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Calculation of Resistive Loads for Elastic Resistive Exercises

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1 ABSTRACT

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

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22

23

24 INTRODUCTION

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

37 Currently there is a gap in the rehabilitation literature as to what specific resistive loads
38 should clinicians prescribe for single-joint exercises used in rehabilitation. Typically patients are
39 given specific exercises such as shoulder external rotation, not bench press, to strengthen injured
40 shoulders. Clinicians often use isometric dynamometers instead of isotonic 1RM to evaluate
41 strength capacity. It is unknown if 50% or another percentage should be used for prescribing
42 resistance loads for isotonic elastic resistance exercises without compensation. Testing isometric
43 strength makes it difficult to find a load that is then appropriate for isotonic exercise. The
44 literature is limited in how to convert an isometric strength measurement to estimate the resistive
45 load to begin exercises, especially with resistance bands. In order to address these and provide
46 clinicians with a means to accurately prescribe effective isotonic elastic exercise loads following

47 an isometric strength assessment we propose the following study with two aims: 1) to determine
48 the average initial resistive loads used by participants performing isolated exercise motion using
49 elastic resistance and 2) to provide a calculation and matrix for clinicians to assist in determining
50 what loads to start their patients.

51 METHODS

52 *Design and Participants*

53 This is a cohort study undergoing a secondary analysis from another clinical trial (In
54 process, *Journal of Strength and Conditioning Research*). The larger clinical trial examined the
55 effectiveness of using a load cell with elastic resistance in strength gain and rate of strength gain
56 compared to no load cell. Thirty-four healthy volunteers, 10 males and 24 females, (31 ± 13 years,
57 170 ± 12 cm, 72.9 ± 17.4 kg) signed a university approved consent form to participate in an eight
58 week study to gain strength in their shoulders and hips. Our participants ranged in training levels
59 from sedentary to moderately active at baseline based on measures from the Marx Shoulder
60 Activity Scale⁸ and Marx Activity Scale,⁹ averaging 9 ± 4 and 5 ± 5 points respectively. The Marx
61 Shoulder Activity Scale ranges from 0-20 points, a higher score indicating a more active
62 individual. The Marx Activity Scale, a lower extremity activity scale, ranges from 0-16. The
63 higher the score on the Marx Activity Scale the higher the activity level.

64 Procedures

65 Study participants underwent baseline isometric strength assessment prior to starting the
66 eight week elastic resistance training program. The details of the training program are presented
67 in the clinical trial. All elastic resistance exercises were completed using a load cell (Roylan
68 Smart Handle®, Patterson Medical Supply, Chicago, IL, USA) to allow for a set load for each

69 exercise. The load cell provided the participant and clinician with exact resistance load being
70 used. The load cell provided an auditory feedback in the form of a beep when the targeted load
71 was obtained. The auditory feedback was maintained as long as the targeted load was meet or
72 exceeded providing some level of motivation for the patient achieve the auditory target.

73 Isometric Strength Testing

74 All strength testing was performed on the BTE Primus (BTE Technologies, Hanover,
75 MD). Baseline strength testing for bilateral shoulder external rotation, shoulder abduction, hip
76 abduction and hip extension was measured in Newtons (N) and the lever arm distance where
77 force was applied from the center of joint rotation for the limb was measured in meters to
78 determine torque produced in Newton-meters (Nm). Each participant was allowed to familiarize
79 themselves with the strength testing positions prior to performing two maximal efforts for five
80 seconds with thirty second rest between trials for all positions (Table 1).^{10,11} Participants were
81 instructed to gradually increase their force produced to reach maximum contraction during
82 familiarization and testing. The average of the two trials was used to represent a participants'
83 level of strength for each position. Procedures were repeated at subsequent two week intervals
84 using the same instructions and positions for the 8 weeks of training. Prior to starting the study
85 the inter-day reliability was established for testing procedures. The intraclass correlation
86 coefficients (ICC) for average percent of body weight generated were found to be highly reliable
87 (0.91-0.95) for all tests.

88 Prior to strength testing, each subject was measured with a standard cloth tape measure to
89 determine the lever arm lengths to determine resistive exercise loads. Shoulder external rotation
90 lever arm was the distance from third metacarpal to the lateral epicondyle. Shoulder abduction

91 was the distance from the third metacarpophalangeal joint to acromion. Hip abduction and
92 extension was the distance from the lateral malleolus to the top of the greater trochanter. This
93 was a crucial part of this study to accomplish our goals. We have determined that using subject's
94 height makes this step unnecessary and will be detailed in the discussion.

95 Calculation of Resistive Loads for Elastic Resistive Exercises

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

108 The Test Torque in Newton-meters (Nm) was determined by multiplying the participants
109 force (N) by the lever arm distance (m) for each of the test positions. For demonstration purposes
110 we have selected one of our 5' 2" participants. Their values from a hip abduction test will be
111 provided for this example. Hip abduction was tested side lying (Figure 1) and dynamometer

112 placed just above the knee, lever arm = 0.33m. The participant averaged 517 N for their testing
113 torque from their two trials:

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

115 To determine the “Exercise Load”, first, the “Test Torque” in Nm was converted to
116 “Exercise Load” in pounds. Then we calculated multiple percentages (50%, 33%, 25%, and
117 15%) to determine which load was appropriate for an individual to start resistive exercises
118 (Figure 2). The Exercise Lever Arm for hip abduction was the distance from the greater
119 trochanter to the lateral malleolus = .73m. Converted Newtons to pounds a constant value of
120 4.45N was used in this conversion.

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

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

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

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

131 RESULTS

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

137 DISCUSSION

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

148 Current literature does not provide a means of converting an isometric strength test to an
149 isotonic exercise. The clinician is faced with the dilemma as to how much resistance should be
150 given for a prescribed training program. With the assistance from the load cell attached to the
151 elastic resistance, we were able to determine that 30% of testing force appeared to be a
152 reasonable and appropriate starting point for shoulder and hip resistive exercises. This study
153 necessitated a means to convert an isometric torque measure to an isotonic resistive load,

154 reiterating the importance of the lever arm. Although clinicians have access to manufactures
155 reference loads for elastic resistance, it is typically not referred to and adding a load cell
156 simplifies the process and provides accurate objective loads.

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

164 This paper provides the steps necessary to convert Test Torque to Exercise Load which
165 was done for this project. However, all the steps and procedures are not practical in a clinical
166 setting. Based on our observations of this study and relatively consistent starting loads around
167 30%, we created a clinician friendly matrix for shoulder and hip muscle strengthening exercises.
168 (Table 4 and 5). The matrix takes into consideration the following factors, subject height,
169 location of strength testing application, and force produced during strength testing. In this study
170 we measured specific limb lengths; however, when we compared our measurements to published
171 anthropometric measures,¹³ we observed nearly perfectly match which allows for a simplified
172 approach to be developed. We found that knowledge of patient height, force produced, and
173 location of applied resistance (above elbow or knee, above wrist or ankle) then clinician can use
174 the matrix to start resistive exercise program. There is no need for the clinician to measure the
175 exercise lever arm individually. We chose the 5th, 50th, and 95th percentile of the male national
176 average as heights as there was only minimal differences between men and women.¹⁴ As

177 demonstrated by the tables there are slight differences between heights, so for simplicity we
178 provided only 3 heights representing 90% of the population. Using our previously mentioned
179 participant above, at 5' 2" with a strength measurement of 517N (116 lbs) of hip abduction, a
180 clinician could use Table 5 to begin the participant at approximately 15.5 lbs for exercise with
181 load at the ankle. Although this does not address all exercises it is reasonable that 30% of
182 maximal force produced would apply to many individuals starting a resistance training program.
183 Obviously individual variations will occur based on specific patient situations and pain levels.
184 This study address the primary objective to provide clinicians with an average initial resistance
185 loads for both elastic and weight training exercises following isometric strength testing.

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