants

This study was conducted on the campus of the University of Central Arkansas in Conway, Arkansas, United States of America. Participants were recruited from the central Arkansas geographic area by study announcements to employees and students of the University of Central Arkansas and through word-of-mouth.

Only participants who had no contraindications to exercise were included in this study. Participant exclusion criteria were: 1) history of a medical condition identified by the American Heart Association as an absolute contraindication to exercise testing (Gibbons et al, 2002); 2) angina (stable or unstable); 3) uncontrolled hypertension; 4) proliferative retinopathy; 5) severe peripheral neuropathy; 6)
nephropathy; 7) autonomic neuropathy; 8) diabetes; or 9) unable to participate in this study due to a physical impairment. To control for the potential confounding variables of gender and age, an equal number of men and women between the ages of 20 and 29 years were included. Each participant was required to complete a written, informed consent form. This study was approved by the University of Central Arkansas Institutional Review Board.

Isokinetic dynamometry testing

Isokinetic dynamometry testing of the knee extensors on the dominant side of the body was assessed using a Biodex System 4 isokinetic dynamometer (Biodex Medical Systems, Inc., Shirley, NY, USA). The dominant side was defined as the side on which the lower extremity that the participant reportedly used for kicking was located. Participants were tested concentrically at 60, 120, and 240 degrees per second through a range of motion of 90 degrees of knee flexion to full knee extension and positioned according to the recommendations of the manufacturer of the dynamometer, which included the use of a thigh stabilization strap. All participants were instructed to refrain from any form of resistance or aerobic training within at least 48 hours of isokinetic dynamometry testing. Prior to testing, a familiarization consisting of one repetition at 50%, 75%, and 100% of maximal effort to produce a maximal contraction at 60 degrees per second was completed (three total repetitions). After a 2-minute rest period, participants performed a set of three repetitions at 100% maximal contraction effort at each testing velocity with a 2-minute rest period between each set. Participants were randomly assigned by a computer to one of two orders of testing velocities. The first order of testing was 60, 120, and 240 degrees per second and the other order of testing was 240, 120, and 60 degrees per second. These two orders of testing velocities were used to counterbalance and avoid order effects of testing velocity. During each repetition, the tester provided the participants with verbal instructions to give a maximum effort. Also, each participant viewed his or her torque production curve on a computer monitor during each repetition and was instructed to attempt to produce a higher torque during each subsequent repetition while viewing the curve. The highest peak torque of the three repetitions was recorded for each testing velocity. Muscle strength was expressed as peak torque in Newton-meters. All isokinetic dynamometry tests were conducted by a tester who was trained on the isokinetic dynamometry testing procedures. The results of previous research indicate that isokinetic dynamometry testing, as described in this study, is reliable (intraclass correlation coefficient = 0.81–0.99) (Drouin et al, 2004; Hartmann, Knols, Murer, and de Bruin, 2009).

8-Repetition maximum testing

For the purpose of collecting 8-repetition maximum test data, the 8-repetition maximum test was conducted using an isotonic resistance training machine. Specifically, the machine utilized for 8-repetition maximum testing was a knee extension machine, the Cybex VR3 Leg Extension (Cybex International, Medway, MA, USA). The knee extension machine was selected for 8-repetition maximum testing in order to test the same muscle group (knee extensors) in the same knee joint position that was used during isokinetic dynamometry testing.

As in the case of isokinetic dynamometry testing, the 8-repetition maximum testing was conducted on the knee extensors on the dominant side of the body. The 8-repetition maximum test procedures used by Taylor and Fletcher (2012) were replicated. All participants were instructed to refrain from any form of resistance or aerobic training within at least 48 hours of 8-repetition maximum testing. Immediately prior to 8-repetition maximum testing, each participant performed a familiarization session using the knee extension machine. During the familiarization session, a resistance (weight) perceived by the participant to be “somewhat easy” to perform for one repetition while gripping the knee extension machine handles was determined. A thigh stabilization strap was not used since it was not a component of the knee extension machine. Stabilization was achieved by the participant holding the handles while positioned in the machine seat with his or her upper torso against the backrest of the seat. Each participant then practiced using the knee extension machine until he or she demonstrated proper technique for a total of eight consecutive repetitions using the “somewhat easy” resistance. After familiarization, the resistance was progressively increased until an 8-repetition maximum was determined. The knee extension machine allowed an increase in resistance as small as 2.27 kilograms (5 pounds). The progression of increase in resistance was based on each participant’s perceived exertion with the goal of measuring the 8-repetition maximum in 3–6 attempts. During each attempt, each participant was instructed to perform exactly eight repetitions while giving a maximal effort. The 8-repetition maximum was defined as the maximum amount of resistance (weight) that was performed for eight repetitions. For example, if a
participant performed eight repetitions of a selected resistance and could subsequently complete only seven repetitions using a slightly greater resistance, the resistance used during the prior attempt, where eight repetitions were performed, was used to record the 8-repetition maximum. The mean number of attempts in determining the 8-repetition maximum was 3–4. The rest period between each attempt was 2–3 minutes. All 8-repetition maximum tests were conducted by a tester who was trained on the testing procedures. The tester also observed to assure that each participant maintained proper exercise technique during testing. Although the reliability of these procedures have not been investigated using the knee extension machine, the findings of previous research suggest that these 8-repetition maximum testing procedures are reliable (intraclass correlation coefficient ≥0.90) using various types of resistance training equipment (chest press, row, pull-down, overhead press) (Taylor and Fletcher, 2012).

Statistical analyses

Linear regression at an α level of 0.05 was used to evaluate the concurrent validity of the 8-repetition maximum test and to derive peak torque prediction equations based on the 8-repetition maximum. Scatter plots with linear regression lines were used to visually illustrate the correlation between isokinetic dynamometry at each testing velocity and 8-repetition maximum testing. The Pearson correlation coefficient (r) was used to assess the relationship between the 8-repetition maximum and peak torque at each testing velocity. The coefficient of determination (r^2) was utilized to indicate the percent of the total variance in peak torques explained by the 8-repetition maximum scores. Statistical analyses were conducted using PASW 17.0 for Windows (SPSS, Inc., Chicago, IL, USA).

An a priori power analysis was conducted to estimate the number of participants needed to obtain a statistical power of 0.90 at an α level of 0.05. The a priori power analysis estimated a sample size of 30 participants would detect a correlation greater than 0.50 with a statistical power of at least 0.90 at an α level of 0.05.

RESULTS

Thirty people (15 males and 15 females, mean age = 23.2 years [standard deviation = 1.0]) participated in this study. The participants’ mean body mass, height, and body mass index were 73.9 kilograms (standard deviation = 11.0), 171.9 centimeters (standard deviation = 8.1), and 25.0 kilograms/meter^2 (standard deviation = 3.3), respectively. No adverse events occurred during this study other than temporary delayed onset of muscle soreness after 8-repetition maximum testing. Temporary delayed onset of muscle soreness was expected to occur after 8-repetition maximum testing due to the combined concentric and eccentric muscle actions and was not considered a significant adverse event. Participants did not report delayed onset of muscle soreness prior to 8-repetition maximum testing.

Means and standard deviations for 8-repetition maximum, actual peak torque, and predicted peak torque scores (based on the 8-repetition maximum) are reported in Table 1. Significant correlations were found between the 8-repetition maximum test and isokinetic dynamometry (Table 2). Linear

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<th>Table 1 8-Repetition maximum and peak torque scores.</th>
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8-RM, 8-repetition maximum; PT–60, peak torque at 60 degrees per second; PT–120, peak torque at 120 degrees per second; PT–240, peak torque at 240 degrees per second.

<table>
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<th>Table 2 Correlation between 8-repetition maximum test and isokinetic dynamometry peak torque scores.</th>
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8-RM, 8-repetition maximum; PT–60, peak torque at 60 degrees per second; PT–120, peak torque at 120 degrees per second; PT–240, peak torque at 240 degrees per second; r, Pearson correlation coefficient; SEE, standard error of the estimate (Newton-meters).
regression equations for predicting peak torque at 60, 120, and 240 degrees per second, respectively, were:

1. $23.6298 + (4.0961 \times 8\text{-}RM)$ (60 degrees/second)
2. $7.4319 + (3.5821 \times 8\text{-}RM)$ (120 degrees/second)
3. $2.3653 + (2.6149 \times 8\text{-}RM)$ (240 degrees/second)

where $8\text{-}RM = 8$-repetition maximum in kilograms. The 8-repetition maximum test explained: 73% ($r^2 = 0.73$); 73% ($r^2 = 0.73$); and 51% ($r^2 = 0.51$) of the total variance in peak torques at 60, 120, and 240 degrees per second, correspondingly. Scatter plots with linear regression lines for 8-repetition maximum test scores versus isokinetic dynamometry test scores are illustrated in Figure 1.

**DISCUSSION**

This study is the first investigation of the correlation between the 8-repetition maximum test and isokinetic dynamometry to evaluate the concurrent validity of the 8-repetition maximum test in the measurement of muscle strength. Portney and Watkins (2009) suggest that correlations ranging from 0.50 to 0.75 indicate a moderate-to-good relationship and correlation values above 0.75 are considered good to excellent. The correlation coefficient of 0.85 between the 8-repetition maximum and isokinetic dynamometry peak torque at 60 and 120 degrees per second indicates that the 8-repetition maximum test demonstrated an appropriate level of correlation to be considered a measure of muscle strength. Scatter plots also illustrated acceptable correlations between 8-repetition maximum testing and isokinetic dynamometry testing.

The finding that the 8-repetition maximum test had a higher correlation to isokinetic dynamometry testing at 60 and 120 degrees per second than 240 degrees per second might be explained by the specificity of testing. During 8-repetition maximum testing, each participant was assessed using the knee extension machine to specifically test the knee extensor muscle group in the same, open-chain knee joint position and movement that was used during isokinetic dynamometry testing. Furthermore, the velocity of muscle contraction during 8-repetition maximum testing, while not controlled, was likely closer and more specific to the isokinetic dynamometry testing velocities of 60 and 120 degrees per second than 240 degrees per second. A strong inverse relationship (Pearson $r = 0.99$) has been shown between force and velocity of muscle contraction, meaning muscle force output will increase and the velocity of concentric contraction will decrease, simultaneously, in response to an increase in external resistance (Gonzalez-Badillo and Sanchez-Medina, 2010). Thus, the specificity of testing the knee extensors in a similar manner to isokinetic dynamometry testing at 60 and 120 degrees per second...
second is likely responsible for contributing to the validity of the 8-repetition maximum test.

The results of this study are similar to the findings of previous research. A study by Verdiijk, van Loon, Meijer, and Savelberg (2009) investigated the validity of 1-repetition maximum testing in measuring muscle strength by evaluating the correlation between 1-repetition maximum testing and isokinetic dynamometry testing of the knee extensors at 120 and 240 degrees per second. The findings by Verdiijk, van Loon, Meijer, and Savelberg (2009) showed that 1-repetition maximum testing using the knee extension machine had a higher association with isokinetic dynamometry testing at 120 degrees per second (Pearson $r = 0.85$) than 240 degree per second (Pearson $r = 0.78$). The results of this present investigation found comparable correlations between 8-repetition maximum testing and isokinetic dynamometry testing at 120 (Pearson $r = 0.85$) and 240 (Pearson $r = 0.71$) degrees per second.

Previous research indicates that slower velocities of muscle contraction are associated with higher production of muscle force (Gonzalez-Badillo and Sanchez-Medina, 2010). The highest correlations in this study were between the 8-repetition maximum scores and the slower isokinetic peak torque values (at 60 and 120 degrees per second), which provides supportive evidence that the 8-repetition maximum test is a measure of muscle strength. The coefficients of determination for total variance in peak torques at 60 ($r^2 = 0.73$) and 120 ($r^2 = 0.73$) degrees per second indicates that the 8-repetition maximum test accounted for 73% of the variance and additional, unknown predictive factors existed. Such additional predictive variables could include degree of muscle fatigue or amount of energy expenditure during 8-repetition maximum testing, as an increase in muscle work requires greater energy expenditure (Scott, Leary, and Tenbraak, 2011).

The clinical implications of the findings of this study were considered. The methods for measuring muscle strength include isokinetic dynamometry testing and the 1-repetition maximum test. However, isokinetic dynamometry is cost-prohibitive for many clinics and clinicians need more cost-effective modes of evaluating muscle strength. The 1-repetition maximum test may be more cost-effective than isokinetic dynamometry, but some clinicians have reservations about using such a test due to documented injuries during testing (Shaw, McCully, and Posner, 1995). The results of this present study indicate that the 8-repetition maximum test using a more affordable knee extension machine (approximately $3,000) is strongly correlated to isokinetic dynamometry and is a valid measure of muscle strength. Clinicians may also predict peak torque for 8-repetition maximum testing using the prediction equations from this study. However, future research is needed to cross-validate these equations for predicting peak torque.

Limitations of this study include the homogenous sample and lack of inclusion of patients with physical impairments. A homogenous sample for age was selected to control for such a potential confounding variable. However, a heterogeneous sample would be desirable so that the validity of the 8-repetition maximum test could be evaluated across multiple age ranges. An inclusion criterion for this investigation was that no participant could have a contraindication to exercise. In future studies of the 8-repetition maximum test, patients with health conditions should continue to be evaluated for such contraindications before inclusion. Another limitation is that the findings of this investigation cannot necessarily be assumed for all types of resistance training equipment. Also, the responsiveness of the 8-repetition maximum test to detect change in muscle strength over time was not analyzed in this study. Future studies comparing the responsiveness to detect muscle strength change over time between the 8-repetition maximum test and isokinetic dynamometry would be valuable.

**CONCLUSION**

Muscle strength assessment is a common part of the physical examination of a patient. The valid measurement of muscle strength is important, since muscle strength has been associated with a number of meaningful outcomes. The findings of this study suggest that 8-repetition maximum testing, as described in this investigation, is strongly correlated to the gold standard of isokinetic dynamometry and can be appropriately used as a valid, alternative measure of muscle strength.

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**Declaration of interest**: The authors report no declarations of interest.

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