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A Comparison of Strength and Resistance Curves for the Internal and External Rotators of the Shoulder.

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ABSTRACT

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Progressive overload through the range of motion (ROM) is important for proper rehabilitation of muscle strength yet varies across types of resistance for a given exercise. The purpose of this study was to compare strength curves (SC) for shoulder internal (IR) and external rotation (ER) with resistance curves (RC) for two application angles (A and B) of Thera-Band® resistance to determine which application angle best overloads IR and ER through the ROM. Thirty volunteer subjects participated in this study. SCs were obtained experimentally by measuring maximal isometric torque for IR and ER from 30° to 135°. RCs were calculated using regression equations from the literature. Significant differences ($p < 0.05$) were found between the SCs and RCs for both application angles during IR and ER. The findings of this study indicate that application angles A and B do not provide optimal loading when performing shoulder IR and ER exercises.

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CHAPTER 1

INTRODUCTION

Of all the joints in the human body, the shoulder, also known as the glenohumeral joint, has the greatest ROM. Due to this large degree of motion the joint is very unstable. At various points throughout the ROM, only about 30% of the humeral head is in contact with the glenoid fossa (Howell & Kraft, 1991; Soslowsky, Flatow, Bigliani, & Mow, 1992; Soslowsky, Flatow, Bigliani, Pawluk, et al., 1992). This complex joint allows 3° of freedom: abduction/adduction, flexion/extension, and internal/external rotation (Kulig, Andrews, & Hay, 1984; Norkin & Levangie, 1992). The various complexities of the glenohumeral joint rely heavily on the static (capsule and ligaments) and dynamic stabilizers (muscles). Therefore, strengthening the musculature is an integral part of injury prevention and rehabilitation of the shoulder. In order to strengthen the muscles of the shoulder one must understand the relationship between the application of resistive modes of exercise and anatomical torque-angle (strength) curves of the shoulder muscles.

Strength is the magnitude of a force exerted by a muscle or muscle group on the skeletal system at the attachment site of interest (Kulig et al., 1984). An increase in strength can be gained through progressive resistive exercise in a variety of modes such as isometric, isotonic, and isokinetic. Each mode, except isometric, can use concentric and/or eccentric muscle actions. Elastic resistance is a distinctive resistance tool that is commonly used to strengthen the shoulder. It does not depend on gravity like most other progressive resistive exercises. Instead, it relies upon the stress-strain properties of the material (Jones et al., 1998; Page, Labbe, & Topp, 2000). Elastic resistance is different from the other modes of resistance exercises in that as the joint goes through the ROM, the resistance force increases linearly.

To increase strength, the muscle(s) should be challenged throughout the joint's full ROM, which is commonly known as the overload principle. Literature suggests that loading the muscle to its limit through the joint's full ROM is superior to a constant resistance (e.g., isotonics) that is limited to overloading the muscle only at its sticking point (Cabell & Zebas, 1999; Garrett, Duncan, & Malone, 1988; Kulig et al., 1984). Though this theory has not yet been scientifically proven, it remains credible that a strengthening device should provide a resistance that corresponds to the torque output of the involved joint through its ROM (Cabell & Zebas, 1999). Therefore, resistance training should follow the strength curve of the involved joint. It is known that muscles or muscle groups do not exert a constant torque through the involved joint's ROM. Hence, variable weight machines (e.g., Nautilus Sports/Medical Industries, Deland, Florida) have been made that attempt to provide resistance that mimics the strength curve of the involved joint. However, these types of machines are questionable with regards to their effect on strength training (Cabell & Zebas, 1999). Furthermore, these types of machines are far more expensive when compared to elastic resistance. Although free weights are relatively inexpensive and easily accessible, free weight exercises typically do not mimic the strength curve of the involved joint. It is also difficult to perform free weight exercises that are specific to sports movements.

The use of elastic resistance in the form of elastic bands or tubing has gained widespread popularity in the clinic because it is inexpensive and can be used in exercises that are sport specific. However, because elastic resistance increases linearly as it is stretched, it may be even less favorable to the strength curve of the involved joint. Furthermore, the lack of standardized elastic exercise techniques may also result in a poor match between the strength curve and the resistance curve. Many patients are sent home with elastic resistance to perform various exercises, with the instructions written on paper and pictures illustrating how to do the exercises. Patients are usually told to secure the resistance to a doorknob or a table leg, or to simply stand on it. Several considerations are overlooked when prescribing exercise in this manner. For example, in order to perform shoulder internal rotation exercises, patients are usually told to stand perpendicular to a doorknob on which the resistance is secured. The first problem is that the resistance will not be at the same height for a patient who is five feet tall compared to another who is six feet tall. Secondly, most of the time the patients are told to stand with their bodies' perpendicular to the point at which the resistance is secured, but are not told how far away they should stand from the door. Failure to consider either of these differences between patients results in different resistance curves because of different application angles and different starting resistances.

To date, there have been very few studies that determine the effects of elastic resistance on strength gains for the shoulder (Hintermeister, Lange, Schultheis, Bey, & Hawkins, 1998; Hughes, Hurd, Jones, & Sprigle, 1999; Macko, Manley, Maul, Roth, & Sakalas, 1999; Treiber, Lott, Duncan, Slavens, & Davis, 1998). Furthermore, there are no studies thus far that examine whether there is an optimal application angle for elastic resistance. Therefore, studies need to be done to examine whether elastic resistance applied to the shoulder can closely mimic the strength curve of the shoulder musculature, thereby increasing the chances for optimal strength gains.

Statement of the Problem

Strengthening the shoulder plays an integral role in the prevention and rehabilitation of shoulder injuries. However, when elastic resistance exercises are incorporated into the strengthening program, little consideration is given to the exercise technique. Therefore, the strength curve and the resistance curve may not match each other in a way that provides progressive resistance. A person may be doing the exercise in such a way that the resistance torque is large when the anatomical position is weakest and may not benefit from the exercise. Rehabilitation and strengthening of a muscle(s) must be done with care and a purpose. The purpose of this study was to develop experimental strength curves for the internal and external rotators of the shoulder in a neutral position and calculate theoretical resistance curves for two different application angles (A and B) to see which angle best replicates the respective strength curve. The primary dependent variables were experimentally determined muscle torque and theoretically determined resistance torque at shoulder joint angles of 30°, 45°, 60°, 75°, 90°, 105°, 120°, and 135° (0° is full external rotation). The independent variables were the application angle and the curve type. The independent variable, application angle, had two levels: a) directly to the side of the subject, on the same line of the transverse axis that went through the humeroradial joint, and b) anterior to the first location that was the measured forearm length recorded from the strength apparatus. The independent variable, curve type, had two levels: a) strength curve and b) resistance curve.

Hypotheses

To evaluate the problem stated for this study, the following hypotheses were tested:

H_{A1}: For shoulder internal rotation, there will be a difference between the shapes of the theoretical resistance curves produced at application angle A and B.

H_{A2}: For shoulder external rotation, there will be a difference between the shapes of the theoretical resistance curves produced at application angle A and B.

H_{A3}: For shoulder internal rotation, there will be a difference between the shape of the theoretical resistance curve calculated for application angle A, and the shape of the experimental strength curve.

H_{A4}: For shoulder internal rotation, there will be a difference between the shape of the theoretical resistance curve calculated for application angle B, and the shape of the experimental strength curve.

H_{A5}: For shoulder external rotation, there will be a difference between the shape of the theoretical resistance curve calculated for application angle A, and the shape of the experimental strength curve.

H_{A6}: For shoulder external rotation, there will be a difference between the shape of the theoretical resistance curve calculated for application angle B, and the shape of the experimental strength curve.

Assumptions

The following assumptions were made for this study:

1. The subjects would perform their best isometric contractions in the development of individual experimental strength curves.
2. Thera-Band® elastic resistance would provide predictable, linear, and consistent increase in force and elongation.
3. The testing procedures used for development of the individual experimental strength curves would allow sufficient time to reduce the effects of fatigue.
4. Randomization of the testing order of the joint angles for data collection of the individual experimental strength curves would not produce significantly different torques.

Limitations

The following limitations were identified for this study:

1. The subjects in this study were volunteers.
2. The physical condition and strength levels varied among the subjects.
3. The theoretical resistance curves were calculated for the specifications of this study only. Any change in the specifications used to calculate the curves would result in a different shape and/or magnitude.

Delimitations

Thirty subjects (ages 18 to 30 years, 15 males, 15 females) volunteered to participate in this study. The subjects used their dominant arm to develop experimental strength curves for internal and external rotation of the shoulder in the neutral position. The subjects did not have any history of shoulder pathology with the involved arm. The data were collected during one test session. Each subject performed maximal isometric contractions for both internal and external rotation at shoulder joint angles of 30°, 45°, 60°, 75°, 90°, 105°, 120°, and 135°. The subjects performed three trials at each angle. For each trial, the subjects were asked to quickly build up to a maximum contraction, without jerking, and to hold this contraction for three seconds. The subjects stood in a position that is similar to what is most often recommended in clinical situations for performing the strengthening exercises.

The data for the theoretical resistance curves were calculated using regression equations from the literature for blue-colored Thera-Band® tubing (Hughes et al., 1999). The resistance curves, for shoulder internal and external rotation, were determined for two different anchor locations (application angle A and B). The first anchor location was directly to the side of the subject. The second anchor location was anterior to the first location. The distance between the first and second anchor location was the measured forearm length recorded from the strength apparatus. The resistance curves for each movement (shoulder internal and external rotation) were compared against each other. Finally, for each movement, each resistance curve was compared to the respective experimental strength curve to determine which application angle is most appropriate for muscle strengthening.

Operational Definition of Terms

The following are operational terms that must be defined for the understanding of this study:

1. Experimental strength curve: Isometric torque measurements are taken at specific angles through the involved joint's ROM, and then plotted using a line graph. Thus, a graphical representation results, which provides an understanding of what a muscle group's ultimate torque is about a joint through the ROM.
2. External Rotation: Turning away or outwardly from the body's midline.
3. Internal Rotation: Turning towards or inwardly to the body's midline.
4. Strength: A muscle's or muscle group's maximal ability to generate force against an unyielding resistance.

5. Theoretical resistance curve: the resistance torque created about the involved joint caused by a resistive force (e.g., dumbbells, Thera-Band®, etc.) and the moment arm created about the glenohumeral joint. Plotting the resistance torque against the shoulder joint angle through the ROM will generate the experimental resistance curve.

CHAPTER 2

REVIEW OF LITERATURE

Elastic resistance is commonly used in shoulder rehabilitation. However, the application angle of this resistance is not usually controlled during exercise. The purpose of this study was to develop experimental strength curves for the internal and external rotators of the shoulder in a neutral position and calculate theoretical resistance curves for two different application angles to see which angle best replicates the respective strength curves. This chapter reviews the literature in the following areas related to the study: (a) use of strength curves in rehabilitation, (b) development of strength curves, (c) use of elastic resistance in rehabilitation, and (d) a summary.

Use of Strength Curves in Rehabilitation

One of the main objectives in rehabilitation is to gain strength. Strength has been defined inconsistently throughout literature due to the mode (isometric, isotonic, isokinetic, etc.) of exercise in which strength is assessed (Atha, 1981; Baechle & Earle, 2000; Bandy, Lovelace-Chandler, & McKitrick-Bandy, 1990). For the purpose of this study, strength was defined as the muscle's or muscle group's maximal ability to generate torque against an unyielding resistance. While improving muscle *force* is the objective of strength training programs, the actual measure that is most often obtained is that of muscle *torque* output. Muscle torque is a product of the muscle's force and its moment arm. Therefore, the term muscle torque is used in this study when discussing external measures of muscle strength.

In order to gain strength, the overload principle must be applied, which states that the muscle must be challenged to exert a force greater than what it is accustomed to. To properly strengthen the muscle(s) through the joint's full range of motion (ROM), the overload should be applied to a muscle group through the ROM. A direct relationship between the muscle torque and the involved joint angle can be calculated throughout the ROM, resulting in a strength curve

(Garrett et al., 1988; Herzog, Hasler, & Abrahamse, 1991; Kulig et al., 1984; Winters & Kleweno, 1993). When using the overload principle, the resistance should follow the strength curve of the muscle(s) about a joint during strength training.

The maximum torque that a muscle can produce is a product of the muscle's maximum force and its moment arm. The maximum force of a muscle is dependent upon the physiological cross-sectional area (PCSA) of the muscle, the muscle length, the speed of contraction, and several neural factors such as size, number, and type of motor units recruited (Herzog et al., 1991; Kulig et al., 1984). The moment arm of a muscle is dependent on muscle insertion angle and distance of attachment from the joint of interest. Strength curves can be calculated for individual muscles but are more often presented for muscle groups because this is more practical for use in strength training. The shape of a strength curve is mostly dependent upon the moment arm and the length-tension relationship of each muscle about the joint. As the moment arm of a muscle becomes larger, the torque produced around the joint's axis becomes larger as well. Each muscle has a unique length-tension relationship in which there is an optimal length at which the muscle will produce its greatest force. Therefore, there is a point at which the moment arm and length-tension relationship of the muscles combines together to create the most torque capable at that joint. PCSA and the velocity of muscle action will affect the magnitude of the torque produced, but the curve will appear similar in shape through the ROM (Baechle & Earle, 2000; Fulton et al., n.d.). A curvilinear relationship exists between muscle action and velocity (Baechle & Earle). As velocity increases during concentric muscle action the torque capability of the joint decreases. In contrast, as velocity increases during eccentric muscle action the torque capability of the joint increases to a point, beyond which it decreases with increasing speed (Baechle & Earle).

The shape of a strength curve usually falls within one of three categories: (1) ascending, (2) descending, and (3) ascending-descending (Kulig et al., 1984). An ascending strength curve is produced when the torque created by the muscle group increases as the joint angle of the involved joint increases. Conversely, a descending strength curve is produced when the torque created by the muscle group decreases as the joint angle of the involved joint increases. An ascending-descending strength curve is produced when the torque created by the muscle group first increases then decreases as the joint angle of the involved joint increases.

From person to person neither the shape nor the magnitude of the strength curve will be exactly the same. However, the strength curve will have a shape that is similar to the generalized strength curve for a particular joint. There are two advantages to knowing the shape of the strength curve for a specific motion at a particular joint. First, knowing the strength allows one to develop an effective strengthening program for injury prevention or rehabilitation (Garrett et al., 1988). A muscle or muscle group should be stressed throughout the full ROM in order to gain optimal increases in strength (Cabell & Zebas, 1999; Garrett et al.; Kulig et al., 1984). Therefore, by knowing the strength curve, one can apply the resistance to the muscle(s) in a manner that will correctly overload the muscle throughout the ROM and increase the opportunity for optimal strength gains. Second, because strength curves represent what normally occurs throughout the ROM of a particular joint, therapists can compare curves produced by someone who has a musculoskeletal discrepancy with the normal curve (Fulton et al., n.d.). From this comparison, the therapist knows where in the ROM the person has decreased functional strength. Therefore, the therapist can prescribe exercises that will increase strength in the specific ROM where the person is weak.

Development of Strength Curves

Strength curves can be developed either theoretically or experimentally. Kulig et al. (1984) have stated that a strength curve represents a muscle group's maximum potential torque through the ROM only when the following criteria are met: (1) there is only one joint in motion, (2) the muscle(s) being assessed are the dominant causes for the joint movement, and (3) the involved joint movement is constrained to one rotational degree of freedom. Besides the physiologic and geometric factors discussed earlier, there are several design factors such as population studied, psychological conditions, and exercise conditions that may also influence the shape of a strength curve (Garrett et al., 1988; Kulig et al.). These two methods for developing strength curves and the design considerations will be reviewed in the following sections.

The shoulder complex is the most complex coordinated joint system in the human body. It is comprised of four joints: the sternoclavicular, acromioclavicular, and scapulothoracic joints, which make up the shoulder girdle, and the glenohumeral, which is more commonly called the shoulder joint. The glenohumeral joint has three degrees of freedom that allows for a large degree of motion that is controlled by 11 muscles: biceps brachii, triceps brachii, subscapularis, supraspinatus, infraspinatus, teres minor, teres major, latissimus dorsi, deltoid, coracobrachialis, and pectoralis (Veeger, Van der Helm, Van der Woude, Pronk, & Rozendal, 1991). Due to the large degree of motion and number of muscles crossing the glenohumeral joint, creating strength curves for this joint is very complicated.

To date, strength curves for the shoulder have not been identified for internal and external rotation in the neutral position. In the following two subsections, studies will be presented in which strength curves have been developed theoretically and experimentally and correlations between the two methods have been examined. Due to the lack of literature on strength curves for internal and external rotation of the shoulder, strength curve studies on other various joints are discussed to help develop the framework for the development of strength curves for this study.

Theoretical Strength Curves

The literature suggests that if certain musculoskeletal parameters can be obtained, then strength curves can be calculated without obtaining the resultant force by an external strength-testing device. The musculoskeletal parameters needed in order to determine the shape of a theoretical strength curve are the moment arm of the individual muscles about the joint and the force-length relations of the muscles (Herzog et al., 1991; Plagenhoef, 1987). If the specific magnitude of the torque output is desired, then additional information is needed: (1) the PCSA, (2) the portion of the muscle used in the movement, (3) the angle difference between the line of pull of the muscle and the line of motion of the segment, and (4) the angle difference between the line of pull of the muscle and the degree of muscle pennation (Plagenhoef). Most of these parameters can only be obtained from cadavers, therefore, making it very difficult to develop theoretical strength curves as compared to experimental strength curves (Herzog et al.).

Herzog et al. (1991) calculated theoretical strength curves for the knee extensors using the force-length relations. The theoretical curves were calculated for hip angles of 180° (lying) and 90° (sitting). The force-length relations were calculated for each muscle of the four knee extensors based on the cross-bridge theory, which required that (a) the lengths of the muscle fibers as a function of joint angle were known, (b) average sarcomere lengths of the muscle fibers were known, and (c) the arrangement of thick and thin filament cross-bridging were known. Four cadavers were used to obtain fiber lengths of the knee extensors in the anatomical position. Sarcomere lengths were measured using histological analysis from three fibers of each muscle, totaling 45 individual measurements. In a previous study, lengths of the fibers and changes in moment arms of the knee extensors were reported from nine radiographs taken while the subject performed isometric contractions. The arrangement and lengths of thick and thin filaments were also taken from the literature. The force-length relations of the knee extensor muscles were calculated, assuming that the maximal force of the individual muscle was related to the PCSA. The specific values were determined using procedures from another study. The four knee extensor force values were summed together at corresponding knee angles through the ROM. The authors found that, theoretically, the three vasti muscles are capable of producing torque throughout the entire ROM. The three vasti were predicted to exert their peak torque between 95° and 130° (180° = full extension). The location of the peak torque for the rectus femoris was dependent on the hip joint angle. The following conclusions were made from the theoretical strength curves: (1) as the knee joint angle approached full extension, knee extension strength was predicted to be greater for the hip joint position at 180°, (2) as the knee joint angle approached full extension, knee extension strength was predicted to be less for the hip joint position at 90°, and (3) theoretical peak knee extension strength was predicted to be 7% greater at the hip joint angle of 180° than 90°. Hence, it is crucial to recognize multiarticular muscles that cross the involved joint when obtaining strength curves for a given joint, because the positioning of the person will affect the shape of the curve due to changes in the moment arm lengths and the length-tension relationship.

Hutchins, Gonzalez, and Barr (1993) developed theoretical strength curves for elbow flexion and extension. The model used to create the theoretical strength curve was based on procedures that were previously described in literature for the lower extremity. The authors represented the following muscles in the model: biceps brachii, brachialis, brachioradialis, triceps brachii, supinator, pronator teres, anconeus, and pronator quadratus. Musculotendon length, musculotendon velocity, potential muscle force, origin/insertion points, and moment arm lengths were used in the calculation of the theoretical strength curves. Values for musculotendon length, potential muscle force, and origin/insertion points were taken from previous literature. The moment arm lengths were calculated by the cross product of the vectors created by the origin/insertion points and the joint center. The calculated moment arm curve correlated well with previous values in literature. Musculotendon velocity was set as zero since this model represented only isometric contractions. The theoretical flexion model produced a peak torque of 55 ft-lb at 80° (0° is full extension). The theoretical extension model produced a peak torque of 39 ft-lb at 50°.

The length of the moment arm of the muscle about the joint is a large predictor for the amount of torque produced by the muscle. Kuechle et al. (2000) examined 12 cadavers to determine the contribution of the moment arm to torque output for ten muscles that cross the shoulder. The shoulders were dissected and the scapula was mounted to an acrylic testing frame.

Stitched lines were attached to the respective muscle insertions. The lines were attached on the superficial aspect of the musculotendinous junction at the midpoint where the muscle inserted into the bone. The lines were then passed through the frame and each line was attached to individual electropotentiometers. The potentiometer measured the amount of movement of the line, which represented muscle shortening/lengthening. An electromagnetic tracking device was attached to the humerus and scapula, which measured three-dimensional position of the humerus relative to the scapula. The humerus was abducted to 90° in the coronal, sagittal, and scapular planes, and also in the neutral position with the arm at the side. The moment arms for each muscle were measured throughout humeral rotation in both positions. The moment arm data for each specimen was multiplied by a ratio of the average humeral head radius to the humeral head radius for that specimen.

The resulting data were then averaged with the other cadavers, which generated mean moment arms for each muscle throughout humeral rotation in the respective positions. The study found that the infraspinatus and subscapularis are potentially the most powerful external and internal rotators. The authors acknowledged that the study was limited because some of the muscles were represented with only one cable attachment (e.g., subscapularis). Additionally, the scapula was fixed and unable to move so scapulothoracic movement was not represented. The authors also stated that potential moment and torque could be calculated, creating potential strength curves that could assist with the identification of selected rehabilitative exercises.

Experimental Strength Curves

Experimental strength curves are calculated by measuring the external force as a function of the angle of the joint. The external force values are usually obtained using an external strength-measuring device (e.g., isokinetic dynamometer) throughout the joint's ROM in a continuous or discrete manner. The force values are then multiplied by the distance from the joint to the point of external force application to produce a muscle torque curve through the

ROM. There are no established standardized procedures for obtaining strength curve data (Kulig et al., 1984). Therefore, several design problems or inconsistencies can occur during the data collection, which may result in different strength curves across studies. Most of these result when the experimenter does not clearly define the assessment protocol before the study. One particular problem that occurs is failure to consistently define across studies the beginning joint angle (Kulig et al.). For example, full extension at the elbow may be considered 0° in some studies and 180° in others. As a result, one study may report that the strength curve for the elbow extensors is ascending while another study reports it as descending, when in reality the strength curves are identical. Therefore, joint angle measurements should be consistently defined across studies, and should be clearly stated in the written article. A second problem arises due to the different modes that can be used to assess muscle strength. Strength can be measured during isometric, concentric, and eccentric conditions at varying speeds and under various loading conditions (e.g., isotonic and isokinetic) (Kulig et al.). It has been shown that the shape of the strength curves is the same when comparing isometric to concentric or eccentric isokinetic testing for a specific motion at a specific joint; only the magnitude differs (Fulton et al., n.d.; Baechle & Earle, 2000). However, differences among concentric, eccentric, and isometric muscle actions as well as different loading conditions have not been thoroughly investigated. Again, it is imperative that the protocol for strength assessment be defined clearly so that comparisons can be made across studies.

As discussed earlier, Herzog et al. (1991) calculated theoretical strength curves for the knee extensors. They also obtained experimental strength curves and compared them to the theoretical curves. The experimental curves were measured for eight male subjects. Before data collection, the subjects had to go through a standardized warm-up. Subjects were asked to perform four maximal isometric contractions of the knee extensors every 15° (60°, 75°, 90°, 105°, 120°, 135°, and 150° of flexion, with 180° representing full knee extension). This was completed at hip joint angles of 90° and 180° (180° represented full hip extension). Each subject was instructed to slowly contract to his maximal effort and hold this effort for one second. This was to ensure pure isometric contraction conditions and prevent injury. Each subject was allowed as much rest necessary between each trial in order to promote maximal isometric contractions. The strength data were collected using an isokinetic dynamometer. The data were analyzed using the Chi-square distribution ($p \leq 0.05$) to assess for differences in the strength curves obtained for the sitting and lying positions. The statistical tests were performed on the mean muscle torques that were calculated for the largest and smallest knee joint angles, and for the mean peak muscle torque. The two mean experimental knee extensor curves (hip angles at 180° and 90°) were significantly different from each other in the following ways: (1) at the knee joint angle of 150°, the mean extensor torque was greater at the 180° hip joint angle, (2) at the knee joint angle of 60°, the mean extensor torque was greater at the 90° hip joint angle, and (3) the mean peak knee extensor torque was greater for the hip joint angle at 90°. For the theoretical strength curves, peak muscle torque occurred at knee joint angles of 100° - 110° and 120° for hip angles of 180° and 90°, respectively. The experimental strength curves agreed with the theoretical curves, with peak muscle torque occurring at 105° and 120°, respectively. The only discrepancy between the theoretical and experimental strength curves was the mean peak torque between the two hip joint angles. The theoretical strength curves predicted that the hip joint angle at 180° would produce a 7% larger torque. However, the experimental strength curves obtained showed a 9% larger torque when the hip joint angle was at 90°.

Kuhlman et al. (1992) collected strength data for shoulder external rotation and shoulder abduction in 39 subjects. The subjects were divided into three groups defined by age and sex: (1) younger males (n = 21, 19 - 30 years old), (2) older males (n = 9, 51 - 65 years old), and (3) females (n = 9, 50 - 65 years old). All subjects were right-handed and had no previous injury or treatment to any part of the upper extremity or neck. The strength data were collected isokinetically (90°/s and 210°/s) and isometrically by an isokinetic dynamometer. To test external rotation strength each subject was secured firmly to a bench in the supine position. Each subject was positioned in the plane of the scapula, with the arm abducted 45° and horizontally abducted 30°. Shoulder rotation was limited to 60° of internal and external rotation. Isometric strength was collected at -60°, -30°, 0°, 30°, and 60° (negative for internal rotation positions) for the younger males. The positions were changed to -60°, -45°, -30°, and 0° for the two other groups due to unreliable repeat tests performed earlier in the study. During isometric testing, subjects performed three maximal contractions at each position with ten seconds of rest between each effort, and two minutes of rest between each position. Each isometric contraction was held for three seconds. Peak isokinetic torque for each subject was taken as an average from the three maximum efforts performed at that particular speed. Isometric peak torque was taken from the maximum effort at the respective position.

The authors found that there were significant differences ($p \leq 0.02$ for all three groups) in the total work between the two speeds of isokinetic testing. There was a significant difference ($p < 0.05$) in average peak torque only in the group of younger males. Peak isokinetic torque was found to occur between -45° and -55°. Isometric torque was found to be greater than isokinetic torque in each group. Peak isometric torque was significantly greater ($p \leq 0.05$) at both -60° and -30° than peak isokinetic torque and other isometric positions for the group of younger males. The remaining two groups did not show any significant difference between isokinetic and isometric torque. Qualitatively, isometric testing through the ROM produced a descending strength curve.

To test abduction strength subjects were secured firmly to a chair that stabilized the trunk and shoulders. Abduction was tested in the plane of the scapula for both isokinetic and isometric testing. Isokinetic testing was performed between 20° and 120° of abduction at 90°/s and 210°/s. Isometric strength was collected at 30°, 60°, 90°, and 120° for the younger males. The positions were changed to 20°, 45°, and 90° for the two other groups. The same protocol as described for external rotation was used for testing abduction strength. Isokinetic data for the older males and females groups at 210°/s were omitted because some subjects were unable to perform at this speed. Peak isometric torques produced at 30° and 60° were significantly greater than the remaining angles. Furthermore, peak isometric torque produced at 30° and 60° were significantly greater than isokinetic peak torque at 210°/s. Qualitatively, the group of younger males produced an ascending-descending strength curve.

Multiarticular muscles have a major influence on the shape of a strength curve, depending largely on the position of the involved joints. Winters and Kleweno (1993) studied the strength curve of the shoulder flexors with the elbow fully extended and flexed to 90° to determine the effect that the multiarticular biceps brachii had on shoulder flexion. Shoulder flexion strength was measured on an isokinetic dynamometer. Eight subjects (4 males, 4 females) participated in the study. The subjects came in for five testing sessions. The first session was used to familiarize the subjects to the isokinetic dynamometer and the protocol of the study. The other four sessions were for strength data collection. The subjects performed maximal isometric contractions at every 15° from 0° to 135° (0° was considered anatomical position). The subjects were to hold the contractions for a count of two, which was approximately 2 - 2.5 seconds each. The testing positions were repeated at 60°, 75°, and 90° so the subjects could be readjusted to the dynamometer. The readjustment was to realign the center of axis of the shoulder. Strength data was averaged separately for males and females and for the two elbow positions.

The authors found a significant difference ($p < 0.005$) for strength curve slopes between males and females subjects. As shoulder flexion increased, the females became relatively stronger with respect to the males. Furthermore, for the males there was an upward shift in the strength curve by 5 - 10 Nm when the elbow was extended compared to when it was flexed at 90°. Elbow position did not have the same effect for females until shoulder angles were greater than 100°. The authors speculated that the upward shift could be explained by two possible mechanisms: (1) the force-length relationship of the biceps brachii, or (2) an increase in passive resistance in the triceps brachii when the elbow was flexed. Additionally, the authors used a theoretical model to predict forces for shoulder flexion in the two elbow positions. However, neither methods nor analyses for the model were described. The authors only noted that the model simulation supported the results of the experimental data.

As described earlier, Hutchins et al. (1993) calculated theoretical strength curves for elbow flexion and extension. They also calculated experimental strength curves for comparison with the theoretical curves. The experimental strength curves were measured using an isokinetic dynamometer. Only two subjects were used in this study. The subjects performed maximal isometric contractions every 15° through their entire ROM for flexion and extension. The subjects were allowed a three-minute recovery between each isometric contraction. The data from the two subjects were averaged together to create an experimental curve to compare with the theoretical curve. No statistical analysis was used to test for differences between the experimental and theoretical flexion/extension strength curves. The experimental flexion strength curve produced a peak torque of 55 ft-lbs at 75° (0° is full extension). The experimental extension strength curve produced a peak torque of 34 ft-lb at 45°. Therefore, the theoretical and experimental strength curves produced peak torques within 5° of each other for both flexion and extension. Futhermore, the magnitude of the peak torque was the same for the theoretical and experimental flexion strength curves. However, there was a difference of 9 ft-lb between the theoretical and experimental extension curves. Qualitatively, the theoretical and experimental strength curves compared well with each other.

Timm (1997) collected isokinetic strength data for internal and external rotation of the shoulder in 241 high school baseball pitchers who were diagnosed with shoulder impingement syndrome. The strength data were collected for both the involved and noninvolved arms in order to make comparisons between normal and impingement syndrome shoulders. The data were collected using an isokinetic dynamometer. Each subject performed five repetitions of internal and external rotation at speeds of 60, 120, 180, 240, and 300 °/s. Subjects were strapped to a tilt table while standing by the dynamometer. The strapping guarded against excessive movement of the torso during testing. The subject's upper arm was positioned in the scapular plane with the humerus in 70° of elevation and 30° of horizontal abduction. Isokinetic strength curves were obtained only at 60 °/s. The results of the study showed, qualitatively, that the shapes of the isokinetic strength curves for the involved and noninvolved shoulders were consistent between subjects. A general decrease in peak isokinetic torque was observed with the involved shoulder. Furthermore, both internal and external rotation in the noninvolved shoulder produced an ascending-descending isokinetic strength curve.

Use of Elastic Resistance in Rehabilitation

Because the shoulder is a very mobile joint, the rotator cuff plays a large role in keeping the joint stable. The rotator cuff serves as a dynamic stabilizer, so keeping the rotator cuff muscles strong is essential in preventing injury. Elastic resistance is one of the most commonly used resistance modes in shoulder strengthening and/or rehabilitation (Aronen, 1999; Curtis et al., 1999; Hintermeister et al., 1998; Hughes et al., 1999; Jackins & Matsen, III, 1994; Macko et al., 1999; Powers, 1998; Regan & Underwood, 1981; Treiber et al., 1998). One reason it is often used is because it is cheap, versatile, and portable (Aronen, 1999; Hughes et al., 1999; Jones et al., 1998; Regan & Underwood, 1981). Another reason elastic resistance is commonly used is because it depends on the placement of the resistance, not on gravity (Hintermeister et al., 1998; Hughes et al., 1999). This allows the therapist to place the resistance upon the shoulder at more functional positions, which is not easily done with conventional resistive devices. Because the resistance can be placed in a functional position, elastic resistance not only increases strength, but also improves performance in sports skills (Treiber et al., 1998). As with any strength training, the resistance must be increased as the person adapts. Elastic resistance must be increased as well, however, the amount of increase is not easily measured. Most therapists increase the resistance by changing to a different band that is thicker, which has a greater magnitude of resistance. Most companies that market elastic resistance designate colors to represent differences in the amount of resistance given by the material.

The elastic force of a material is defined by the modulus of elasticity, $E = (\Delta\sigma)/(\Delta\varepsilon)$, where the elastic modulus (E) is equal to the change in stress ($\Delta\sigma$) divided by the change in strain ($\Delta\varepsilon$) (McGinnis, 1999). Being able to quantify elastic force allows one to calculate the resistance torque produced by elastic resistance on a joint during a particular exercise. The resistance torque can be calculated for most all PREs. The components needed to calculate the resistance torque are the involved joint angle, the length of the segment from the joint's center of rotation to the point of applied resistance, the direction of the resistance force, the amount of the resistance force, and the moment arm created by the resistance force about the involved joint. First, the moment arm is obtained by calculating the cross product of the vectors created by the direction of the resistance force and the involved joint's center of rotation. Second, the resistance torque is calculated using the equation $T_r = F_r \times d_r$, where T_r = the resistance torque created about the involved joint, F_r = the amount of resistance force, and d_r = the calculated moment arm for F_r created about the involved joint. The resistance torque is calculated at specific joint angles through the ROM. Then, by plotting T_r against the joint angle through the ROM generates a resistance torque curve. However, calculating the resistance torque for elastic resistance is a little more complex due to the change in resistance as the elastic band is stretched, and the change in direction of the resistance force through the involved joint's ROM. Nonetheless, these two variables can be ascertained and calculated to develop a resistance torque curve.

Hughes et al. (1999) tested whether Thera-Band® tubing had a linear relationship between the percent elongation and tension. They also estimated the resistance provided by Thera-Band® during shoulder abduction. Fifteen subjects (9 males, 6 females) participated in the study. All subjects performed shoulder abduction exercises with their right arm only. A strain gauge tensiometer was used to record the amount of resistive force created by the tubing. The tensiometer was attached to a platform that was constructed by the investigators. The platform was also used to standardize foot positions for the subjects during the exercises. Two video cameras recorded the exercises, which were then digitized to calculate joint position and angle data. Anthropometric measurements were recorded for the subject's arm length, distance from the center of the glenohumeral joint to the floor, and from the third metacarpophalangeal (MCP) joint to the floor. Reflective markers were placed on the subjects and were used to calculate shoulder abduction angle during the digitization process. For each subject, the original tubing length for each of the six colors was cut to equal the distance between the subject's third MCP joint to the tensiometer so that the starting joint angle and tube tension was the same (e.g., there was no extra slack in the tubing, and no tension had been developed by stretching the tubing). The subjects performed five repetitions for each color of tubing. The subjects also had to hold their arm positions momentarily at shoulder abduction angles of 30°, 60°, 90°, 120°, and 150° (0° is with the subjects arm down by their side); these angles were approximated by having lines drawn on the background cardboard. The reason that the subjects held these positions was to reduce the effects of acceleration. The subjects were allowed to rest for a period of two minutes after each color of tubing. Resistance torque was also calculated as if the subjects were using dumbbells with resistance of a 5- and 10-pound load. The resistance curves developed for the elastic resistance and dumbbells demonstrated ascending-descending curves.

The authors found significant differences in tension for the different colors of tubing ($p < 0.05$), except between blue and black tubing tension at 30° of shoulder abduction. Strong relationships to linearity were determined with regression equations for the various colors of tubing ($r^2_{yellow} = 0.74$, $r^2_{red} = 0.94$, $r^2_{green} = 0.98$, $r^2_{blue} = 0.96$, $r^2_{black} = 0.98$, $r^2_{silver} = 0.98$). These results were inconsistent with those reported by Jones et al. (1998), who found no significant differences in the force between yellow and green, and between green and black Thera-Band® bands. Jones et al. (1998) concluded that because the force capabilities overlap among the bands, some of the different colored bands are not necessary.

Page et al. (2000) established regression equations for seven Thera-Band® bands ($p <$ .000), which had strong relationships to linearity ($r^2_{yellow} = 0.973$, $r^2_{red} = 0.947$, $r^2_{green} = 0.981$, $r^2_{blue} = 0.981$, $r^2_{black} = 0.981$, $r^2_{silver} = 0.987$, $r^2_{gold} = 0.988$). Each color was tested five times at lengths of 18”, 24”, 30”, and 36”. One end of the band was attached to a Thera-Band® Exercise Handle and the other end was fastened to a strain gauge. During data collection each band was stretched approximately one inch per second. The band resistance was recorded from 25% - 250% elongation from the original resting length. The authors concluded that Thera-Band® bands produce a consistent, linear, and predictable increase in resistance throughout the seven colors.

Treiber et al. (1998) studied tennis serve performance after a four-week training program using Thera-Band® and lightweight dumbbells together. The study used 25 (12 males, 13 females) subjects who played at the college level. Pretest and posttest assessments of internal and external rotation strength and serve performance were collected. Strength was assessed using an isokinetic dynamometer. Subjects were tested with the shoulder in 90° of abduction and the elbow in 90° of flexion at two different speeds. Serve performance was tested by assessing maximal velocity and average velocity of eight serves. The strengthening exercises for internal and external rotation involved the use of Thera-Band®, where the subjects were positioned in 90° of abduction in the coronal plane. The resistance was attached on a wall at a height midway between the subject’s elbow and hand. Lightweight dumbbells were used for the empty can exercise. The authors found an increase in the ratio of peak internal and external rotation ($p <$ 0.01) torque to body weight. They also found an increase in both peak and average velocity of serves ($p < 0.01$).

There is a lot of literature (Aronen, 1999; Curtis et al., 1999; Hintermeister et al., 1998; Hughes et al., 1999; Jackins & Matsen, III, 1994; Macko et al., 1999; Powers, 1998; Regan & Underwood, 1981; Treiber et al., 1998) that recognizes elastic resistance to be beneficial to shoulder strengthening/rehabilitation. However, there are only a few studies that examine the actual gains from the use of elastic resistance. Other than Hughes et al. (1999), who recognized that there might be a difference when a different angle is used, there is not any research that examines the benefits of different application angles of elastic resistance, especially for the internal and external rotators of the shoulder.

Summary

From a rehabilitation point of view, it is critical to know the shape of the strength curve of the involved group of muscles. This enables the therapist to apply resistance in a way that creates an overload throughout the ROM. Furthermore, if the person produces an atypical curve, resistance can be applied to overload only the ROM where an increase in strength is needed. After the discrepancy is resolved, the therapist can begin to apply resistance that creates an overload through the entire ROM, thereby, effectively training the muscles through their entirety.

The use of elastic resistance should be used in a manner that will provide resistance through the ROM similar to the shape of the strength curve of the involved joint. Due to the elastic nature of elastic resistance, the load will become greater through the ROM. Therefore, elastic resistance may not be beneficial for all joints and their corresponding motions. For example, the study by Hughes et al. (1999) demonstrated the relationship of the resistance curves created by Thera-Band® and by dumbbells; however, these resistance curves do not correspond well to the strength curve for shoulder abduction. By altering the application angle, the resistance curve would change and possibly coincide with the strength curve for shoulder abduction. Nonetheless, this is not known because the author only assessed resistance from one application angle. Studies should be done to assess elastic resistance applied at different angles to see if one application angle is better than another in providing an overload to the muscles throughout the joint ROM.

CHAPTER 3

RESEARCH METHODOLOGY

The purpose of this study was to develop experimental strength curves for the internal and external rotators of the shoulder in a neutral position and calculate theoretical resistance curves for two different application angles to see which angle best replicated the respective strength curves. This chapter explains the methods that were involved with this study. The chapter includes: a) pilot study, b) subjects, c) instrumentation, d) research protocol, and e) design and analysis.

Pilot Study

A pilot study was performed to assess the test-retest reliability of the apparatus used to measure the torque output during shoulder internal and external rotation isometric contractions. Five volunteer subjects participated in the pilot study. Data were collected as described in the following sections. The subjects were tested on two separate days with a maximum of one-day rest. From the pilot study the researcher was able to identify flaws that were corrected before data collection. Furthermore, the pilot study provided information about how long it took to collect and analyze the data for the strength curves per subject. This provided the information needed by researcher to allow enough time for data collection per subject. Lastly, the main concern was to determine if the angles of internal and external rotation for the experimental strength curves could be reproduced with sufficient test-retest reliability.

The data collected from the pilot study were analyzed using SPSS for Windows (Version 10.0; SPSS, Inc.; Chicago, IL) to calculate the averaged measure Intraclass Correlation Coefficient (ICC). The statistical analyses assessed test-retest reliability across trials and across days for both internal and external rotation at 30°, 45°, 60°, 75°, 90°, 105°, 120°, and 135°. The reliability across trials was assessed using the torque data collected on day one for all three trials for both movements. Peak torques from days one and two, which were attained by using the highest torque value of the three trials per subject, were used to assess the reliability across days for both movements.

Subjects

Thirty subjects (ages 18 to 30 years, 15 males, 15 females) volunteered to participate in this study. The subjects used their dominant arm to develop strength curves for internal and external rotation of the shoulder. Dominance was determined by asking the subjects which arm they used to throw a ball. The subjects did not have any history of shoulder pathology with the involved arm. All subjects read and signed an informed consent approved by the East Tennessee State University's Institutional Review Board (See Appendix).

Instrumentation

The apparatus used to measure shoulder internal and external torque was built by the Greenwood County Career Center (Greenwood, South Carolina) machine tool class and the primary investigator. A torque transducer was coupled into the shaft of the apparatus (see Figure 1) that measured torque applied by the subject during the isometric contractions. The transducer (Sensotec model QSFK-9 1200 in-lb; Columbus, OH) was factory calibrated from 0 - 1200 in-lbs. The signal from the transducer was sent to a signal conditioner (Sensotec model GM; Columbus, OH) that displayed the torque values to the closest tenth in-lb. The signal conditioner had a peak detector option that identified the highest positive value, which was used to obtain peak torque measures during the data collection.

Because the peak detector option identified only the highest positive value, peak torque values could only be collected for one rotational movement (internal or external rotation). Therefore, the signal conditioner had to be re-wired by switching the wires at the excitation terminals at the back of the conditioner. This switched the direction of the direct-current to the conditioner, thereby switching the positive and negative values, which allowed the researcher to collect peak torque values for both movements. Therefore, the transducer was shunt-calibrated before every test session and between both movements to insure that accurate torque values were collected.

In order to allow for accurate torque measurements to be collected, the apparatus was adjustable to fit each subject appropriately. The height of the apparatus was adjusted for each subject by moving the shaft of the apparatus up or down. The shaft was encased by the base of the apparatus by which two set screws were tightened to lock the shaft of the apparatus at the appropriate height and prevent the shaft from rotating and sliding up or down. Each subject's arm was secured to the arm of the apparatus by an affixed padded cuff and adjustable Velcro strap, which prevented the proximal forearm from moving and, thereby, prevented false torque measurements. The handle of the apparatus was adjustable for each subject's forearm length. The handle, which the subjects grasped to apply torque during the isometric contractions, was adjusted by sliding it proximally or distally to the axis of rotation (see Figure 1).

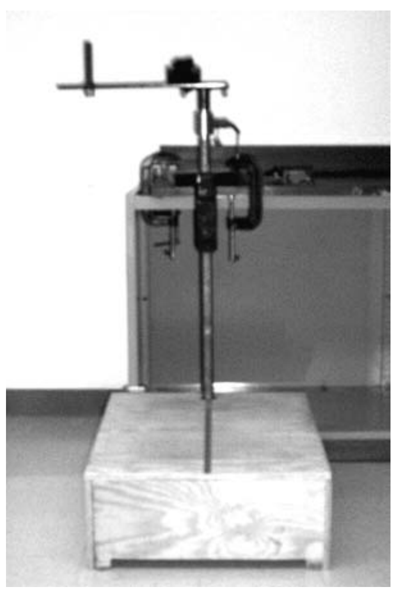

Figure 1. Strength Apparatus. Picture of strength apparatus used to measure shoulder internal and external rotation strength. The line drawn on the box was used to align the subjects' lateral malleoli.

Research Protocol

Strength Curves

Experimental strength curves were obtained for shoulder internal and external rotation by measuring each subject's maximal isometric torque at 30°, 45°, 60°, 75°, 90°, 105°, 120°, and 135°, for both movements. The starting position for measuring the degrees of rotation was at full external rotation (see Figure 2), with the arm in an anatomical position relative to the frontal and sagittal planes. Each subject stood in a position that is similar to what is most often recommended for clinical conditions when performing strengthening exercises for internal and external rotation (see Figure 3). The researcher positioned each subject's feet shoulder width apart, and aligned the lateral malleoli with a line drawn on the box upon which the subject stood (see Figure 1). The subjects were asked to stand with proper posture and look straight ahead, which placed the trunk of the subjects in an anatomically correct position. The noninvolved arm was positioned behind the back with the hand tucked into the waist of the subject's clothing. The subjects were asked to stand as still as possible during the contraction trials to avoid movement of the torso and head to prevent distorted torque values.

The apparatus was placed to hold the subjects upper arm in a neutral position relative to the anatomical position, and the forearm was flexed at 90°. The forearm was positioned on the arm of the apparatus by lining up the subject's humeroradial joint with the apparatus' axis of rotation. The subject's forearm was secured in the affixed cuff by an adjustable Velcro strap to prevent the forearm from slipping on the device, which prevented false torque values. In order to position the handle in the correct position, the subject was asked to firmly grasp the handle while the researcher locked it into place.

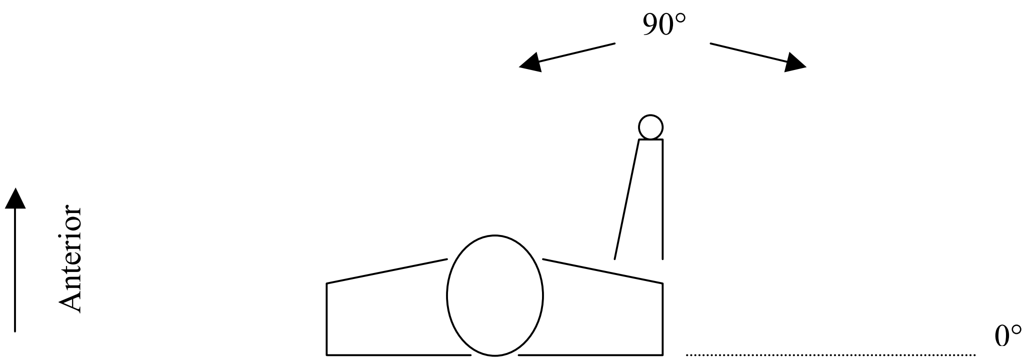

Figure 2. Reference System. The schematic demonstrates how degrees of internal and external rotation were measured for the strength and resistance curves.

Figure 3. Subject Position during Strength Assessment. Shoulder internal and external rotation isometric torque was obtained while the subjects stood in a position that is similar to what is most often recommended for clinical conditions when performing strengthening exercises for internal and external rotation.

Prior to testing each subject participated in a warm-up and familiarization period. The warm-up consisted of shoulder internal and external rotation exercises using green colored Thera-Band® tubing as the resistance. During the warm-up exercises each subject stood in the same position that was used during the test session, as described above. Furthermore, each subject stood so that the anchor location of the tubing was directly to the side, on the same line of the transverse axis. Each subject was allowed to move closer or farther away from the anchor location to decrease or increase the resistance in order to achieve a sufficient warm-up of the muscles and to minimize the effects of fatigue. For both internal and external rotation exercises, each subject performed three sets of 10 repetitions. The subjects performed one set of internal rotation followed immediately by one set of external rotation. The subjects were allowed one minute of rest before the next set of internal and external rotation exercises.

Following the warm-up exercises, each subject went through a familiarization period in order to learn the correct technique for performing the isometric contractions. Each subject was secured and positioned as described above. The subjects only performed three isometric contraction trials at angles 30°, 90°, and 135° for both internal and external rotation in order to reduce the effects of fatigue. The subjects were asked to contract at about 50% of their maximum capability during the practice trials. For each trial, the subjects were instructed to quickly build up their contraction without jerking and hold this contraction for three seconds. The subjects were allowed 15 seconds of rest after each trial. After the last contraction trail at each angle the subjects were allowed one minute of rest before the first trial at the next angle. During the familiarization period, each subject was given corrective criticism to insure correct technique for the test session. The researcher made clear to each subject that the contraction times were controlled by the researcher during the test session by giving the commands contract and relax. The researcher also explained that during the test session there would be no verbal communication during the trials except for the commands and corrective criticism, if needed. Following the familiarization period, the subjects were given approximately two minutes rest before the beginning of the test session.

For the test session, each subject performed three maximum isometric contraction trials at each angle for both internal and external rotation. For each trial, the subjects were asked to quickly build up to a maximum contraction (approximately 0.5 seconds) without jerking and hold this contraction for three seconds. The subjects were allowed 15 seconds of rest after each trial. After the last trail at each angle the subjects were allowed two minutes of rest before the first trial at the next angle. The order of the data collection started with internal rotation at 30° and advanced every 15° finishing at 135°. The order was reversed for external rotation. The subjects were allowed five minutes and 48 seconds of rest between internal and external rotation. This time was standardized for all subjects to allow the researcher sufficient time to re-wire and calibrate the transducer.

For each subject, the peak torque of the three trials for each angle was used in the development of the experimental strength curves. The peak torques gathered from the subjects were used to calculate an averaged peak torque for the respective joint angle. Thus, an experimental strength curve was generated for both internal and external rotation by plotting the averaged peak torque against the respective joint angle through the ROM.

<u>Resistance Curves</u>

The resistance curves for internal and external rotation were calculated as if elastic resistance was anchored from two different locations. The first anchor location (application angle A) was directly to the side of the subject, on the same line of the transverse axis that goes through the humeroradial joint (see Figure 4). The second anchor location (application angle B) was anterior to the first location, which was the measured distance taken from the axis of rotation to the center of the handle on the arm of the strength apparatus (see Figure 4).

The resistance curves for both internal and external rotation were calculated as if a person was standing with the involved shoulder's axis of rotation at the elbow joint 121.9 centimeters (cm) from application angle A. The calculations for resistance were made as if two pieces of blue-colored Thera-Band® tubing (Hygienic Corporation; Akron, Ohio) were measured and cut; one for application angle A and one for application angle B. The initial tubing length was calculated to be the length of the subject's arm subtracted from the measured distance between the application angle attachment point and the involved shoulder's internal/external rotation axis at the elbow joint. For example, when a tubing length was calculated for a forearm length of 32 cm, the length was calculated to be 89.9 cm for application angle A. This resulted by subtracting the forearm length (32 cm) from the calculated length between the shoulder's rotation axis at the elbow to application angle A (121.9 cm). Therefore, when a tubing length was calculated for a forearm length of 32 cm, the calculated length between the shoulder's rotation axis at the elbow joint and application angle B was calculated to be 126 cm. Next, the forearm length (32 cm) was subtracted from 126 cm, which resulted with a calculated initial tubing length of 94 cm.

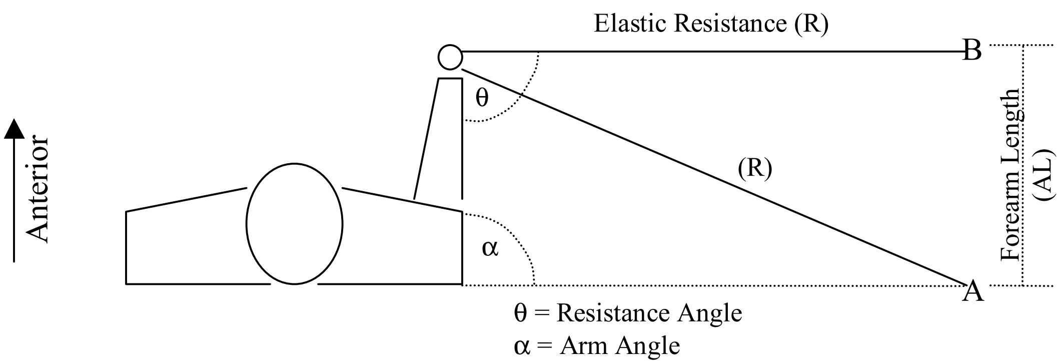

Figure 4. Application Angles A and B. Schematic of application angles for elastic resistance for internal rotation. This view is as if looking straight down from above the subject. The first anchor location (A) was to the side of the subject, on the same line of the transverse axis that goes through the humeroradial joint. The second anchor location (B) was anterior to the first, which was the measured distance taken from the axis of rotation to the center of the handle on the arm of the strength apparatus. The resistance torque (T_r) was calculated using the formula, $T_r = AL \times R (\sin \theta)$.

The resistance torque was calculated using the equation $T_r = AL \times R (\sin \theta)$, where T_r = the resistance torque created about the shoulder joint, AL = the arm length of the subject, R = elastic resistance force, and $\sin \theta$ = the angle created by the subject's arm and the elastic tubing (see Figure 4). The resistance force produced by the elastic tubing was calculated using the regression equation $Y = 0.03 (x) + 3.07$, where Y = predicted tubing tension (F_r), and x = percent change in tubing length (Hughes et al., 1999). The experimental resistance torque curves for internal and external rotation were generated by plotting T_r against the joint angle through the ROM.

Design and Analysis

The design of this study was experimental. The primary dependent variables were muscle torque (experimentally determined) and resistance torque (theoretically determined) at 30°, 45°, 60°, 75°, 90°, 105°, 120°, and 135°. The independent variables were the application angle and the curve type. The independent variable, application angle, had two levels: a) directly to the side of the subject, on the same line of the transverse axis that goes through the humeroradial joint, and b) anterior to the first location which was the measured distance taken from the axis of rotation to the center of the handle on the arm of the strength apparatus. The independent variable, curve type, had two levels: a) strength curve and b) resistance curve.

To evaluate the problem, three comparisons were made for each direction of shoulder rotation. First, differences between the resistance curves for the two application angles were calculated using a 2 x 8 repeated measures ANOVA. If a significant main effect for joint angle was observed, pairwise comparisons were made using the Bonferroni test. If a significant interaction between joint angle and application angle was observed, dependent *t*-tests were used to examine torque differences between the two application angles at each joint angle. The *p*-value for the dependent *t*-tests were adjusted for eight comparisons using the Bonferonni technique (.05/8), therefore, significance was accepted at the 0.00625 level.

Second, differences between the strength curve and the resistance curve at application angle A were determined using a one-way repeated measures ANOVA for both internal and external rotation. Third, differences between the muscle torque and the resistance torque at application angle B were determined using a one-way repeated measures ANOVA. These two comparisons allowed the investigator to determine which application angle of resistance best matched the strength curve of the shoulder internal and external rotators. To simplify the resistance vs. strength comparisons, the torque values for the resistance curves were scaled so that the resistance torque value at 30° equaled the strength torque value at 30°. The resistance torque values for the remaining joint angles were then scaled, using this initial value. Mean differences between the strength and resistance torque values at each joint angle were then calculated and used as the dependent variable for the one-way repeated measures ANOVAs. If a significant main effect was observed, pairwise comparisons were made using the Bonferroni technique. The pairwise comparisons allowed the investigator to determine where there was a difference between the two curves. A significant difference between the mean torque differences indicated that the curves no longer paralleled each other, indicating that the curves were shaped differently.

All statistical analyses were calculated using SPSS for Windows (v.10.0, SPSS, Inc.). For each comparison, significance was at the 0.05 level.

CHAPTER 4

RESULTS AND DISCUSSION

The purpose of this study was to develop experimental strength curves for the internal and external rotators of the shoulder in the neutral position and calculate theoretical resistance curves for two different application angles to see which angle best replicated the strength curves. The results of this study are presented in this chapter as follows: a) pilot study, b) subjects, c) comparison of application angles for internal and external rotation resistance curves, d) comparison of strength curves to resistance curves for internal and external rotation, and e) discussion of the results.

Pilot Study

To establish test-retest reliability of the strength apparatus for this study, a pilot study was conducted prior to this investigation using five volunteer subjects. These subjects were recruited from graduate students attending East Tennessee State University who held graduate assistantship positions with the BucSports Athletic Medicine Center (East Tennessee State University; Johnson City, TN). The subjects were tested on two separate days with a maximum of one-day rest. The researcher collected shoulder internal and external rotation isometric strength from each subject using the procedures described in the previous chapter. Also, the pilot study allowed the researcher to identify flaws and correct them before data collection of this study. The averaged measure intraclass correlation coefficient (ICC) was calculated to establish reliability across trials and across days. The ICC values across trials ranged from 0.929 – 0.999 (M = 0.990, SD = 0.014) which were slightly higher than the ICC values across days that ranged from 0.929 – 0.999 (M = 0.975; SD = 0.022). The ICC and the standard error of the measurement (*SEM*) values are presented in Table 1. These results demonstrated that the angles of internal and external rotation on the strength apparatus were reproducible with ample test-retest reliability. Furthermore, the researcher found the test session to last approximately one hour per subject.

The pilot study also served to provide the researcher with information concerning any flaws that needed to be corrected before the study. The researcher found it necessary to remind the subjects before the contraction trials at each angle to maintain the proper posture and use correct form during the isometric contractions. In addition, one subject performed an isometric contraction in the opposite rotational direction for one trial. In order to prevent further occurrences, the researcher decided to remind the subjects between each angle during the test session of the direction in which to perform the contractions.

Table 1
Test-Retest Reliability for the Strength Apparatus

	Internal rotation				External rotation			
Joint	Across trials		Across days		Across trials		Across days	
angle	ICC	*SEM*	ICC	*SEM*	ICC	*SEM*	ICC	*SEM*
30	0.993	3.5	0.983	4.8	0.954	1.1	0.959	1.1
45	0.998	1.6	0.998	1.8	0.929	2.0	0.962	1.4
60	0.999	1.3	0.999	1.3	0.990	0.8	0.929	2.1
75	0.999	0.9	0.982	5.2	0.994	0.7	0.934	2.2
90	0.998	1.3	0.989	3.4	0.985	1.6	0.996	0.9
105	0.999	0.8	0.978	4.0	0.997	0.9	0.983	2.2
120	0.994	1.7	0.971	3.8	0.997	1.9	0.990	2.2
135	0.995	1.2	0.958	3.4	0.998	0.9	0.994	1.7

Note. ICC = intraclass correlation coefficient; *SEM* = standard error of the measurement (Nm).

Subjects

Thirty volunteer subjects (15 men, 15 women) participated in this study. Subjects were recruited from BucSports Athletic Medicine Center; various physical activity classes in the Department of Physical Education, Exercise and Sport Sciences; and the Human Performance Laboratory at East Tennessee State University. Subject demographics are presented in Table 2. In addition, 26 of the 30 subjects were of White ethnicity, and 4 of the 30 subjects were of Black ethnicity. All subjects were right hand dominant and did not have a history of shoulder pathology with the dominant arm. Each subject signed an informed consent approved by the East Tennessee State University's Institutional Review Board.

Table 2
Subject Demographics

Variable	*M* ± *SD*	Minimum	Maximum
Age (years)	21.9 ± 2.6	18.0	27.0
Height (cm)	170.1 ± 20.1	76.3	195.6
Weight (kg)	78.1 ± 15.3	50.1	116.9
Forearm Length (cm)	32.4 ± 2.5	28.0	38.9

Comparison of Application Angles for Internal and External Rotation Resistance Curves

A 2 x 8 (application angle by joint angle) repeated measures ANOVA was used to determine differences between the shape of the shoulder internal rotation resistance curves A and B. Significant ($p < 0.001$) main effects were found for both application angle and joint angle. Furthermore, there was a significant ($p < 0.001$) application angle by joint angle interaction, indicating a difference in the shape of the two resistance curves. Pairwise comparisons for each joint angle demonstrated that the resistance torques at each angle were significantly different ($p < 0.001$) from each other through the range of motion (ROM). In order to examine the differences in resistance torque between application angles (A and B), dependent *t*-tests were calculated at joint angles 30°, 45°, 60°, 75°, 90°, 105°, 120°, and 135°. Significant differences ($p < 0.001$) were found for all torque values through the ROM between application angles A and B. The means and standard deviations of the resistance torque values through the ROM for shoulder internal rotation resistance curves A and B, as well as the results for the dependent *t*-tests, are presented in Table 3. Graphical representation of internal rotation resistance curves A and B are depicted in Figure 5.

Table 3
Statistical Results for Shoulder Internal Rotation Theoretical Resistance Curves

Joint angle (degrees)*	Resistance torque (Nm) application angle A*	Resistance torque (Nm) application angle B*	*t*	*p*
30	2.3 ± 0.3	1.1 ± 0.0	27.5	<0.001
45	3.5 ± 0.4	2.3 ± 0.2	25.5	<0.001
60	4.5 ± 0.6	3.4 ± 0.3	23.9	<0.001
75	5.3 ± 0.7	4.4 ± 0.5	22.3	<0.001
90	5.7 ± 0.7	5.2 ± 0.6	19.6	<0.001
105	5.7 ± 0.7	5.6 ± 0.7	9.5	<0.001
120	5.2 ± 0.7	5.6 ± 0.7	56.4	<0.001
135	4.3 ± 0.6	5.1 ± 0.7	34.0	<0.001

Note. Values are based on *M* and *SD*. Nm = Newton-meters. * = significant ($p < 0.001$) application angle by joint angle interaction, indicating a difference between the shapes of the two curves. The *p*-values are presented for the dependent *t*-tests, which indicated differences in resistance torque between application angles A and B for each joint angle through the ROM.

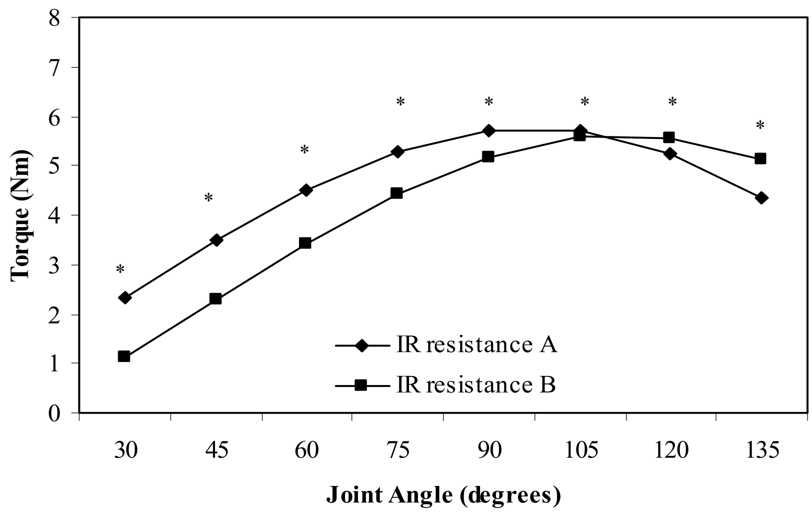

Figure 5. Internal Rotation Resistance Curves. Theoretical resistance curves calculated for shoulder internal rotation for application angles A and B. Asterisk (*) represents significant difference in resistance torque ($p < 0.001$) between the application angles at the respective joint angle.

The shape of the internal rotation resistance curves for application angles A and B were categorized as ascending-descending curves. The resistance produced from application angle A created a greater resistance peak torque (5.7 ± 0.7 Nm) than application angle B (5.6 ± 0.7 Nm). The peak resistance torque for application angle A occurred at joint angles 90° and 105°, whereas the peak resistance torque for application angle B occurred later in the ROM at joint angles 105° and 120°. The least amount of resistance occurred at joint angle 30° (the starting position for the internal rotation exercises) for both application angles A and B, with resistance torques starting at 2.3 ± 0.3 Nm and 1.1 ± 0.0 Nm, respectively. The resistance torque provided from application angle A was significantly ($p < 0.001$) greater than application angle B for the first six joint angles (30° - 105°) in the ROM. The two curves crossed after joint angle 105° as resistance curve A began to descend and resistance curve B was at its peak. Thus, after joint angle 105° application angle B provided significantly ($p < 0.001$) greater resistance torques for joint angles 120° and 135°.

A 2 x 8 (application angle by joint angle) repeated measures ANOVA was used to determine differences between the shape of the shoulder external rotation resistance curves A and B. Significant ($p < 0.001$) main effects were found for both application angle and joint angle. Furthermore, there was a significant ($p < 0.001$) application angle by joint angle interaction, indicating a difference in the shape of the two resistance curves. Pairwise comparisons for each joint angle demonstrated that the resistance torques at each angle were significantly different ($p < 0.001$) from each other through the range of motion (ROM). In order to examine the differences in resistance torque between application angles (A and B), dependent *t*-tests were calculated at joint angles 30°, 45°, 60°, 75°, 90°, 105°, 120°, and 135°. Significant differences ($p < 0.001$) were found for all torque values through the ROM between application angles A and B. The means and standard deviations of the resistance torque values through the ROM for shoulder external rotation resistance curves A and B, as well as the results for the dependent *t*-tests, are presented in Table 4. Graphical representation of external rotation resistance curves A and B are depicted in Figure 6.

Table 4
Statistical Results for Shoulder External Rotation Theoretical Resistance Curves

Joint angle*	Resistance torque (Nm) application angle A*	Resistance torque (Nm) application angle B*	*t*	*p*
30	4.3 ± 0.6	5.1 ± 0.7	27.5	<0.001
45	5.2 ± 0.7	5.6 ± 0.7	25.5	<0.001
60	5.7 ± 0.7	5.6 ± 0.7	23.9	<0.001
75	5.7 ± 0.7	5.2 ± 0.6	22.3	<0.001
90	5.3 ± 0.7	4.4 ± 0.5	19.6	<0.001
105	4.5 ± 0.6	3.4 ± 0.3	9.5	<0.001
120	3.5 ± 0.4	2.3 ± 0.2	56.4	<0.001
135	2.3 ± 0.3	1.1 ± 0.0	34.0	<0.001

Note. Values are based on *M* and *SD*. Nm = Newton-meters. * = significant ($p < 0.001$) application angle by joint angle interaction, indicating a difference between the shapes of the two curves. The *p*-values are presented for the dependent *t*-tests, which indicated differences in resistance torque between application angles A and B for each joint angle through the ROM.

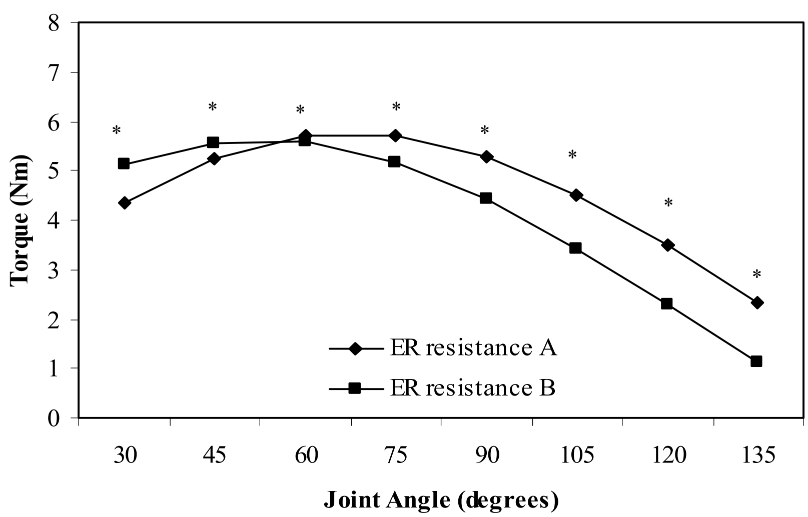

Figure 6. External Rotation Resistance Curves. Theoretical resistance curves calculated for shoulder external rotation for application angles A and B. Asterisk (*) represents significant difference in resistance torque ($p < 0.001$) between application angles at the respective joint angle.

The shape of the external rotation resistance curves for application angles A and B were categorized as ascending-descending curves. The resistance produced from application angle A created a greater resistance peak torque (5.7 ± 0.7 Nm) than application angle B (5.6 ± 0.7 Nm). The peak resistance torque for application angle A occurred at joint angles 60° and 75°, whereas the peak resistance torque for application angle B occurred at joint angles 45° and 60°. The resistance torque provided from application angle B was significantly ($p < 0.001$) greater than application angle A for joint angles 30° and 45°. The two curves crossed after joint angle 45° which resulted with application angle A providing a significantly ($p < 0.001$) greater resistance torque for joint angles 60° through 135°.

Comparison of Strength Curves to Resistance Curves for Internal and External Rotation

Thirty subjects performed isometric strength trials for shoulder internal and external rotation at joint angles 30°, 45°, 60°, 75°, 90°, 105°, 120°, and 135°. The strength data were used to generate strength curves to evaluate the strength capabilities of the shoulder internal and external rotators through the ROM. These data were compiled and compared to the calculated theoretical resistance curves to determine whether application angle A or application angle B was the more appropriate position for shoulder internal and external rotation strengthening exercises.

To analyze these data a constant value was used to scale the resistance curves for each subject. This constant was determined by subtracting the resistance torque from the strength torque at 30°. This constant was then added to each resistance torque value through the ROM so that the resistance torque value at 30° equaled the strength torque value at 30° for each subject. One-way repeated measures ANOVAs were used to determine differences between the strength and resistance curves for internal and external rotation of the shoulder.

Internal Rotation Strength and Resistance Curves

For resistance curve A, a significant ($p < 0.001$) angle effect was observed, which indicated that the strength curve and resistance curve were different. The means and standard deviations of the torque values through the ROM for the internal rotation strength curve and scaled resistance curve A are presented in Table 5. Graphical representation of the internal strength curve and scaled resistance curve A are depicted in Figure 7.

Table 5
Results for the Comparison of the Internal Rotation Strength Curve Compared to the Internal Rotation Resistance Curve A

Joint angle	Internal Rotation Strength Curve (Nm)	Internal Rotation Resistance Curve A (Nm)†
30	36.4 ± 18.5	36.4 ± 18.5
45	38.4 ± 19.0	37.6 ± 18.5
60	39.6 ± 19.4	38.6 ± 18.6
75	39.1 ± 18.8	39.4 ± 18.6
90	38.2 ± 17.7	39.8 ± 18.6
105*	33.9 ± 15.8	39.8 ± 18.6
120*	31.5 ± 14.2	39.3 ± 18.6
135*	28.4 ± 12.5	38.4 ± 18.6

Note. Values are based on *M* and *SD*. Nm = Newton-meters. † = the resistance torque values are scaled for statistical analysis. * = significant difference in torque ($p < 0.05$) between the strength and resistance curves, indicating a difference between the two curves at these joint angles.

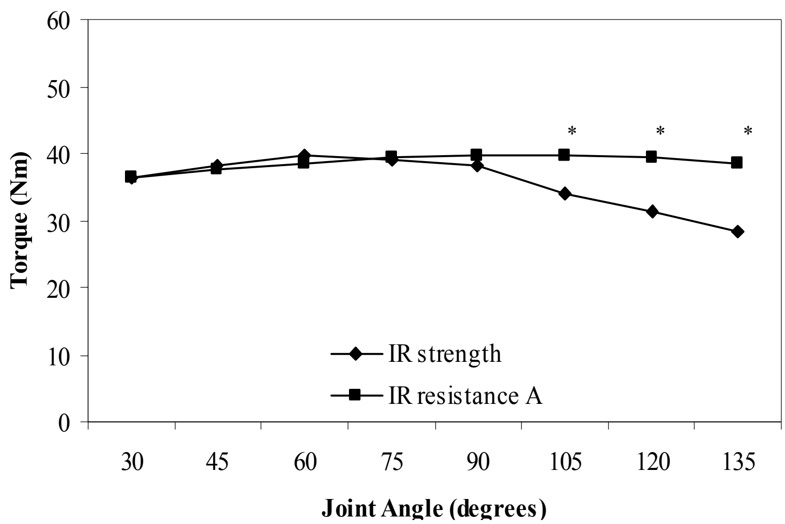

Figure 7. Internal Rotation Strength Curve Compared to Internal Rotation Resistance Curve A. The curves represent the mean torques for all subjects ($N = 30$) at the respective joint angles. Asterisk (*) represents significant difference ($p < 0.05$) between the strength and scaled resistance curves at the respective joint angles.

The mean difference between the two curves was not significantly different from 30° to 90°, indicating that the shapes of the two curves were similar through this part of the ROM. The strength curve peaked (39.6 ± 19.4 Nm) at joint angle 60°. After 90°, the two curves began to diverge, as indicated by the results from the pairwise comparisons. Significant differences ($p < 0.05$) were found at joint angles 105°, 120°, and 135° with differences between the two curves of 5.8 Nm (15%), 7.9 Nm (20%), and 10.0 Nm (26%), respectively. The strength curve decreased in torque through the remaining ROM. Resistance curve A continued to increase in torque and peaked (39.8 ± 18.6 Nm) at joint angles 90° and 105°. From there, it gradually decreased through the remaining ROM.

For resistance curve B, a significant ($p < 0.001$) angle effect was observed, which indicated that the strength curve and resistance curve were different. The means and standard deviations of the torque values through the ROM for the internal rotation strength curve and scaled resistance curve B are presented in Table 6. Graphical representation of the internal strength curve and scaled resistance curve B are depicted in Figure 8.

Table 6
Results for the Comparison of the Internal Rotation Strength Curve Compared to the Internal Rotation Resistance Curve B

Joint angle	Internal Rotation Strength Curve (Nm)	Internal Rotation Resistance Curve B (Nm)†
30	36.4 ± 18.5	36.4 ± 18.5
45	38.4 ± 19.0	37.6 ± 18.5
60	39.6 ± 19.4	38.7 ± 18.6
75	39.1 ± 18.8	39.7 ± 18.6
90	38.2 ± 17.7	40.5 ± 18.7
105*	33.9 ± 15.8	40.9 ± 18.7
120*	31.5 ± 14.2	40.9 ± 18.7
135*	28.4 ± 12.5	40.4 ± 18.7

Note. Values are based on *M* and *SD*. Nm = Newton-meters. † = the resistance torque values are scaled for statistical analysis. * = significant difference in torque ($p < 0.05$) between the strength and resistance curves, indicating a difference between the two curves at these joint angles.

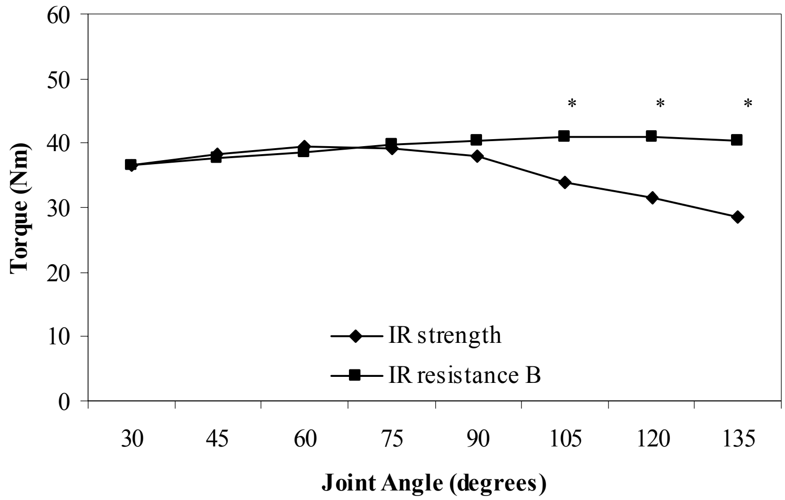

Figure 8. Internal Rotation Strength Curve Compared to Internal Rotation Resistance Curve B. The curves represent the mean torques for all subjects (*N* = 30) at the respective joint angles. Asterisk (*) represents significant difference ($p < 0.05$) between the strength and scaled resistance curves at the respective joint angle.

The mean difference between the two curves was not significantly different from 30° to 90°, indicating that the shapes of the two curves were similar through this part of the ROM. The strength curve peaked (39.6 ± 19.4 Nm) at joint angle 60°. After 90°, the two curves began to diverge, as indicated by the results from the pairwise comparisons. Significant differences ($p < 0.05$) were found at joint angles 105°, 120°, and 135° with differences between the two curves of 6.9 Nm (17%), 9.4 Nm (23%), and 12.0 Nm (30%), respectively. The strength curve decreased in torque through the remaining ROM. Resistance curve B continued to increase in torque and peaked (40.9 ± 18.7 Nm) at joint angles 105° and 120°. From there, it gradually decreased through the remaining ROM.

External Rotation Strength and Resistance Curves

For resistance curve A, a significant ($p < 0.001$) angle effect was observed, which indicated that the strength curve and resistance curve were different. The means and standard deviations of the torque values through the ROM for the external rotation strength curve and scaled resistance curve A are presented in Table 7. Graphical representation of the external strength curve and scaled resistance curve A are depicted in Figure 9.

Table 7
Results for the Comparison of the External Rotation Strength Curve Compared to the External Rotation Resistance Curve A

Joint angle	External Rotation Strength Curve (Nm)	External Rotation Resistance Curve A (Nm)†
30	18.9 ± 8.0	18.9 ± 8.0
45	22.0 ± 8.2	19.8 ± 8.1
60	23.4 ± 8.9	20.3 ± 8.1
75	26.8 ± 10.3	20.3 ± 8.0
90	28.2 ± 11.4	19.9 ± 8.1
105	29.1 ± 13.1	19.1 ± 8.0
120	29.9 ± 14.1	18.1 ± 7.9
135	30.0 ± 14.8	16.9 ± 7.9

Note. Values are based on *M* and *SD*. Nm = Newton-meters. † = the resistance torque values are scaled for statistical analysis. Statistical analysis indicated that there was a gradual divergence of the torques across the joint angles. For a complete discussion of the statistical analysis, please see text.

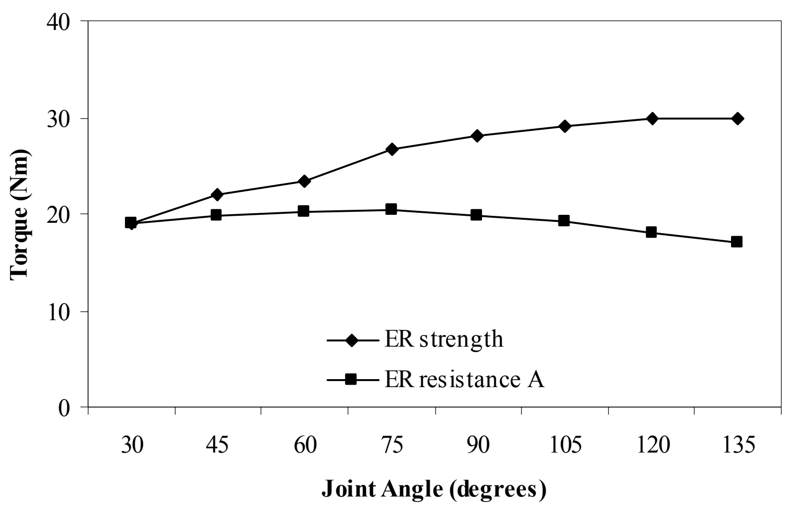

Figure 9. External Rotation Strength Curve Compared to External Rotation Resistance Curve A. The curves represent the mean torques for all subjects (*N* = 30) at the respective joint angles. Statistical analysis indicated that there was a gradual divergence of the torques across the joint angles. For a complete discussion of the statistical analysis, please see text.

The shape of the external rotation strength curve was categorized as an ascending curve, while resistance curve A was categorized as an ascending-descending curve. The results of the pairwise comparisons indicated that the two curves diverged from each other after 30°. Significant differences were not observed between 45° and 60°, 75° and 90°, 90° and 105°, and 120° and 135°. However, all other pairwise comparisons ($p < 0.05$) were significantly different, indicating a gradual divergence of the two curves across joint angle. The rate at which the two curves diverged was slow, but the results indicate that the curves are different from each other throughout the entire ROM. The external rotation strength curve gradually increased in torque from 18.9 Nm at 30° to 30 Nm at 135°. The resistance curve started with a torque of 18.9 Nm at joint angle 30°, increased to its peak of 20.3 Nm at 60° and 75°, and then decreased gradually to 16.9 Nm at 135°. Percent differences between the curves ranged from 10% at 45° to 44% at 135°.

For resistance curve B, a significant ($p < 0.001$) angle effect was observed, which indicated that the strength curve and resistance curve were different. The means and standard deviations of the torque values through the ROM for the external rotation strength curve and scaled resistance curve B are presented in Table 8. Graphical representation of the external strength curve and scaled resistance curve B are depicted in Figure 10.

Table 8

Results for the Comparison of the External Rotation Strength Curve Compared to the External Rotation Resistance Curve B

Joint angle	External Rotation Strength Curve (Nm)	External Rotation Resistance Curve B (Nm)†
30	18.9 ± 8.0	18.9 ± 8.0
45	22.0 ± 8.2	19.4 ± 8.0
60	23.4 ± 8.9	19.4 ± 8.0
75	26.8 ± 10.3	19.0 ± 7.8
90	28.2 ± 11.4	18.3 ± 7.9
105	29.1 ± 13.1	17.3 ± 7.8
120	29.9 ± 14.1	16.1 ± 7.8
135	30.0 ± 14.8	15.0 ± 7.7

Note. Values are based on *M* and *SD*. Nm = Newton-meters. † = the resistance torque values are scaled for statistical analysis. Statistical analysis indicated that there was a gradual divergence of the torques across the joint angles. For a complete discussion of the statistical analysis, please see text.

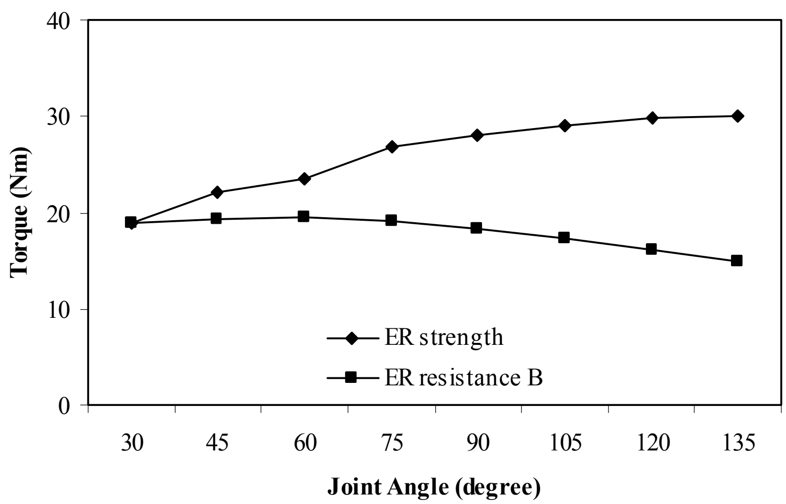

Figure 10. External Rotation Strength Curve Compared to External Rotation Resistance Curve B. The curves represent the mean torques for all subjects (*N* = 30) at the respective joint angles. Statistical analysis indicated that there was a gradual divergence of the torques across the joint angles. For a complete discussion of the statistical analysis, please see text.

The shape of the external rotation strength curve was categorized as an ascending curve, while resistance curve B was categorized as an ascending-descending curve. The results of the pairwise comparisons indicated that the two curves diverged from each other after 30°.

Significant differences were not observed between 45° and 60°, 90° and 105°, and 120° and 135°. However, all other pairwise comparisons ($p < 0.05$) were significantly different, indicating a gradual divergence of the two curves across joint angle. The rate at which the two curves diverged was slow, but the results indicate that the curves are different from each other throughout the entire ROM. The external rotation strength curve gradually increased in torque from 18.9 Nm at 30° to 30 Nm at 135°. The resistance curve started with a torque of 18.9 Nm at joint angle 30°, increased to its peak of 19.4 Nm at 45° and 60°, and then decreased gradually to 15.0 Nm at 135°. Percent differences between the curves ranged from 12% at 45° to 50% at 135°.

Discussion of the Results

Progressive overload through the ROM is important for proper rehabilitation of muscle strength, yet this varies across types of resistance for a given exercise. Elastic resistance is commonly used in shoulder rehabilitation. Some of the most common exercises performed by patients in the clinic, athletic training room, or at home are shoulder internal and external rotation exercises with the upper arm positioned down by the side in a neutral position. However, the application angle of this resistance is not usually controlled during the exercises. Therefore, the purpose of this study was to compare strength curves for shoulder internal and external rotation with resistance curves for two application angles (A and B) of Thera-Band® resistance to determine which application angle best overloads the muscles through the ROM. The following discussion includes the following topics: a) internal and external rotation strength measurements, b) comparison of resistance curves for internal and external rotation, and c) comparison of strength curves to resistance curves for internal and external rotation.

Internal and External Rotation Strength Measurements

Numerous investigators have previously examined shoulder internal and external rotation strength, although comparisons across studies are difficult due to the variation in sample characteristics and measurement methodology. Variations in measurement methodology include load conditions, movement speed, shoulder position, and stabilization restraints, which result in differences in the magnitudes and positions of peak strength for the joint motion. In terms of joint position, the general consensus in the literature is that shoulder internal and external rotation strength should be tested in the plane of the scapula (approximately 30° to 45° anterior to the coronal plane) (Kramer & Ng, 1996; Kuhlman et al., 1992; Malerba, Adam, Harris, & Krebs, 1993; Timm, 1997). It has been shown that testing in the plane of the scapula places the internal and external rotators in the most efficient position for producing torque by (1) maximizing joint congruency between the scapula and humerus, thereby increasing the stability of the glenohumeral joint; (2) minimizing the risk of soft tissue impingement between the humerus and the undersurface of the acromion; and therefore, (3) increasing patient comfort during testing (Kramer & Ng; Kuhlman et al.; Malerba et al.; Timm). The use of different shoulder joint positions during testing results in differences in the shape and magnitude of the reported strength curves because of changes in moment arm lengths and length-tension relationships in the various muscles of the shoulder. The strength curves for this study were collected with the shoulder in the neutral position and subjects standing in a position that is similar to that most often recommended for clinical conditions when performing strengthening exercises for internal and external rotation. Only the arm being tested was restrained by straps. To stabilize other body segments, subjects were instructed to resist their movements by their own strength, similar to what is normally performed in rehabilitation.

The shoulder internal rotation strength values reported in this study are similar to values reported previously by Kramer and Ng (1996). They reported an isometric internal rotation torque of 43 ± 21 Nm. However, the position of the arm was in the scapular plane, and the strength measurements were only taken at one joint angle. The joint angle was described as being at the mid-position of shoulder rotation. Therefore, their values may not represent peak torque. Mayer, Horstmann, Röcker, Heitkamp, and Dickhuth (1994) reported isometric strength for males and females with the arm positioned in the plane of the scapula. Isometric strength was collected at various positions through the ROM, though, these positions were not specified. Peak torques occurred between -20° and 23° (70° - 113° using this study's reference system), with peak torques of 43 ± 12 Nm and 21 ± 7 Nm for males and females, respectively. The only similarities between Mayer and the present study were the peak torques for females (21 ± 7 Nm vs. 24.7 ± 6.5 Nm, respectively). However, the peak torque for males (43 ± 12 Nm vs. 54.6 ± 16 Nm), and the location of peak torque in the ROM for both males and females (70° - 113° vs. 60°) were different from that reported in our study.

The shoulder external rotation strength values reported in this study are also similar to values reported previously by Kramer and Ng (1996). They reported isometric external rotation with a torque of 32 ± 13 Nm. These strength data were collected with the arm in the scapular plane, and the strength measurements were taken at only one joint angle. Again, their values may not represent peak values. Mayer et al. (1994) also reported external rotation strength data for men and women. Peak torques occurred between joint angles -45° and 12° (45° - 102° using this study's reference system), with peak torque values of 30 ± 10 Nm and 15 ± 5 Nm, respectively. Again, the subjects' shoulders were positioned in the plane of the scapula. Neither the peak torques (males 39.6 ± 15.5 Nm; females 20.7 ± 3.9 Nm) nor the location of peak torques in the ROM (males 135°; females 120°) were similar to the current study.

The results of Mayer et al. (1994) are most likely different from our values because of the differences in arm position between the two studies. The different position caused a change in the length tension and moment arm lengths of the muscles, which would therefore cause changes in the strength data. These differences in peak torques between Mayer and the present study correspond with the findings of Kuechle et al. (2000), who examined muscle moment arm lengths of the shoulder. Kuechle found that when the humerus was moved from the neutral position to the scapular plane, the mean moment arms of the subscapularis (neutral 2.18 cm; scapular 1.75 cm), pectoralis major (1.84 cm; 1.56 cm), and anterior deltoid (0.68 cm; 0.32 cm) muscles decreased for shoulder internal rotation. The same was found for external rotation with decreased mean moment arms in the infraspinatus (-2.34 cm; -1.61 cm), teres minor (-2.00 cm; -1.94 cm), and posterior deltoid (-0.39 cm; 0.01 cm). Furthermore, previous studies have shown that the length-tension relationship of an active muscle is bell-shaped, meaning maximum contraction occurs when there is an optimal overlap of the thick and thin muscle filaments (Bobbert, Ettema, & Huijing, 1990; Kaufman, An, & Chao, 1989). When the filaments are stretched, as when the humerus is moved from the neutral position to the scapular plane, the overlap of thick and thin filaments is decreased, which shifts the position where potential maximum muscle force occurs to later in the ROM. Thus, a decrease in moment arm lengths and a change in the position of potential maximum muscle force equals a decrease in internal and external rotation torque and a change in the position of the peak torque in the ROM.

According to the author's knowledge, no previous studies have developed isometric strength curves for shoulder internal rotation with the shoulder in the neutral position. Timm (1997) developed an isokinetic strength curve for shoulder internal rotation. The strength curve was collected at 60°/s during concentric muscle actions. No quantitative data were presented by Timm, however, qualitatively the shape of the isokinetic strength curve was similar to the shape of the strength curve developed for the current study with the peaks occurring approximately at the same point in the ROM. Both strength curves were categorized as ascending-descending curves.

The internal rotation strength curve developed in this study was categorized as an ascending-descending strength curve. From the beginning of the ROM (30°), internal rotation torque increased until the curve peaked at 60°, with a peak torque of 39.6 ± 19.4 Nm (males 54.6 ± 16.0 Nm; females 24.7 ± 6.5 Nm). After 60°, internal rotation torque decreased through the remaining ROM. The shape of the strength curve indicated that the moment arms and length-tension relationships of the internal rotators of the shoulder play influential roles in measured strength during internal rotation. According to Kuechle et al. (2000), the moment arm lengths of the subscapularis and anterior deltoid muscles progressively decreased during shoulder internal rotation from a position of full external rotation, while the remaining moment arms of the internal rotators were relatively unchanged through the ROM. Therefore, it seems that the strength curve would be shaped like a descending curve. However, the length-tension relationship may be the more dominant factor as to why the strength curve is ascending-descending. The muscle length changes of the internal rotators from 30° - 60° may be located on the ascending portion of the length-tension curve which explains the increase in torque. The muscles should develop maximal force when there is a maximum overlap of the thick and thin filaments. Then as the muscle shortens past the optimal length for muscle force, the filaments become extensively overlapped and an interference occurs with the cross-bridging of the filaments, which results in a drastic decrease in force. This was considered as to why the torques at the beginning of the ROM were greater than the torques at the end of the ROM.

Kulhman et al. (1992) collected male strength data to develop shoulder external rotation isometric strength curves with the shoulder positioned in the scapular plane. The study found that peak isometric torque occurred at -60° (140° using this study's reference system) with a peak torque of 45.3 ± 7.8 Nm. These results were similar to the male data of the current study where peak torque occurred at 135° with a peak torque of 39.6 ± 15.5 Nm. The difference between the strength curve's largest and smallest torque was similar when comparing Kulhman et al. to our study, with differences being 12.8 Nm and 16.1 Nm, respectively. The shape of the external rotation strength curve is similar when compared to the current study's external rotation strength curve with differences occurring primarily in the magnitude of the curves (see Figure 11). The potential moment arm and force-length changes due to differing arm positions do not explain the magnitudes differences of the two curves.

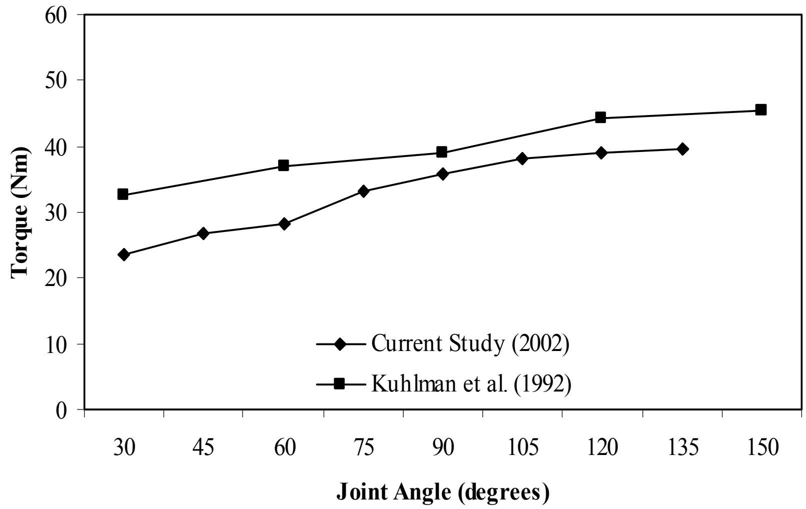

Figure 11. Isometric External Rotation Strength Curves for the Shoulder. The strength curve in the current study was developed with the arm positioned down by the side in the neutral position. Kuhlman et al. (1992) developed strength curves with the arm positioned in the scapular plane. The strength curves used in this figure were developed using male subjects.

The external rotation strength curve developed in this study was categorized as an ascending strength curve according to the reference system. At the beginning of the ROM (135°), external rotation was at its peak (30.0 ± 14.8 Nm). After 135°, the external rotation torque decreased through the remaining ROM. While the shape of the strength curve may indicate that the moment arms of the external rotators play a large role in the beginning ROM, Kuechle et al. (2000) reported that the moment arms of the external rotators remain relatively unchanged during humeral rotation. Therefore, the muscle fiber lengths may be on the descending side of the bell-shaped length-tension relationship curve when the shoulder is in the neutral position. Hence, at 135° the thick and thin filaments were overlapped at the position for optimal muscle tension, and as the shoulder externally rotated the filaments excessively overlapped, causing a decrease in torque through the remaining ROM.

Comparison of Resistance Curves for Internal and External Rotation

Differences in the resistance curves between application angles A and B were were found for both internal and external rotation. However, the differences between the two curves were small, ranging from 1.2 Nm to 0.1 Nm at specific joint angles. All four resistance curves were categorized as ascending-descending curves.

At the beginning of the ROM (30°) for internal rotation, the resistance torque from application angle A (2.3 ± 0.3 Nm) was greater than application angle B (1.1 ± 0.0 Nm). As the shoulder internally rotated the resistance torque from application angle A increased 3.4 Nm to its peak at 90° - 105°, with a peak torque of 5.7 ± 0.7 Nm. However, for application angle B the increase in resistance torque was greater (4.5 Nm) and peaked at 105° - 120°, with a peak torque of 5.6 ± 0.7 Nm. The two curves crossed each other after 105° with resistance torque from application angle B being more than application angle A. The torque from application angle A decreased to 4.3 ± 0.6 Nm, while the torque from application angle B remained at its peak for one more joint angle and then decreased to 5.1 ± 0.7 Nm at the end of the ROM.

For external rotation, the resistance at the beginning of the ROM (135°) was greater from application angle A (2.3 ± 0.3 Nm) than application angle B (1.1 ± 0.0 Nm). As the shoulder externally rotated the resistance torque from application angle A increased only 3.4 Nm to its peak at 75° - 60°, with a peak torque of 5.7 ± 0.7 Nm. However, for application angle B the increase in resistance torque was greater (4.5 Nm), and peaked at 60° - 45°, with a peak torque of 5.6 ± 0.7 Nm. The two curves crossed each other after 60° with resistance torque from application angle B being more than application angle A. The torque from application angle A decreased to 4.3 ± 0.6 Nm, while the torque from application angle B remained at its peak for one more joint angle and then decreased to 5.1 ± 0.7 Nm at the end of the ROM.

The shapes of the resistance curves from application angle A and B, regardless of the direction of shoulder rotation, are different due to changes in the lengths of the moment arms that were created about the shoulder from the elastic resistance. The torque data indicate that the moment arm created from application angle A was larger than the moment arm created from application B during the first six joint angles of the respective direction of shoulder rotation. For the last two joint angles for the respective direction of shoulder rotation the moment arms created from application angle B are larger than the ones for application angle A. If there were no moment arms involved in the movement then the shapes of the resistance curves would no longer be curved since it is known that Thera-Band® increases in resistance linearly (Hughes et al., 1999; Page et al., 2000). If this were so the resistance would appear to increase in a straight line through the ROM of the respective joint movement.

Comparison of Strength Curves to Resistance Curves for Internal and External Rotation

The shapes of the internal rotation resistance and strength curves were categorized as ascending-descending. The two resistance curves were compared to see which one best matched the shape of the strength curve (see Figures 12). The results of the statistical analyses demonstrated that the two resistance curves were not significantly different from the strength curve from 30° to 90°, however, the two curves were different at 105°, 120°, and 135°. Therefore, the statistical analyses demonstrated that the two resistance curves were not different from each other when compared to the strength curve.

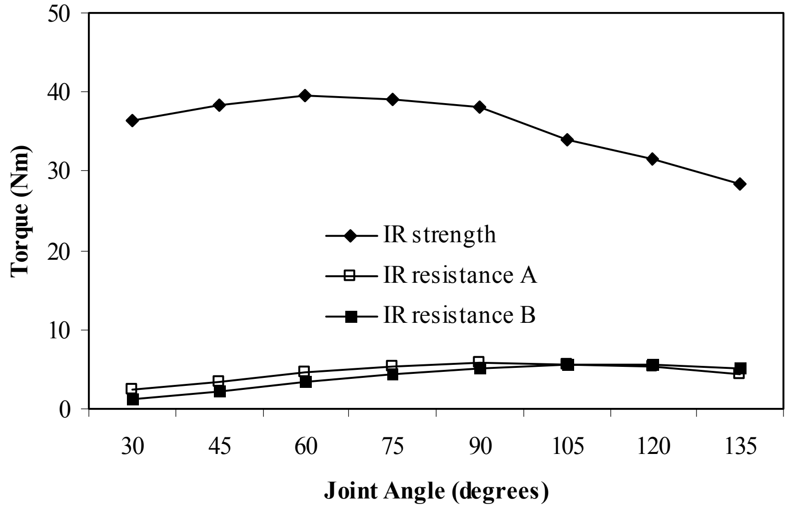

Figure 12. Internal Rotation Strength Curves Compared to Resistance Curves A and B. Graphical comparison of internal rotation strength curve against internal rotation resistance curves from application angles A and B.

One of the main objectives during strength training and rehabilitation is to gain strength. To increase strength, the muscles should be challenged through the full ROM; therefore, the resistance should correspond to the strength of the involved joint motion through the ROM, or to its strength curve (Cabell & Zebas, 1999; Garrett et al., 1988; Kulig et al., 1984). The results of this study suggest that proper strength training for internal rotation would occur only from joint angles 30° through 90° (see Figure 12), regardless of the application angle. The resistance from the blue-colored Thera-Band® provides only 6.3 % - 14.9% and 3% - 13.6% of maximum strength through these joint angles for application angles A and B, respectively. These loads are not sufficient for eliciting strength gains in the normal population. However, when rehabilitating an injured individual, the overload may be sufficient to increase strength. The therapist could even use the two application angles as a progression of exercises, given the 23% difference between them. The individual could start with exercises from application angle B and work towards application angle A, since application angle A provides approximately one Nm (or 23%) more resistance than application angle B. The exercise through the remaining ROM (105°, 120°, and 135°) could be performed by a normal healthy person; however, the person would not be training appropriately in order to overload the muscles in the same manner of the strength curve.

For rehabilitation purposes, it appears that internal rotation exercises should avoid the later part of the ROM. The person may not be able to perform against the resistance, which could bring about potential injury to the already injured individual. Take the example of the person who has had a rotator cuff repair. The larger muscles around the joint may be capable of performing the exercise. The rotator cuff's role during normal joint movement is to counteract the larger muscles and prevent dislocation of the humerus. Thus, due to muscle weakness from the repair, there is a potential for injury to occur because the rotator cuff cannot counteract the larger muscles. After baseline strength is established in the patient the strengthening exercises need to become more intense. Therefore, in the clinical setting these differences between application A and B are probably not important because the two are similar when compared to the strength curve. Most therapists progress the resistance of the exercise by changing to a different band that is thicker (e.g. changing from blue-colored to black-colored Thera-Band® tubing), which has a greater resistance force. This would be more convenient to the therapist and patient by reducing the confusion of which application angle to use when performing the exercises. Furthermore, the magnitude of the strength curve can be increased by starting the exercises with the elastic resistance stretched, thereby, increasing the elastic resistance through the ROM and increasing the resistance torque. The shape of the resistance should be similar since Thera-Band® increases linearly in elastic force.

The shapes of the external rotation resistance curves were categorized as ascending-descending while the external rotation strength curve was categorized as ascending. The results of the statistical analyses demonstrated that the two resistance curves were significantly different from joint angle 30° to 135°. The results showed that the two resistance curves diverge immediately from the strength curve (see Figure 13).

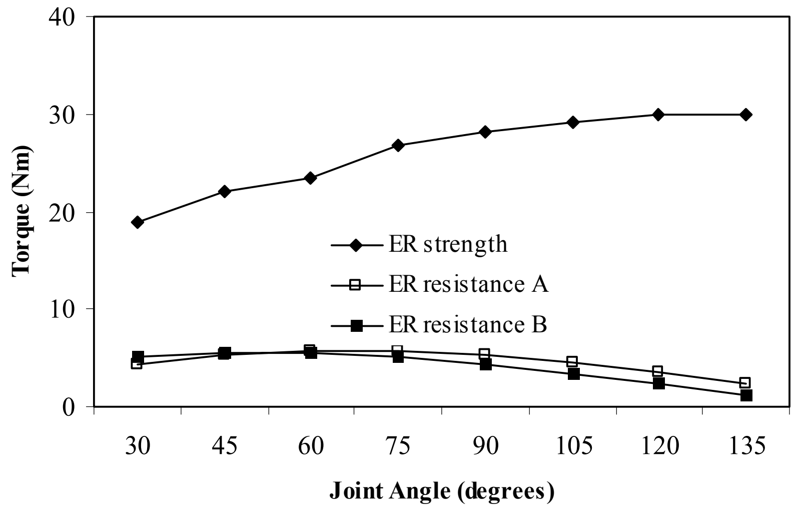

Figure 13. External Rotation Strength Curve Compared to Resistance Curves A and B. Graphical comparison of external rotation strength curve against internal rotation resistance curves from application angles A and B.

From a clinical standpoint, exercises in the neutral shoulder position which use application angles A and B should not be used as a strengthening exercise for the external rotators of the shoulder. Although Thera-Band® provides a resistance through the ROM, the resistance does not correspond to the strength curve at all. This could create a potential injury to an individual who is going through rehabilitation of an injury. Where the individual is the weakest, the resistance is at its highest and where s/he is strongest, the resistance is at its lowest. The person has the potential to start the exercise because the resistance is small; however, as the person externally rotates, the overload on the muscle becomes disproportionately greater. Therefore, the person may stress the muscles inappropriately, which could result in injury. The same example holds true for external rotation where an individual may have a rotator cuff repair. The larger muscles around the joint may be capable of performing the exercise. The rotator cuff's role during normal joint movement is to counteract the larger muscles and prevent dislocation of the humerus. Thus, due to muscle weakness from the repair, there is a potential for injury to occur because the rotator cuff cannot counteract the larger muscles. This especially holds true if the individual is trying to push through the pain.

CHAPTER 5

CONCLUSIONS

Progressive overload through the range of motion (ROM) is important for proper rehabilitation of muscle strength, yet this varies across types of resistance for a given exercise. Elastic resistance is commonly used in shoulder rehabilitation. One of the most common exercises performed by patients in the clinic, athletic training room, or at home is internal and external rotation exercises with the upper arm positioned down by the side in a neutral position. However, the application angle of this resistance is not usually controlled during the exercises. Therefore, the purpose of this study was to compare strength curves for shoulder internal and external rotation with resistance curves for two application angles (A and B) of Thera-Band® resistance to determine which application angle best overloads internal and external rotation through the ROM. This chapter discusses the results of this study in the following areas: a) summary of the results, b) conclusions, and c) recommendations.

Summary of the Results

The following is a summary of the results of this study based on the hypotheses formulated:

H_{A1}: For shoulder internal rotation, there will be a difference between the shapes of the theoretical resistance curves produced at application angle A and B. - SUPPORTED

H_{A2}: For shoulder external rotation, there will be a difference between the shapes of the theoretical resistance curves produced at application angle A and B. - SUPPORTED

H_{A3}: For shoulder internal rotation, there will be a difference between the shape of the theoretical resistance curve calculated for application angle A, and the shape of the experimental strength curve. - SUPPORTED

H_{A4}: For shoulder internal rotation, there will be a difference between the shape of the theoretical resistance curve calculated for application angle B, and the shape of the experimental strength curve. - SUPPORTED

H_{A5}: For shoulder external rotation, there will be a difference between the shape of the theoretical resistance curve calculated for application angle A, and the shape of the experimental strength curve. - SUPPORTED

H_{A6}: For shoulder external rotation, there will be a difference between the shape of the theoretical resistance curve calculated for application angle B, and the shape of the experimental strength curve. - SUPPORTED

Conclusions

The following conclusions were drawn based on the results of this study.

1. The resistance applied from application angle A was statistically different from application angle B for both internal and external rotation exercises for the shoulder in the neutral position.
2. Neither application angle A nor application angle B provided appropriate resistance to create an overload through the entire ROM when performing internal rotation exercises in the neutral position.
3. Neither application angle A nor application angle B provided appropriate resistance to create an overload through the entire ROM when performing external rotation exercises in the neutral position.
4. For internal rotation exercises, the shape of the resistance curve for application angles A or B is not significantly different from the shape of the strength curve from 30° to 90°, and would, therefore, provide an appropriate resistance only through this part of the ROM.

Recommendations

The following recommendations were made for future research relating to this study.

1. Compare the experimental strength curves to experimentally collected resistance curves to examine whether the results from the comparisons made in this study would be replicated with empirical resistance curves.
2. Calculate theoretical strength curves for the internal and external rotators of the shoulder in the neutral position to compare differences with the shape and magnitude of the experimentally collected strength curves.
3. Include a strength training program where subjects use application angle A or application angle B for strengthening exercises and compare pretest and posttest strength data to see if there are any differences between the two application angles for both internal and external rotation.

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APPENDIX
Informed Consent

East Tennessee State University
Veteran's Administration Medical Center
Institutional Review Board

INFORMED CONSENT

PRINCIPAL INVESTIGATORS: Daniel Hannah, ATC; Kathy D. Browder, Ph.D.; Craig E. Broeder, Ph.D.

TITLE OF PROJECT: A Comparison of Strength and Resistance Curves for the Internal and External Rotators of the Shoulder

This Informed Consent will explain about being a research subject in an experiment. It is important that you read this material carefully and then decide if you wish to be a volunteer.

PURPOSE

Strengthening the shoulder plays an integral role in the prevention and rehabilitation of shoulder injuries. One of the more popular forms of resistance used for strengthening the shoulder is elastic bands or tubing. Persons are usually sent home with instructions to tie the elastic band to a doorknob, stand sideways to the door, and proceed with the exercise. Little consideration is given to the angle in which the elastic resistance is applied, and yet it is a very important consideration for producing an appropriate workload for the muscles. Therefore, a person may be doing the exercise in such a way that he/she does not train the muscle, and, consequently, does not benefit from the exercise. The purpose of this study is to examine the effect of two different application angles on the strengthening of the internal and external rotator muscles of the shoulder.

DURATION

This study will require you to attend one testing session. For the testing session, you will come in for one day to test the strength of your shoulder internal and external rotators. This session will last approximately 45 minutes. The testing will be scheduled at your convenience.

PROCEDURES

During the testing session, you will complete a series of tests to measure the strength of your shoulder muscles. Prior to testing you will be asked to participate in a familiarization period where you will be shown how to do the muscle contractions. Then you will be asked to warm up your shoulder with a few practice exercises. Your upper arm and forearm will be strapped to a measuring device that can be moved into different positions. You will be tested in approximately 20-24 different positions for strength at the shoulder. All of the positions will be normal positions that you can reach and maintain comfortably. For each position, you will be asked to push as hard as you can with your hand against a fixed metal surface. A device will be connected to the metal surface so we can measure how much force you are pushing with. You will be asked to push as quickly as you can and as hard as you can, and to hold this contraction for three seconds. You will perform three trials in each position, with 15 seconds of rest between each trial. You will be allowed two minutes of rest between each position.

PRINCIPAL INVESTIGATORS: Daniel Hannah, ATC; Kathy D. Browder, Ph.D.; Craig E. Broeder, Ph.D.

TITLE OF PROJECT: A Comparison of Strength and Resistance Curves for the Internal and External Rotators of the Shoulder

POSSIBLE RISKS/DISCOMFORTS

Your risks are minimal in this study. There is a slight risk of muscle strain during the muscle strength testing, but you will practice and warm up before any of these tests are conducted. The risk to you is no greater than and probably less than that taken if you participated in normal activities of daily living or many types of recreational activity such as basketball, weight training, etc.

POSSIBLE BENEFITS

Although you personally will not benefit from this study, the information gained in this study will provide valuable insight regarding the appropriate use of elastic resistance in strengthening and rehabilitating shoulder internal and external rotation. This study is the first study to examine these questions for the shoulder internal and external rotator muscles.

CONTACT FOR QUESTIONS

If you have any questions, problems, or research-related medical problems at any time, you may call Daniel Hannah at 423-232-0750, Dr. Craig Broeder at 423-439-5380, or Dr. Kathy Browder at 208-885-2192. You may call the Chairman of the Institutional Review Board at 423-439-6134 for any questions you may have about your rights as a research subject.

ALTERNATE PROCEDURES

There are no known alternatives to this study except not to participate.

CONFIDENTIALITY

Every attempt will be made to see that your study results are kept confidential. A copy of the records from this study will be stored in the Department of Physical Education, Exercise and Sport Sciences for at least 10 years after the end of this research. The results of this study may be published and/or presented at meetings without naming you as a subject. Although your rights and privacy will be maintained, the Secretary of the Department of Health and Human Services, the East Tennessee State University/V.A. Medical Center Institutional Review Board, the Food and Drug Administration, and the ETSU Department of Physical Education, Exercise and Sport Sciences have access to the study records. Your records will be kept completely confidential according to current legal requirements. They will not be revealed unless required by law, or as noted above.

PRINCIPAL INVESTIGATORS: Daniel Hannah, ATC; Kathy D. Browder, Ph.D.; Craig E. Broeder, Ph.D.

TITLE OF PROJECT: A Comparison of Strength and Resistance Curves for the Internal and External Rotators of the Shoulder

COMPENSATION FOR MEDICAL TREATMENT

East Tennessee State University (ETSU) will pay the cost of emergency first aid for any injury which may happen as a result of your being in this study. They will not pay for any other medical treatment. Claims against ETSU or any of its agents or employees may be submitted to the Tennessee Claims Commission. These claims will be settled to the extent allowable as provided under TCA Section 9-8-307. For more information about claims call the Chairman of the Institutional Review Board of ETSU at 423/439-6134.

VOLUNTARY PARTICIPATION

The nature demands, risks, and benefits of the project have been explained to me as well as are known and available. I understand what my participation involves. Furthermore, I understand that I am free to ask questions and withdraw from the project at any time, without penalty. I have read, or have had read to me, and fully understand the consent form. I sign it freely and voluntarily. A signed copy has been given to me.

Your study record will be maintained in strictest confidence according to current legal requirements and will not be revealed unless required by law or as noted above.

____
Signature of Volunteer Date

____
Signature of Investigator Date

____
Signature of Witness Date

VITA

DANIEL C. HANNAH

Personal Data:	Date of Birth: June 26, 1978
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