Predicting 1-RM isotonic knee extension strength utilizing isokinetic dynamometry

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The purpose of this study was twofold: determine which isokinetic determinants correlated best with an isotonic one-repetition maximum (1-RM) and to generate, based on these determinants a formula that will allow clinicians to utilize isokinetic testing to predict an isotonic 1-RM. Fifty female subjects, ranging from 18-35 years of age, participated in this study. Strength measurements using a Cybex II isokinetic dynamometer (peak torque, average peak torque, peak torque:body weight, work per repetition, and total work) and a Cybex isotonic knee extension machine were performed. The subject's height and body weight were recorded. Through linear regression analysis the variables peak torque and body weight were determined to be the best predictors of an isotonic 1-RM. These variables were incorporated in the following formula: Predicted 1-RM = 21.38 + (0.24 x Peak Torque) + (0.18 x Body Weight) which may utilized by clinicians to predict an isotonic 1-RM.

Keywords: Repetition maximum, isotonic, isokinetic

1. Introduction

Isometric, isotonic and isokinetic resistance exercise are widely used during rehabilitation. Debate arises as to which method is best suited toward the development of functional muscular performance. It has been suggested [5] that isokinetic exercise was more advantageous in the development of muscle strength as compared to the use of isotonics. However, some studies disagree on which type of exercise transfers best to function [3,16]. Isometric exercises have limited use with full ROM strengthening due to the fact that they only strengthen at specific joint angles. Therefore, isokinetic and isotonic exercises are the two functional options for exercising over the full ROM for a given joint.

Isotonic machines do not require time consuming, skilled set-up following the initial process of determining appropriate resistances. Clinically, this enables a client to independently perform progressive resistance training. Delorme [6] established an isotonic exercise regimen that still remains a viable method of choosing the initial resistance at which one should begin an exercise program. His program was based upon determining the weight that a person can successfully lift ten times. Others, such as Knight [10], have based their regimen on determining the maximum weight that a person can lift for six repetitions. A third option is to utilize a 1-RM to develop a starting point for a resistance program [14]. A 1-RM is defined as the maximal weight an individual can lift through the entire joint ROM one time. However, the determination of these maximal weights requires an extensive, time consuming process of trial and error [17]. In this way, it is apparent that a more efficient and scientific method for determining appropriate weights for rehabilitation exercise is needed.

With the routine use of dynamometric testing results already in place, it is logical to develop a method for using these values to approximate an isotonic 1-RM. However, “the assumption of equivalency between strength assessment modes performed . . . (on isokinetic devices) . . . with other exercise apparatuses is not well established in the research literature” [1]. Thus, limited research exists to make strength comparisons between isokinetic and isotonic equipment. It can be argued that isokinetic testing provides the most accurate
assessment of muscle strength throughout the entire range and therefore should provide a parameter that can be correlated with a 1-RM. Establishing a direct relationship via an equation between peak torque, peak torque as a percentage of body weight, best work repetition, best work repetition as a percentage of body weight, and set total work with a 1-RM would create a quick and easy way to begin progressive resistance exercise at an appropriate resistance. Many clinicians routinely test patients at various intervals during rehabilitation to document objective changes and provide reports to physicians and third party payers. A relationship between isokinetic and isotonic data will increase a therapist’s efficiency by using readily available data. Therefore, the purpose of the study was to delineate the determinants that best predict an isotonic 1-RM using regression analysis. These determinants will then be employed to develop a formula for predicting a subject’s 1-RM.

2. Methods

2.1. Subjects

The protocol for this study was approved by the University Institutional Review Board. Fifty female volunteers (mean age of 25.3 years) were recruited and gave written informed consent to participate in the study. Subjects were screened for high blood pressure (>140/90), diabetes mellitus, systemic pathology, lower extremity pathology, asthma, pregnancy, and prescription medication other than allergy or birth control via a written health questionnaire. Height, weight, and blood pressure were measured and recorded. Individuals involved in an exercise program were asked to maintain a consistent status throughout the duration of the study and were asked to refrain from exercise on the days of data collection.

The subjects were randomly assigned into two groups (Group A or B). Group A was tested first on a Cybex 6000 isokinetic dynamometer. Group B was tested first on a Cybex isotonic knee extension cam-based system. After at least a seven day rest period, Group A was then tested on the Cybex isotonic system and Group B was tested on the isokinetic dynamometer [2]. Prior to the second testing session the subjects were screened for any injuries that may have occurred following the initial testing session. A subject who experienced any symptoms other than transient muscle soreness or fatigue was withdrawn from participation in this study.

2.2. Instrumentation

The Cybex 6000 isokinetic dynamometer was used to test isokinetic knee extension strength from 90 to 0 degrees of knee flexion. The Cybex 6000 was calibrated prior to each test period according to the specifications provided by the manufacturer [4]. The same researcher read the subjects a standardized set of instructions to maintain consistency throughout the protocol. Subjects were not given visual or oral feedback regarding their performance because these types of feedback have been shown to alter isokinetic performance [9]. The seat was adjusted to align the actuator with the knee joint line. Velcro straps (Velcro USA, Inc., Manchester, NH) were utilized to immobilize the subject’s thigh and secure the ankle cuff to the distal anterior shin of the extremity being tested. The distance from the superior aspect of the tibial tuberosity to the superior border of the ankle cuff was then measured and recorded. The trunk was also stabilized utilizing the machine’s seat belt harness system. Subjects were permitted to grasp the handles of the Cybex 6000 seat.

2.3. Procedure

Each isokinetic test period began with a submaximal warm-up of ten repetitions at 60 degrees per second followed by a 2 minute rest period to allow for creatine phosphate replacement [8]. The data collection set, which were conducted at 60 degrees per second, began with three self-determined, step-like submaximal repetitions of 25%, 50% and 75% effort followed by five maximal repetitions. A speed of $60 \, ^\circ \cdot s^{-1}$ for testing knee extension strength and has proven to be the most accurate and reliable measurement of knee extension torque [11]. Isokinetic data including peak torque, peak torque as a percentage of body weight, best work repetition, best work repetition as a percentage of body weight, and set total work were collected on repetitions three, four, and five ensuring maximal
Table 1
Pearson correlations of the 1-repetition maximum with isokinetic independent variables

<table>
<thead>
<tr>
<th>Independent variable</th>
<th>Pearson's R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak torque</td>
<td>0.67</td>
</tr>
<tr>
<td>Body weight</td>
<td>0.64</td>
</tr>
<tr>
<td>Best work repetition</td>
<td>0.61</td>
</tr>
<tr>
<td>Total work for set</td>
<td>0.61</td>
</tr>
<tr>
<td>Height</td>
<td>0.48</td>
</tr>
<tr>
<td>Peak torque as a percentage of body weight</td>
<td>0.31</td>
</tr>
<tr>
<td>Total work as a percentage of body weight</td>
<td>0.21</td>
</tr>
</tbody>
</table>

Following a 2-minute rest period, a retest was conducted. The data from the two tests was removed from the Cybex 6000 central processing unit and recorded on the data collection sheet.

Isotonic testing was conducted on the Cybex knee extension cam system machine. The purpose was to determine the 1-RM of each subject's knee extension. Subjects were read standardized directions for the exercise protocol. Subjects were not given any form of feedback on their performance. Subjects were properly positioned and stabilized with Velcro straps. The distance from the superior aspect of the tibial tuberosity to the superior border of the ankle pad was measured and recorded. The subjects warmed-up with 10 lifts, that were 10 percent of their body weight. All lifts were performed through the available ROM, 110 to 0 degrees of knee flexion.

Subjects began the strength testing by lifting 40 percent of their body weight and were then asked to lift an additional six pounds with each successful lift. After two consecutive lifts, a 2-minute rest was given to the subject to allow for replenishment of creatine phosphate. This sequence continued until the subject was unable to lift the weight through the full ROM. At which point, three pounds was subtracted from the weight and the subject attempted another lift. If the subject was successful, this was considered their 1-RM. If the subject was unsuccessful, their 1-RM was the last weight they successfully lifted through the complete ROM.

3. Results

Fifty female subjects met the inclusion criteria and participated in this study. To determine whether there was a predictive relationship between the isotonic 1-RM and the isokinetic variables, a forward feed multiple regression model using SPSS statistical software (SPSS Inc., Chicago, IL) were analyzed. In this procedure, the following independent variables: height, body weight, peak torque, peak torque as a percentage of body weight, best work repetition, best work repetition as a percentage of body weight, and set total work were placed in a rank order according to their independent correlation with the dependent variable, the isotonic 1-RM. Peak torque was determined to be most highly correlated using Pearson correlations (r = 0.67).

The variable peak torque was first entered into the regression analysis ($R^2 = 0.45$) because of its high correlation. At each subsequent step, a new variable was entered into the model. If the variable provided an increased power in the explanation of the total variance of the isotonic data (indicated by an increase in the $R^2$ value), and if it was determined not to be collinear with the other variables in the equation the valuable was added to the equation. Body weight was determined to be the second most highly correlated independent variable associated with the isotonic 1-RM (Table 1). Thus, body weight was entered into the regression equation with peak torque, generating an $R^2$ value of 0.56. The variable height was subsequently entered, but it did not contribute significantly to the $R^2$ value. Therefore, our linear regression analysis was complete.

A variable was not included in the model if it possessed a high degree of collinearity with other variables being utilized in the model. Collinearity of the independent variables was examined through use of the Variance Inflation Factor (VIF). The variables best work repetition, best work repetition as a percentage of body weight, and total work were determined to have a high degree of collinearity and were eliminated from analysis. The results of the regression analysis demonstrate that an equation utilizing peak torque and body weight explained 56% of the variance observed in
Table 2
Results of linear regression analysis

<table>
<thead>
<tr>
<th>Variable</th>
<th>Beta weight</th>
<th>Standard error of beta weight</th>
<th>T</th>
<th>Significance of T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak torque</td>
<td>0.237076</td>
<td>0.058230</td>
<td>4.071</td>
<td>0.0002</td>
</tr>
<tr>
<td>Body weight</td>
<td>0.182797</td>
<td>0.053277</td>
<td>3.431</td>
<td>0.0013</td>
</tr>
</tbody>
</table>

the isotonic 1-RMs of our subjects \((F = 30.03; \ p = 0.00001)\).

By using the beta weights of peak torque and body weight displayed in Table 2, the following formula was derived which permitted prediction of a subject's 1-RM:

\[
1 \text{ RM} = 21.38 + 0.24 \times \text{Peak torque} + 0.18 \times \text{Body weight}
\]

This equation was then used with the collected data to determine the strength of its predictive value for each subject's 1-RM. The predicted values were found to be on average within 9.8 % of the actual 1-RM values.

4. Discussion

The use of isokinetic testing and isotonic resistance are major components of contemporary rehabilitation seen in many outpatient clinics. Frequently a patient's strength is determined objectively by means of isokinetic dynamometry. However, the use of this information most often stops at this point. That is, practitioners do not have a means of translating isokinetic data into a form that can be used for isotonic resistance. In this study, we focused on this disunity between isokinetics and isotonics by creating a model that predicts a subject's 1-RM using isokinetic data determined by a Cybex 6000 dynamometer on healthy female subjects. As a result of the data analysis, an equation was generated which enabled the utilization of isokinetic data and body weight measurements to closely predict a client's 1-RM without going through a laborious process of trial and error testing.

4.1. Independent variables

The current literature is devoid of any studies addressing a correlation between a 1-RM and isokinetic determinants. Peak torque, however, is known to be an excellent measure of a muscle's ability to generate tension [13]. Therefore, it is not surprising that it was found to be so highly correlated with the isotonic 1-RM. Likewise, body weight was highly correlated with a 1-RM. The importance of body weight in predicting a 1-RM is most likely attributed to its relationship to body muscle mass [8]. Muscle mass in turn is related to a person's ability to generate muscle tension.

The variables best work repetition, best work repetition as a percentage of body weight, and set total work were not as highly correlated with a 1-RM as was peak torque. These variables were found to have a high colinearity with the other variables (peak torque and body weight) already entered in the equation. Thus, adding these variables to the equation did not increase the predictive value.

It is not clear, however, why peak torque had a better correlation with the 1-RM than did these other variables. Best work repetition, best work repetition as a percentage of body weight, and set total work essentially describe the overall sum of force generated through the entire range. Peak torque simply measures the maximal tension generated at one point in the ROM. Since the Cybex isotonic knee extension machine utilizes a cam, this machine should provide maximal resistance to match the natural force production of the muscle. Hence, when one performs a 1-RM, they should be generating maximal tension throughout the full range of motion. The inability to complete a repetition indicated that a subject was unable to generate maximal tension at some point in the ROM. With a 1-RM indicative of a subject's upper limit of the capacity to generate maximal tension, perhaps peak torque may better represent this generation of maximum tension.

Height was determined to have little relationship to a subject's 1-RM. This is probably due to the fact that each machine was adjusted to the same anatomical locations on each subject. This neutralizes the potential influence of different lever arm lengths on torque production.

It would seem plausible that the variable 'peak torque to body weight ratio' would also have a great predictive relationship to a 1-RM considering it is a ratio of the two variables that were ul-
ultimately determined to be the best predictors of a 1-RM. However, peak torque to body weight ratio was determined to have little predictive value. This may be because it was a calculated ratio of the two variables whose expression as a percentage may not be as sensitive to change as the two variables.

In terms of the study limitations, there are a number of factors that can influence an individual's isokinetic and isotonic performance and several of these factors may be responsible for some of the observed variance in this study. Alterations in the positioning between different subjects can result in changes in the lever arm distance and positioning of the limb with respect to the machine's axis of rotation, thus altering biomechanical efficiency. Positioning changes may also result in changes in a subject's pelvic position and limb positioning which influence the length-relationship of the muscle group being tested [15]. With respect to the effect of system's design, structural differences in the seat angle and pad design between the Cybex isotonic leg machine and the Cybex 6000 could introduce some error. Furthermore, it is important to recognize, that velocity and gravity are parameters that are controlled for during isokinetic testing and are not easily controlled for during isotonic performance. This may be responsible for some variability. As a result of the above, until further research is performed, this formula can not be applied to other types of equipment.

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References


