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Calculation of Resistive Loads for Elastic Resistive Exercises

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ABSTRACT

Context: What is the correct resistive load to start resistive training with elastic resistance to gain strength? This question is typically answered by the clinician's best estimate and patient's level of discomfort without objective evidence. **Objective:** To determine the average level of resistance to initiate a strengthening routine with elastic resistance following isometric strength testing. **Design:** Cohort. **Setting:** Clinical. **Participants:** Thirty-four subjects (31±13yrs, 73±17kg, 170±12cm). **Interventions:** The force produced was measured in Newtons (N) with an isometric dynamometer. The force distance was the distance from center of joint to location of force applied was measured in meters to calculate torque that was called "Test Torque" for the purposes of this report. This torque data was converted to "Exercise Load" in pounds based on the location where the resistance was applied, specifically the distance away from the center of rotation of the exercising limb. The average amount of exercise load as percentage of initial Test Torque for each individual for each exercise was recorded to determine what the average level of resistance that could be used for elastic resistance strengthening program. **Main Outcome Measures:** The percentage of initial test torque calculated for the exercise was recorded for each exercise and torque produced was normalized to body weight. **Results:** The average percentage of maximal isometric force that was used to initiate exercises was 30 ± 7% of test torque. **Conclusions:** This provides clinicians with an objective target load to start elastic resistance training. Individual variations will occur but utilization of a load cell during elastic resistance provides objective documentation of exercise progression.

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INTRODUCTION

Elastic resistance training is commonly used to increase muscular strength in orthopedic and sports rehabilitation. Muscular strength gains are effectively increased through various modes such as free weights or elastic resistive bands. [1-3] A critical challenge for clinicians is to determine what resistive load should be used to begin an effective strengthening intervention, particularly when using elastic resistive modes of exercise. The isotonic literature suggests using a one-repetition maximum (1RM) to determine the appropriate load to use for strength training,[4,5] then applying a load between 50-80% of 1RM to facilitate strength gains.[6,7] Unfortunately, this approach is more suited for large muscle groups during bench press or squats which are not as applicable for rehabilitation based strengthening interventions for individuals just starting resisitive exercises or for single-joint motions. Strength testing in the rehabilitation setting is more commonly performed using isometric dynamometers and method to convert isometric strength measures to exercise resistive loads is not well established.

Currently there is a gap in the rehabilitation literature as to what specific resistive loads should clinicians prescribe for single-joint exercises used in rehabilitation. Typically patients are given specific exercises such as shoulder external rotation, not bench press, to strengthen injured shoulders. Clinicians often use isometric dynamometers instead of isotonic 1RM to evaluate strength capacity. It is unknown if 50% or another percentage should be used for prescribing resistance loads for isotonic elastic resistance exercises without compensation. Testing isometric strength makes it difficult to find a load that is then appropriate for isotonic exercise. The literature is limited in how to convert an isometric strength measurement to estimate the resistive load to begin exercises, especially with resistance bands. In order to address these and provide clinicians with a means to accurately prescribe effective isotonic elastic exercise loads following an isometric strength assessment we propose the following study with two aims: 1) to determine the average initial resistive loads used by participants performing isolated exercise motion using elastic resistance and 2) to provide a calculation and matrix for clinicians to assist in determining what loads to start their patients.

METHODS

Design and Participants

This is a cohort study undergoing a secondary analysis from another clinical trial (In process, *Journal of Strength and Conditioning Research*). The larger clinical trial examined the effectiveness of using a load cell with elastic resistance in strength gain and rate of strength gain compared to no load cell. Thirty-four healthy volunteers, 10 males and 24 females, (31±13 years, 170±12cm, 72.9±17.4 kg) signed a university approved consent form to participate in an eight week study to gain strength in their shoulders and hips. Our participants ranged in training levels from sedentary to moderately active at baseline based on measures from the Marx Shoulder Activity Scale[8] and Marx Activity Scale,[9] averaging 9±4 and 5±5 points respectively. The Marx Shoulder Activity Scale ranges from 0-20 points, a higher score indicating a more active individual. The Marx Activity Scale, a lower extremity activity scale, ranges from 0-16. The higher the score on the Marx Activity Scale the higher the activity level.

Procedures

Study participants underwent baseline isometric strength assessment prior to starting the eight week elastic resistance training program. The details of the training program are presented in the clinical trial. All elastic resistance exercises were completed using a load cell (Roylan Smart Handle®, Patterson Medical Supply, Chicago, IL, USA) to allow for a set load for each exercise. The load cell provided the participant and clinician with exact resistance load being used. The load cell provided an auditory feedback in the form of a beep when the targeted load was obtained. The auditory feedback was maintained as long as the targeted load was meet or exceeded providing some level of motivation for the patient achieve the auditory target.

Isometric Strength Testing

All strength testing was performed on the BTE Primus (BTE Technologies, Hanover, MD). Baseline strength testing for bilateral shoulder external rotation, shoulder abduction, hip abduction and hip extension was measured in Newtons (N) and the lever arm distance where force was applied from the center of joint rotation for the limb was measured in meters to determine torque produced in Newton-meters (Nm). Each participant was allowed to familiarize themselves with the strength testing positions prior to performing two maximal efforts for five seconds with thirty second rest between trials for all positions (Table 1).[10,11] Participants were instructed to gradually increase their force produced to reach maximum contraction during familiarization and testing. The average of the two trials was used to represent a participants' level of strength for each position. Procedures were repeated at subsequent two week intervals using the same instructions and positions for the 8 weeks of training. Prior to starting the study the inter-day reliability was established for testing procedures. The intraclass correlation coefficients (ICC) for average percent of body weight generated were found to be highly reliable (0.91-0.95) for all tests.

Prior to strength testing, each subject was measured with a standard cloth tape measure to determine the lever arm lengths to determine resistive exercise loads. Shoulder external rotation lever arm was the distance from third metacarpal to the lateral epicondyle. Shoulder abduction was the distance from the third metacarpophalangeal joint to acromion. Hip abduction and extension was the distance from the lateral malleolus to the top of the greater trochanter. This was a crucial part of this study to accomplish our goals. We have determined that using subject's height makes this step unnecessary and will be detailed in the discussion.

Calculation of Resistive Loads for Elastic Resistive Exercises

The primary aim of this technical report is to describe this calculation process. Multiple items had to be considered to calculate the "Exercise Load" to present as options to the participant when starting their exercise routine. The primary challenge and key clinical point is that lever arm during the exercise may not be same as lever arm during testing. Using previous established testing procedures from the literature[10,11] 3 of 4 testing positions to collect force data was different from where the exercise load would be applied during the exercises. Although not always appreciated during strength testing with a dynamometer the force generated during testing is dependent on lever arm length. Therefore, the torque generated during testing "Testing Torque" had to be converted into an understandable value for patients that we called "Exercise Load." The exercise loads could then be presented to the patients as percentages of maximal load produced to determine the average initial resistive load used during elastic resistance training, this study's primary aim.

The Test Torque in Newton-meters (Nm) was determined by multiplying the participants force (N) by the lever arm distance (m) for each of the test positions. For demonstration purposes we have selected one of our 5' 2" participants. Their values from a hip abduction test will be provided for this example. Hip abduction was tested side lying (Figure 1) and dynamometer placed just above the knee, lever arm = 0.33m. The participant averaged 517 N for their testing torque from their two trials:

Equation one: Force (517 N) x BTE Lever Arm (.33m) = Test Torque (170.6Nm)

To determine the “Exercise Load”, first, the “Test Torque” in Nm was converted to “Exercise Load” in pounds. Then we calculated multiple percentages (50%, 33%, 25%, and 15%) to determine which load was appropriate for an individual to start resistive exercises (Figure 2). The Exercise Lever Arm for hip abduction was the distance from the greater trochanter to the lateral malleolus = .73m. Converted Newtons to pounds a constant value of 4.45N was used in this conversion.

Equation two: Test Torque (170.6Nm)/Exercise Lever Arm (.73m) = (233.7N)/4.45N= “Exercise Load” (52.5lbs)

The Exercise Load was divided into 4 percentages (50%, 33%, 25%, 15%) to provide a range of values for patient.

Equation three: Exercise Load 52.5 lbs*percentage (.33) = “Resistive load” (17.3lbs)

Participants were presented loads in descending order. Participants performed exercises under supervision of certified athletic trainer and asked which load they could use to perform 3 sets of 10 repetitions with proper form at a moderate to difficult intensity. Three sets of 10 was the volume chosen for consistency in the larger study, as we did not want volume to change between subjects. The initial resistance load was recorded at baseline into an excel database.

RESULTS

To determine the average starting loads for each isotonic exercise, descriptive analysis using means, standard deviations and 95% confidence intervals were calculated from the 30 participants. The average initial resistive loads used by participants for all exercises clustered around 30 ± 7% of the maximal exercise load (Table 2). Over subsequent weeks participants worked at an increasesed percent of their baseline measure (Table 3).

DISCUSSION

This is one of the first studies to use a load cell to record the initial load used during elastic resistance exercise. This study provides the clinician with the knowledge that a starting goal of approximately 30% of maximal isometric force generated is a reasonable and appropriate load to begin a progressive resistive exercise training program. The starting loads examined were consistently 30% of maximal isometric force for all four exercises (Table 2). This adds new information that can be used in the rehabilitation setting when isometric force measures are used instead of 1RM for isotonic exercises. The use of 30% of maximal isometric force initially appears to be adequate as strength gains were observed for both upper and lower extremity muscle groups over the course of the training program. There were average strength gains ranging from 14-26% among the 30 participants (Table 3).

Current literature does not provide a means of converting an isometric strength test to an isotonic exercise. The clinician is faced with the dilemma as to how much resistance should be given for a prescribed training program. With the assistance from the load cell attached to the elastic resistance, we were able to determine that 30% of testing force appeared to be a reasonable and appropriate starting point for shoulder and hip resistive exercises. This study necessitated a means to convert an isometric torque measure to an isotonic resistive load, reiterating the importance of the lever arm. Although clinicians have access to manufactures reference loads for elastic resistance, it is typically not referred to and adding a load cell simplifies the process and provides accurate objective loads.

The isometric contraction likely accounts for the percentage used to start training. It was quickly apparent that participants could not correctly perform isotonic exercises at 50% of an isometric maximal force as it was too difficult. As mentioned previously a 1 RM is rarely appropriate in the rehabilitation setting. Isometric contractions allow for greater force being produced compared to an isotonic contraction associated with a 1 RM tests due to the force-velocity relationship .[12] This would explain why the starting loads were 30% of an isometric maximal force.

This paper provides the steps necessary to convert Test Torque to Exercise Load which was done for this project. However, all the steps and procedures are not practical in a clinical setting. Based on our observations of this study and relatively consistent starting loads around 30%, we created a clinician friendly matrix for shoulder and hip muscle strengthening exercises. (Table 4 and 5). The matrix takes into consideration the following factors, subject height, location of strength testing application, and force produced during strength testing. In this study we measured specific limb lengths; however, when we compared our measurements to published anthropometric measures,[13] we observed nearly perfectly match which allows for a simplified approach to be developed. We found that knowledge of patient height, force produced, and location of applied resistance (above elbow or knee, above wrist or ankle) then clinician can use the matrix to start resistive exercise program. There is no need for the clinician to measure the exercise lever arm individually. We chose the 5th, 50th, and 95th percentile of the male national average as heights as there was only minimal differences between men and women.[14] As demonstrated by the tables there are slight differences between heights, so for simplicity we provided only 3 heights representing 90% of the population. Using our previously mentioned participant above, at 5’ 2” with a strength measurement of 517N (116 lbs) of hip abduction, a clinician could use Table 5 to begin the participant at approximately 15.5 lbs for exercise with load at the ankle. Although this does not address all exercises it is reasonable that 30% of maximal force produced would apply to many individuals starting a resistance training program. Obviously individual variations will occur based on specific patient situations and pain levels. This study address the primary objective to provide clinicians with an average initial resistance loads for both elastic and weight training exercises following isometric strength testing.

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