TESTING SHOULDER STRENGTH IN NORMAL SUBJECTS AND SUBJECTS RECOVERING FROM A COMPLETE SHOULDER SEPARATION

by

John B. Frejuk

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MASTER OF PHYSICAL EDUCATION

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ABSTRACT

Testing shoulder strength in normal subjects and subjects recovering from a complete shoulder separation. Frejuk, J.B., University of Manitoba.

The purpose of this study was to develop a protocol using the KINCOM dynamometer to evaluate isokinetic shoulder strength and to compare shoulder strength in injured and uninjured subjects. The protocol was implemented on 20 healthy individuals and 20 patients who were recovering from a third degree acromioclavicular separation. Comparisons were made for peak torque measurements, concentric/eccentric ratios, and agonist antagonist ratios for movements of shoulder flexion, extension, abduction, adduction, internal rotation, external rotation, horizontal abduction, and horizontal adduction at a slow and a fast speed for both concentric and eccentric contraction phases. The control group was utilized for comparison of strength between dominant and non-dominant limbs and 10 of these subjects were used to check the reliability of the newly developed protocol. There were no significant differences ($p<=.01$) between the dominant and non-dominant limbs for the eight movements tested and the protocol was shown to be reliable.

There was a significant reduction (p<=.01) in the peak torque scores of the injured group in shoulder adduction and external rotation. The concentric/eccentric ratios were not affected by the complete AC separation. The flexion/extension ratio was significantly decreased (p<=.01) in the concentric fast test and the internal rotation/external rotation ratios at both speeds and both contraction phases were significantly increased (p<=.01) as a result of the injury. These results indicated that there were several major discrepancies in shoulder strength between normal individuals and individuals recovering from a third degree shoulder separation that should be considered during the rehabilitation period.

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DEDICATION

I dedicate my thesis to my family and to my future wife Christal. Thank you all for your patience and support.

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Chapter I

INTRODUCTION

The shoulder girdle is an intricate association of a number of separate articulations. One of these articulations which plays an important role in the stability and functioning of the shoulder is the acromioclavicular (AC) joint. It is not surprising, then, that a person suffering from a complete AC separation will have experienced not only pain and discomfort but also weakness and stiffness in the injured shoulder.

In order to accurately assess the extent of this strength loss, a reliable and valid protocol must be established which can measure the strength in the numerous movements associated with the shoulder. Although a protocol to test isokinetic shoulder strength is available for use with the Cybex II dynamometer, no such protocol exists for use with the more recently developed Kinetic Communicator Exercise System (KINCOM). The development of a testing protocol using the KINCOM system would allow for more reliable and valid data to be collected. It would also lead to greater consistency of future studies which would allow for a more valid comparison between studies to take place.

The development of a KINCOM shoulder strength testing protocol allows for the comparison of several interesting strength ratios. One of these ratios is the comparison of the dominant and the non-dominant arm for each of the shoulder movements tested. Once a standard dominant versus non-dominant ratio is established, it can be used to determine left-right imbalances. This ipsilateral comparison also allows for a reliable means of monitoring the recovery of an injured athlete.

The concentric versus eccentric strength ratio for each movement along with the agonist versus antagonist strength movements for each arm are also important ratios to be studied. A comparison of these ratios between healthy subjects and subjects who have sustained a recent third degree AC separation may prove to be a useful screening tool for an athlete's return to competition. It is speculated that an imbalance in either of these relationships, either concentric versus eccentric or agonist versus antagonist, may predispose the individual with a recent AC separation to further injury.

Statement of the Problem

There were two main purposes in this study. The first was to develop a protocol using the KINCOM dynamometer to evaluate isokinetic shoulder strength. The second was to compare shoulder strength in subjects with a recent third degree AC separation with uninjured subjects.

The second purpose can be broken into two subproblems, specifically:

1) To compare relationships between concentric and eccentric strength scores for each shoulder movement for both injured and uninjured subjects.

2) To compare the relationships between agonist and antagonist strength scores for four pairs of shoulder movements for both injured and uninjured subjects.

Limitations

The following points must be considered when reviewing this study:

1) The study was conducted using only male subjects between the ages of 18 and 50.

2) All subjects in the injured group suffered from a noncomplicated third degree AC separation.

3) The peak torque values which were measured for each subject were dependent upon the motivation of each subject at the time of testing and his willingness to exert a maximum effort.

4) The measure of strength used in ths study was determined only from peak torque measurements.

Definition of Terms

Third degree AC separation

As used in this paper, a third degree AC separation involves complete dislocation of the AC joint with rupture of the coracoclavicular (CC) ligaments, the AC ligaments, the surrounding capsule, and the fibers of the deltoid and trapezius muscles (Powers and Bach, 1974).

Surgical treatment

As used in this paper, a treatment whereby one of a number of surgical procedures is used to reduce the clavicle through fixation to the acromion process by a screw, wire, or other means.

Conservative treatment

As used in this paper, a treatment in which no surgical procedure is carried out and the injured arm is simply immobilized in a sling or cast for a certain period of time.

Torque

The product of the magnitude of the forces applied and the shortest or perpendicular distance between the lines of action of the two forces (Hay and Reid, 1982).

Peak torque

As used in this paper, the greatest or maximum torque achieved in a specific range of each movement at each speed.

Isokinetic

Movement in which the speed or velocity of the moving limb is kept constant.

Strength

As used in this study, strength is measured by the peak torque value for each test.

Chapter II

REVIEW OF RELATED LITERATURE

2.1 SHOULDER ANATOMY AND FUNCTION

To fully understand how a third degree AC separation may affect the strength of the shoulder, it is first necessary to review the basic anatomy and functioning of the shoulder complex. Special consideration will be given to the acromioclavicular joint. It is important to realize, however, that the shoulder acts as a unit and that all of the articulations involved in the functioning of the shoulder have a special purpose in the many movements that take place in the shoulder girdle.

2.1.1 Skeletal Configuration

The upper limb girdle is designed primarily for mobility with the clavicle being the only bone uniting the upper limb to the axial skeleton. Bony fixation to the vertebral column behind is never achieved as the scapula is allowed to move freely on the chest wall (Basmajian, 1982). The scapula is actually suspended on the lateral end of the clavicle, which enables the shoulder blade to be far enough laterally to allow the arm to swing freely past the chest wall. It is obvious that the articulations between the lateral end of the clavicle and the scapula provide the primary basis for stability in the shoulder girdle (Basmajian, 1984). It is this stability provided by the clavicle and scapula that allows for a great range of movement to occur in the glenohumeral joint.

The shoulder joint is more properly referred to as the glenohumeral joint. It is the articulation between the head of the humerus and the glenoid cavity of the scapula. The glenohumeral joint is a multi-axial ball-and-socket joint which allows movement in all three planes of motion. It is important to realize that many movements occur in the glenohumeral joint alone but that they also very commonly occur with movements of the entire shoulder region (Rockwood and Green, 1984). Movements of the shoulder region primarily involve the clavicle and scapula, while movements in the shoulder joint occur solely between the scapula and the humerus.

The clavicle is situated at the root of the neck with the medial portion articulating with the manubrium. Its medial two thirds is bowed with the convexity forward while the lateral one third is bowed with the concavity forward. The lateral one third is also flat and relatively weak as compared to the medial portion. The lateral end of the clavicle does not reach the 'point of the shoulder' which is entirely formed by the acromion (Basmajian, 1984). The clavicle, instead, forms an articulation with the acromion process approximately two to three centimeters medial to the "point" of the shoulder.

The acromion process is part of the spine of the scapula. The spine of the scapula arises from the posterior vertebral border and as it passes laterally toward the glenoid cavity it gradually increases in prominence until it becomes a free process of bone. This bone which projects above and behind the glenoid cavity is the acromion process. The superior border of the scapula also includes another projection of bone which is known as the coracoid process. This process is also important to the shoulder complex as it too articulates with the clavicle.

2.1.2 The AC Joint

The AC joint is classified as a diarthroidal joint with the articular surfaces being covered with fibrocartilage (Rockwood and Green, 1984). The joint is surrounded by a thin capsule that is reinforced above and below by the superior and inferior AC ligaments and also by the weaker anterior and posterior AC ligaments.

The deltoid and trapezius muscles play a major role in the strengthening and stability of this joint, as fibers from both of these muscles blend with those of the superior aspect of the clavicle and acromion process.

The primary stabilizer of the AC joint is the strong CC ligament (Stewart, 1985). The fibers of this ligament run from the outer inferior surface of the clavicle to the base of the coracoid process of the scapula. The CC ligament is composed of two bands which are sometimes separated by a bursae (Rockwood and Green, 1984). The cone shaped band is the conoid ligament which has its apex attaching on the posteromedial side of the base of the coracoid process and its base attaching onto the conoid tubercle on the posterior undersurface of the clavicle. The trapezoid ligament is the band which arises anterior and lateral to the conoid ligament on the coracoid process and attaches to the rough undersurface of the clavicle. These very strong structures prevent the clavicle from riding upward and dislocating over the acromion process.

Codman (1981), as reported by Rockwood and Green (1984), stated that the AC joint is only slightly movable and that it may twist a little, rock a little, swing a little, slide a little, and also act like a hinge. Rockwood and Green (1984) pointed out some studies which suggested that total range of motion of the AC joint was 20 degrees while in their studies they found only five to eight degrees of motion. Basmajian (1984) refers to the AC joint as being relatively unimportant as it takes little or no part in the transmission of forces. Stewart (1985), on the other hand, suggested that the AC joint has a very important function in supporting the upper part of the shoulder. Stewart (1985) also pointed out that the stability of the AC joint is maintained by the ligaments which surround it. Perhaps a more logical approach in determining the importance of the AC joint is to review the anatomical configuration and functioning of the shoulder following a complete separation of this joint.

2.1.3 Mechanism of Injury to the AC Joint

The principal factors in the mechanism of an AC separation are outlined by Glick, Milburn, Haggerty, and Nishimoto (1977). They include: landing on the point of the shoulder which drives the acromion downward; a blow from behind with the ipsilateral arm fixed on the ground which drives the clavicle forward and away from the acromion; and a fall onto an outstretched arm or elbow causing an outward and backward force on the acromion. Rockwood and Green (1984) suggested that the most common of these mechanisms is a direct force that occurs from a fall on the point of the shoulder. Bailey, Metten, O'Connor, Titus, Baril, and Moosman (1975) indicated that injuries to the AC joint probably parallel the degree of violence to which the joint has been subjected. This means that the displacement in the AC joint is directly related to the degree of stretching or tearing that has occurred in the ligaments and the muscle attachments surrounding the joint.

2.1.4 Pathology of an AC Injury

There is a definite sequence in which the pathological processes occur during the course of the AC separation. Glick et al. (1977) have established the order in which this sequence occurs and have separated this sequence into three distinct steps.

The primary injury is a tear to the AC ligament which allows a slight elevation of the clavicle. The second step involves the tearing or stretching of the deltoid origin and trapezius insertion on the distal end of the clavicle which allows further elevation of the clavicle. A tear or stretch of the CC ligament is the final injury in the sequence which causes even more elevation in the clavicle and is considered to be the best indicator that a complete separation of the AC joint has occurred.

There are a number of other injuries that may occur at the same time as the AC separation. The most common of these is a fracture of the clavicle or the coracoid process which would further complicate the injury (Rockwood and Green, 1984). It is beyond the scope of this paper to include all of these other injuries and as a result the remainder of this section will focus on the uncomplicated AC separation.

2.1.5 Classification of AC Injuries

There are a number of classification schemes which have been developed to describe the various degrees (also commonly referred to as types) of an AC separation. Tossy, Mead, and Sigmond (1963) were the first to describe types of AC separations and divide them into groups. Powers and Bach (1974) pointed out that most authors over the years have followed this outline and consequently it will be used in this review.

The type I injury involves a tear of the AC ligament and capsule with very little elevation of the lateral clavicle and with the AC ligament still intact. The type II separation includes complete rupture of the AC ligaments with a stretch or incomplete rupture of the CC ligaments. Although the clavicle may be elevated, the inferior edge will not be above the superior edge of the acromion process. The type III separation involves the complete dislocation of the AC joint, with rupture of the CC ligaments, the AC ligaments, the capsule surrounding the joint, and the fibers of the deltoid and trapezius muscles. The result of the third degree AC separation is what Powers and Bach (1974) refer to as the 'free floating clavicle'. As Rockwood and Green (1984) suggest, however, the anatomical feature of the third degree separation is the downward sag of the shoulder and not the upward displacement of the clavicle. A correct anatomic diagnosis as to the type and degree of the injury is important when testing the individual and attempting to quantify the strength loss.

2.1.6 Short-term Results of Injury

It is generally agreed in the literature that a certain amount of weakness will be present in the injured shoulder for a short period of time following a complete AC separation (Anzel and Streitz, 1974; Paavolainen, Bjorkenheim, Pakku, and Slatis, 1978; Rosenorn and Brix Pedersen, 1974). There have actually been a number of researchers who have documented specific weaknesses present following a complete AC separation. Walsh, Peterson, Shelton, and Neuman (1985) pointed out that one would expect to find weakness of abduction and flexion in the patient with an incompletely resolved AC injury. Horn (1954), as reported by Glick et al. (1977), studied manual laborers with complete AC separations and reported finding a weakness in forward flexion. Weakness in forward flexion and abduction was also reported in 8 of 34 patients with a complete AC separation by Glick et al. (1977). These researchers documented the weaknesses that were found in the shoulder following a complete AC separation but failed to comment on the possible reasons for these weaknesses.

2.2 MUSCLE IMBALANCES

Muscle imbalance, according to Grace (1985), literally means a lack of balance in the form of either an asymmetry existing between extremities or a differential occurring with an anticipated normal value or ratio. This latter asymmetry can represent a difference between opposing muscle groups within the same extremity (agonist-antagonist imbalance) or a difference between the concentric and eccentric force exerted within one particular muscle group.

Several authors have suggested that a discrepancy of 10 percent or more between the expected agonist-antagonist ratio or between the normal balance of the two extremities represents a muscle imbalance (Gilliam, Sady, Freedson, and Vallanacci, 1979; Mira, Carlisle, and Greer, 1980). Grace (1985) claimed that the actual magnitude of what constitutes balance and imbalance has never been accurately defined. In addition this work (cited above) was generally limited to testing of the lower extremities and the results may not be valid to use when comparing the strength relationships found in the shoulder.

Campbell and Glenn (1979), as reported by Grace (1985), suggested that athletes with previous joint injuries and those whose injuries that have required surgery often had muscle weakness, imbalance, and a high rate of reinjury. Injuries to the joints and soft tissue areas were more prone to occur in muscle groups that were weak or imbalanced (Knight, 1980). This implies that individuals such as those recovering from a complete AC separation may have specific muscle group imbalances that may predispose them to further injury. Rockwood and Green (1984) suggested that an athlete suffering from a grade III AC separation should not be permitted to return to contact sports or undue stress until he/she has regained full strength of the injured shoulder. The question which must now be addressed is how to test athletes to determine if they have fully recovered the strength in their injured limb and to what extent should muscle imbalances be used in making this determination. Grace (1985) pointed out that the use of isokinetic muscle testing has revolutionized the ability to quantify this extremity muscle imbalance and as a result some of these questions may soon be answered.

2.2.1 Agonist-Antagonist Relationships

Grace et al.(1984) suggested that an imbalance between antagonist muscles causes the weaker muscle group to be more vulnerable to stress. This weakness may occur naturally or may be the result of injury. These agonist-antagonist muscle relationships have been studied by a number of researchers, but unfortunately the majority of the studies have been restricted to testing the lower extremities.

The most widely studied agonist-antagonist relationship is that which exists between the quadriceps femoris and the hamstrings, or between knee flexors and knee extensors. A number of researchers have offered what they consider to be the ideal agonist-antagonist relationship between these two muscle groups and this flexion:extension ratio has been reported to range from 50 to 77 percent (Gilliam et al.,1979; Mira et al.,1980; Nosse, 1982).

No studies could be found that compared the many agonist-antagonist relationships that occur in shoulder movements. There were also no studies found that made assumptions on how an AC separation may affect these relationships.

2.2.2 Concentric-Eccentric Relationships

A muscle contraction, which is the state of muscle when tension is generated across a number of actin and myosin filaments, may be either concentric, eccentric, or isometric (Komi, 1986). The muscle is said to be contracting concentrically when shortening and the net muscle moment is in the same direction as the change in the joint angle. An eccentric contraction occurs when the muscle is lengthening and the net muscle moment is in the opposite direction to the change in joint angle. A muscle is said to be contracting isometrically when the muscle length and joint angle remain unchanged (Komi, 1986).

At comparable velocities, eccentric contractions can result in far greater external force development (Knuttgen, 1986; Komi, 1986). Edman, Elzinga, and Noble (1978) showed that this increase in force output during an eccentric contraction was due primarily to chemomechanical factors. It has been suggested that fewer motor units are recruited in an eccentric contraction to produce the same force as in a concentric contraction (Komi and Buskirk, 1972). Although it has been shown that more force can be produced in an eccentric contraction, the ratio of concentric to eccentric strength has not been well-documented. A search of the recent isokinetic literature did not reveal a single study comparing the concentric and eccentric strength of the upper body muscle groups.

2.3 ISOKINETIC STRENGTH TESTING

2.3.1 The History of Isokinetics

In recent years the measurement of muscle force under conditions of constant velocity has become very popular. Osternig, Sawhill, Bates, and Hamill (1982) suggested that part of this popularity may be attributed to the ease with which information about dynamic muscular contractions is provided by isokinetic dynamometers. The development and refinement of isokinetic strength testing devices (such as the Cybex II and the KINCOM) has made the use of cable tensiometers and other forms of static dynamometers obsolete. These new machines enable the researcher to calculate torque, force, work, and power scores from an isokinetic test simply, quickly, and accurately. Grace et al. (1984) pointed out that such a device can be used to measure the magnitude and pattern of torque generated by a muscle group across a specific joint and, in so doing, produce an accurate and complete determination of muscle function between the ipsilateral and contralateral extremities as well as the agonist and antagonist muscle groups within the same extremity.

The origins of the isokinetic principle are credited to Perrine who was responsible for producing the first isokinetic device in 1965 (Kusakin, 1971). Although a number of researchers had been using a constant velocity ergometer as early as Levin and Wyman in 1927, it was the commercial availability of Perrine's Cybex machine that created the current interest in isokinetics (Osternig et al., 1982). This modern isokinetic device was designed in such a way as to allow subjects to exert a maximum force against a resisting arm which was rotating at a constant velocity. The force which was being applied to the lever arm could be measured by use of a strain guage, and recorded for instantaneous feedback or for future analysis. An important feature of this lever arm is that it does not allow the force being exerted on it to alter its acceleration. For any force being exerted against the arm there is an equal and opposite reaction force to counterbalance it. The strength curves created by the machine should purely represent the force being exerted by the subject and should not be affected by a change in acceleration. One of the shortcomings of the Cybex machine is the fact that there seems to be a great deal of torque overshoot present, due to acceleration of the Cybex arm, which can dramatically alter the results of a maximum strength test (Sapega, Nicholas, Sokolow, and Saranti, 1982).

A newer isokinetic strength device is the KINCOM system. This device is similar to the Cybex machine in that it is designed to measure torque production during several different modes of exercise, the most useful of which is the isokinetic mode. The KINCOM also provides additional features such as allowing for measurement of torque produced during eccentric contractions under a precise, computer-controlled hydraulic system. The KINCOM was the first strength testing device that was capable of testing the strength of an individual during the eccentric phase of a contraction. Farrell and Richards (1986), in their analysis of the reliability and validity of the KINCOM device, found that the KINCOM did not greatly overshoot the target lever arm speed, when compared to the Cybex. They concluded that the KINCOM unit appeared to produce valid and reliable force measurements, as well as producing accurate lever arm speeds and position measurements. The KINCOM system offers a valid and reliable means of testing the isokinetic strength of an individual, providing the exercise is performed correctly.

2.3.2 Problems Encountered in Isokinetic Isolated-Joint Testing

There are a number of problems which face the tester when carrying out isolated-joint strength testing. Some of these problems are addressed in a manual which was published by the Cybex Corporation (1980) in an attempt to educate the user of the Cybex II dynamometer and the UBXT upper body table.

One of the major concerns expressed in this manual is how to deal with the stabilization and positioning of the subject in order to minimize the effects of other body movements on the strength scores being produced. It is difficult to position a subject in such a way as to eliminate the force producing movements of muscle groups other than those which are being tested. Stabilizing the subject with velcro straps can be effective, but may also interfere with the range of motion of a particular movement. Manual stabilization (in which the tester uses his/her own body to help stabilize the subject) may also be an effective means of eliminating unwanted movements. The problem with manual stabilization is the possible lack of consistency which may arise between tests or between subjects. The consistency with which the tester carries out the protocol is just as important as the method of stabilization.

A further problem which confronts the tester involves the location of the true (or best) axis of rotation for a particular test. The axis of the machine is the point around which the lever arm rotates (Cybex Corporation, 1980). Similarily, the axis of rotation of any body segment is the center of the joint through which that body segment is moving (Hay and Reid, 1982). It is important to align these two axes to ensure that the subject can move through a maximum functional range of motion. This also allows the subject to move freely and comfortably throughout the exercise, which may help in attaining his/her maximum force output (Cybex Corporation, 1980).

Several problems may arise from improperly lining up the axis of the machine with the subject's joint axis of rotation. The main problem is that the force which can be applied to the lever arm may be altered, creating either an increase or a decrease in the true force production. A second problem which may arise from improper alignment is a decrease in the stabilization of the subject, the consequences of which have already been discussed. It is imperative, then, that the tester has a sound knowledge of anatomy and that time and care are taken when aligning the two axes of rotation.

Another problem that is encountered in isolated-joint testing involves the selection of the appropriate speed at which to test certain movements. The tester must take into account the functional speed demands and capabilities of the joint and muscle groups being tested (Cybex Corporation, 1980). The selected speed must also accommodate the type of subjects which are being tested with regards to their activity patterns and health. Elsner, Pedegana, and Lang (1983) pointed out that the faster test speeds have yielded the most accurate results, as they make stabilization easier and have less potential for injury to the patient. The test speeds, however, must represent typical movements of the subjects being tested while at the same time be safe and produce reliable scores.

2.4 TESTING ISOKINETIC SHOULDER STRENGTH

There are very few standardized protocols for testing shoulder function of both injured and non-injured limbs. Assessment of the weakness of the shoulder by measuring the forces produced by the arm has rarely been carried out (Wallace, 1984). The multi-joint configuration of the shoulder creates many problems in developing a reliable and valid testing protocol. Many of the problems which were discussed in the previous section become even greater when testing movements of the shoulder girdle.

2.4.1 Positioning and Stabilization

The alignment of the axis of the machine with the shoulder joint is very difficult because functional shoulder movements rarely have a single or fixed axis of rotation (Cybex Corporation, 1980). This means that the tester must use a compromise axis of rotation to test a specific movement which most accurately aligns with the axis of the machine. Elsner et al. (1983) developed a strength testing protocol for the upper extremity using the Cybex II and the UBXT upper body table. They found that the alignment of the joint axis was affected by three variables: the height of the dynamometer, the length of the lever arm, and the position of the table. There were no studies found that described the alignment of the subject with the machine in which the KINCOM system was used.

Stabilization of the subject is also quite difficult when carrying out tests on the upper limb. It is difficult to standardize strapping techniques among researchers due to the negligence of many researchers in documenting these techniques. The Cybex Corporation (1980) has provided quite a detailed manual which includes the strapping techniques for each of the shoulder tests which were carried out in this study. These techniques are designed strictly for use with the Cybex UBXT equipment and are not easily adaptable to the KINCOM exercise system. It is possible, however, to utilize the main principles and strategies of the Cybex strapping techniques in an attempt to develop similar strapping techniques for use with the KINCOM. It is important to realize that the KINCOM system does not come equipped with straps or stabilization devices and as a result it is the tester's responsibility to develop appropriate strapping procedures and to acquire the necessary materials which can be used for stabilization purposes.

The Cybex Corporation (1980) suggests that in order to ensure maximum test reproducibility in the shoulder it is necessary to establish and stabilize a reproducible body position. This prevents any movement from occurring that is proximal to the joint being tested. The strapping technique to ensure that this reproducibility is present is the same for all of the shoulder movements tested.

A pelvic stabilization strap is applied around the waist in order to ensure that the subject remains against the seat during the testing. A torso stabilization strap is also used to prevent movement of the upper body. This strap is positioned around the chest and slightly beneath the axillary area and around the back of the table where it is tightened.

There is also a handle that is held with the non-tested hand which allows the subjects to help stabilize themselves during the test. It is pointed out in the Cybex manual that these handles must be adjusted so that the two shoulders are level when the limb being tested is in the neutral or starting position. This ensures that the body is kept in an aligned position and the subject is not altering the force being produced through lateral flexion of the trunk. The KINCOM system does not have these handles, although the subject is able to hold onto the table itself in most of the shoulder tests.

Although the protocol for Cybex isokinetic shoulder testing is fairly rigid, it does allow for some manual stabilization. The Cybex Corporation Manual suggests that manual stabilization by the tester may be required for very strong subjects or for subjects who are unable to use their injured arm to help stabilize themselves when testing the uninjured limb. Description of the use of manual stabilization could not be found in any of the articles reviewed that used either the KINCOM or the Cybex exercise devices.

2.4.2 Range of Motion and Speed

A review regarding the appropriate range of motion and speed for a specific test is important because these two factors are heavily interdependent. There are a wide variety of testing speeds that have been used by various researchers to test identical movements. Similarily, the range of motion for any particular shoulder test is found to vary considerably from one study to the next. This variation in protocols is primarily due to the fact that researchers are often studying quite different relationships from similar movements. This review will focus on determining the appropriate range of motion and speed for a test in which only peak torque is required.

As stated previously, there is a definite relationship between the range of motion of a test and the speed with which the test should be carried out. Osternig, Hamill, Sawhill, and Bates (1983) stated that, as the dynamometer speed increases, the joint arc or range of motion must also increase. This increase in the joint arc is necessary due to the fact that isokinetic dynamometers require an acceleration period prior to applying resistance to the exercising muscle. A test that is carried out with a limited range of movement requires the subject to rapidly accelerate the limb in order to produce resistance within the desired joint range. If muscle loading is to occur, according to Davies (1984), the patient must be able to accelerate the arm fast enough to meet the predetermined speed. Moffroid and Whipple (1969) stated that enough time must be given for the contractile component of the muscle to develop to its fullest capacity. They also pointed out that as the speed of the dynamometer increases, peak torque occurs increasingly later in the range of motion. This means that tests which use a small range of motion must use relatively slow speeds to ensure that the peak torque is reached in the predetermined range.

The protocols for testing various shoulder movements, which were established by the Cybex Corporation (1980), enable the tester to choose the desired range of movement for each test. The start and finish positions for each test are set using a blocking technique. This technique requires the tester to place extensions of the testing table (or other stationary pads) in a position which restricts or stops the movement of the arm at the desired start angle and finish angle.

The KINCOM, on the other hand, does not use external structures to block the movement of the subject's arm. The range is set by the tester prior to each test and the lever arm automatically stops at the preset return position. It is important to remember that the KINCOM lever arm is controlled by a computer that can be programmed to stop the lever arm at any angle throughout the range of motion. This makes it much easier to set the desired start and return angles and also allows the tester to use a very individualized range of motion for each subject. There must be an attempt, however, to keep these angles fairly consistent between subjects to ensure that the peak torque is accurately recorded in each test.

The Cybex Corporation (1980) has offered suggestions for setting the range of movement for each of the separate tests of the shoulder. For shoulder abduction the suggestion is to test from the anatomical position to a position between 90 and 170 degrees of abduction. Shoulder adduction is tested from the end position of the abduction test (stated above) back to the anatomical position. For shoulder extension the test is started in a maximum range of flexion and is stopped at approximately five degrees of flexion. The test for flexion uses the same angles but is carried out in the opposite direction. Horizontal abduction is started in a maximum position of horizontal adduction and is stopped at approximately 85 degrees, with 90 degrees representing the frontal plane of the body. The horizontal adduction test is started from this frontal plane position of 90 degrees and travels through as much as 135 degrees of horizontal adduction. The test for internal rotation begins in a position of full external rotation and moves approximately 70 degrees past the neutral position, with the neutral position being that in which the arm is parallel with the floor. The external rotation test begins in 70 degrees of internal rotation and ends at approximately 90 degrees, with the arm being perpendicular to the floor.

These suggestions in the Cybex guide for isokinetic testing were designed for the healthy individual. It is often necessary to make adjustments to these recommendations, especially when dealing with an injured population. Elsner et al.(1983) suggested that adaptations to the protocol developed by the Cybex Corporation are necessary for patients with 'old' AC separations. They recommended that these subjects be tested through a pain-free range of motion and that abduction and flexion be limited to less than 90 degrees.

The joint range in which measurements are taken is by no means unimportant and according to Gransberg and Knutsson (1983), it is a critical variable to consider when comparing studies. They suggested that the torque recorded in the early phase of the movement does not accurately reflect the maximum contractile capacity of the musculature. It is important, therefore, to document the approximate testing angles of each movement to ensure that the angle of peak torque production is within the tested range of motion.

The testing speeds selected are also very important as they have a great influence on the magnitude of the forces which will be produced. A number of studies using isokinetic dynamometers have found support for the classic force-velocity relationship by showing that there is a drop in peak isokinetic torque with increasing speeds (Moffroid and Whipple, 1970; Barnes, 1975; Thorstensson, Grimbly, and Karlson, 1976; Lesmes, Costill, Coyle, and Fink, 1978). The researcher must understand this relationship when choosing the test speeds and be certain to maintain the same testing speeds for each subject.

The speeds must, to some extent, match the range of movement which is being used in the tests. Davies (1984) recommends that short arc isokinetic tests, such as those used with injured subjects, should be performed at intermediate velocities ranging from 60 to 180 degrees per second (d/s). The Cybex Corporation (1980) suggests using 60 d/s as a slow speed and 180 d/s as a fast speed for typical orthopaedic patients when testing all shoulder movements. Walsh et al. (1985) measured peak torque of patients with AC separations at speeds of 60 and 240 d/s. Elsner et al. (1983) stated, however, that the orthopaedic patient is now tested at 90 and 210 d/s and speculate that speeds greater than 300 d/s may be necessary for accurate evaluation of both upper and lower extremities. An opposite opinion is held by Wallace et al. (1984) who tested patients with shoulder disorders and found that those patients could not tolerate speeds higher than 100 d/s. They recommended that speeds of 60 or 30 d/s be used.

2.4.3 Standardization of Measurements

The stability of measurements is obtained by controlling or standardizing several other testing factors which have not yet been mentioned. These include the order in which the tests are conducted, the number of trials which are performed for each specific test, and the amount of rest that is allowed between successive tests. These three variables can have a dramatic effect on the outcome of the testing, as each is capable of altering the force which is being produced throughout the testing series.

The protocol must also be designed to allow for proper warm-up and adequate repetitions (to obtain maximum force) while at the same time minimizing the fatigue factor. There are several guidelines in the literature which help the researcher to combine these factors in such a way as to allow for reliable and efficient data collection in a series of shoulder tests.

2.4.3.1 Order

The order in which the various tests of shoulder functioning are carried out must be standardized for each subject. The recommended order of testing using the Cybex II dynamometer is presented in their guide for isokinetic testing (Cybex Corporation, 1980). A shoulder test series begins by testing abduction and adduction, followed by extension and flexion, horizontal abduction and adduction, and finally internal and external rotation. The tests are carried out alternating back and forth between the uninjured and injured limb in each pattern. The main reason given for using this sequence of testing was that it minimized the accessory and positioning changes that must be carried out between each group of movements. Elsner et al.(1983) used this order of testing when establishing a protocol for strength testing of the upper extremity. They determined that doing the testing in a set pattern allowed a test to be done in a smooth sequence and helped to prevent confusion in the marking of the strip charts. Walsh et al.(1985) carried out a study looking at shoulder strength following AC injury and reported measuring peak torque in extension, flexion, internal rotation, external rotation, abduction, adduction, horizontal abduction, and horizontal adduction. They failed to mention if this was the order in which the tests were carried out. There were no studies found which offered an order for testing a series of shoulder movements using the KINCOM system.

2.4.3.2 Number of Repetitions

The number of repetitions or trials in each test is very important in obtaining stable measurements of human performance on an isokinetic dynamometer (Osternig et al., 1983). Johnson and Siegel (1978) tested the reliability of knee extension movements and concluded that three submaximal trials followed by three maximal warm-up efforts is essential in obtaining stable measurements. It is important to realize that fatigue was not discussed in this study and that this recommendation only applies when testing a single movement. Sawhill, Bates, Osternig, and Hamill (1982) suggested that four performance trials would provide satisfactory yet economical information for stability of isokinetic data. In this study, however, the subjects were allowed submaximal warm-ups prior to the maximal testing in order to become familiar with the isokinetic apparatus. Mawdsley and Knapik (1982) recommended that, when testing subjects in a single session, at least one maximal trial should occur before recording criterion strength scores. Although it is still questionable as to the necessity of submaximal or maximal warm-ups, Osternig et al. (1983) suggests that submaximal warm-ups reduce the risk of muscle strain. This is especially true for novice subjects who have sustained a recent injury.

Elsner et al.(1983) suggested using four repetitions at the slow speed of 90 d/s and five repetitions at the fast speed of 210 d/s. They also suggested that several additional warm-up repetitions may be necessary when testing shoulder abduction and adduction of subjects with recent AC separations in order to decrease the patient's apprehension. There are no recommendations in the KINCOM instructions manual,which is supplied by Med-Ex Diagnostics of Canada (1985), as to the number of repetitions to use when using their dynamometer. There were also no studies available that offered any such recommendations. The recommendations that are offered for use with the Cybex II dynamometer may not be acceptable for use with the KINCOM system due to the fact that testing with the latter machine involves not only concentric repetitions but also eccentric repetitions.

2.4.3.3 Rest

The amount of rest that is allowed between each successive test is another important factor when testing complete shoulder strength in a continuous series of tests. It is obvious that a rest period is needed between each test sequence because of the repeated involvement of some muscles in each of the shoulder movements (Cybex Corporation, 1980). Cybex suggests that two to three minutes is sufficient if only strength and power tests are being performed. This includes the time between successive tests on a single limb as well as when testing alternate limbs. The majority of the studies that were reviewed did not report the length of the rest interval used in the testing procedure. It is reasonable to assume that most studies followed the guidelines established by the Cybex Corporation and standardized the rest period that was allowed between each test.

Chapter III

METHODS AND PROCEDURES

3.1 INTRODUCTION

This chapter is separated into four sections: subjects; experimental design; data collection; and data analysis. The first section describes the recruitment process used to collect the subjects for this study and characterizes the requirements for acceptance into each group. The experimental design section explains the type of research carried out and the preliminary steps taken prior to the actual testing taking place. The data collection section describes in detail the KINCOM isokinetic strength testing protocol developed for this study with a description of each movement carried out. The data analysis section is separated into four sub-sections: the analysis of peak torque values, means and comparisons, reliability checks, and dominant versus non-dominant limbs.

3.2 SUBJECTS

There were two groups of subjects. The first group included 20 subjects who had recently sustained a third degree AC separation. A recent injury was defined as being an injury that had occurred within a 12 month period prior to testing. These subjects were all male and were between the ages of 18 and 50 years. Within this group of 20 injured subjects there were 10 subjects who had been treated conservatively and 10 subjects who had undergone surgery to reduce the clavicle. This enabled the results of this study to represent both types of treatments equally. A comparison of strength following conservative and surgical treatment was the subject of a separate paper (MacDonald, P.B., Alexander, M.J., Frejuk, J.,and Johnson, G.E., 1988).

The injured group was recruited with the help of a local orthopedic surgeon who also had a special interest in this study and acted as a secondary researcher for this paper. A number of local orthopaedic physicians and physiotherapists were asked if they would help in obtaining subjects for the study. The physicians were requested to screen out any patients who had sustained further complications to their shoulders as a result of their recent injury.

The patients that met these criteria were then contacted and asked if they would be interested in taking part in a research project involving their recent injury. If interested the patients were contacted by the researchers and given more information regarding the study.

This recruitment process continued following a quota sampling design with controlled assignment until ten subjects in each of the two injured categories were collected. The potential subjects were contacted in the order in which their names were received from the physicians who were helping in the collection process. The patients who were found to meet all of the requirements for the study were then tested at their convenience and a list of alternate subjects was used in the case where one of the origional 20 subjects decided at a later time not to take part in the study.

The second group of subjects used in the study served as a control group. This group represented a cross-section of the normal male population within the age range of 18 to 50 years. These subjects were screened to ensure that they had no history of any severe injury to either of their shoulders. The subjects were recruited on a volunteer basis from both within and outside of the University of Manitoba. This recruitment continued until the quota of 20 subjects was reached.

3.3 EXPERIMENTAL DESIGN

The design of this study followed that of a static group comparison in that each subject was only tested once and there was no follow-up testing, except in the case of the reliability check. The researchers had no input as to the type or the amount of rehabilitation that each subject may have followed prior to being tested. A questionnaire, modified from that of Walsh et al.(1985), was filled out by each injured subject at the time of testing which included a detailed description of the type and the amount of physical activity of each subject prior to and following his injury. A copy of this questionnaire can be found in Appendix A of this paper. Although this information was not statistically analyzed, the questionnaires were used to compare the history of subjects in the injured group. The history of the control group was also obtained and a similar comparison between the two groups, injured and noninjured, was made.

The tests were designed in an attempt to minimize the potential harm to the subjects. The research proposal was approved by the Committee on Research Involving Human Subjects. Each subject was also asked to read and sign an informed consent form (Appendix B). This form reviewed the tests which were carried out and also informed the subjects as to the possible risks present during the testing.

3.4 DATA COLLECTION

The testing as well as the interviews were carried out in the Sport and Exercise Sciences Research Institute located in the Max Bell Center at the University of Manitoba.

Forty subjects were tested during a period of approximately nine months. These included 20 normal subjects and 20 subjects with recent third degree AC separations. An effort was made to standardize the time of day at which the subjects were tested although the various time commitments of the subjects made this difficult. Ten control group subjects were also used in a reliability check to test the new strength protocol. These ten subjects were chosen at random and asked to complete the entire testing protocol a second time. The subjects were given a minimum of two days between subsequent tests and were tested no later than four days after their initial test.

The subjects were asked to refrain from exercise for at least 24 hours prior to being tested as well as refraining from smoking or eating for at least two hours prior to the test. A recommendation was also made to wear loose clothing to the testing sessions.

Each subject fully understood what was expected of him during the testing. The subjects were informed that a maximal effort was required on their part in order to obtain valid data. Each subject was also verbally motivated during each of the movements. This motivation was kept as consistent as possible for each of the subjects.

3.4.1 KINCOM Isokinetic Strength Testing Protocol

The strength testing of the shoulder was carried out using the Kinetic Communicator Exercise System (KINCOM). There were eight shoulder movements examined in this study and each movement was carried out at two speeds. The slow speed was 50 d/s in both the concentric and eccentric phases of the movement. The fast speed was set at 180 d/s for the concentric motion and 90 d/s for the eccentric motion. Both shoulders were tested in movements of flexion, extension, adduction, abduction, internal rotation, external rotation, horizontal abduction and horizontal adduction. Testing these movements in both concentric and eccentric phases at two speeds yielded a total of 32 peak torque scores for each subject.

Before the actual tests were carried out, each subject was given an explanation of the protocol which was to be followed. The subjects were also introduced to the KINCOM machine and were allowed several practice trials in order to familiarize themselves with the "feel" of the movements. Subjects were encouraged to practice the eccentric portion of each movement because most subjects were not familiar with exerting force during this type of contraction. Subjects were allowed a three minute rest period after this practice before the maximum strength tests were started. The subjects were also given a three minute rest period before each successive test as to eliminate the fatigue factor during the testing. The tests were arranged so that one arm was tested for a short period of time and then the other arm was tested. This was done so that one group of muscles was not overworked and fatigue could not alter the data collection.

The eight movements were paired so that a particular movement was accompanied by its antagonistic counterpart: that is, flexion was grouped with extension, adduction with abduction, internal rotation with external rotation, and horizontal abduction with horizontal adduction. The tests were then administered in the above order so that one of the four pairs of tests was carried out on the right side and then the same pair of tests were carried out on the left side. In each group of tests the slow speed was carried out prior to the fast speed. For example, each subject first performed the shoulder flexion test on his right side at both the slow speed and the fast speed. These two tests were followed by the shoulder extension test at the slow speed and then at the fast speed, using the same shoulder. After these four tests, the same tests were performed using the opposite shoulder. This procedure continued so that the subject performed a series of four tests on the right shoulder and was then moved to perform the same tests on the left shoulder until all four pairs of movements were completed.

The protocol followed for each test is given below. It is important to note that the term "pad" used in the following description of the protocols refers to the shin pad that is supplied for use with the KINCOM system, unless otherwise stated.

1. Shoulder flexion

a) subject sits in the KINCOM chair with the axis of the machine lined up with the left-right axis of the glenohumeral joint.

b) the arm of the KINCOM is adjusted so that the pad is proximal to the elbow on the anterior brachium.

c) a strap is placed around the chest of the subject which keeps the subject stabilized against the back of the chair.

d) the start angle of the limb is at 0 degrees flexion and the return angle is set at a comfortable position of shoulder flexion (approximately 90 degrees for most subjects).

2) Shoulder extension

a) subject sits in chair with the lateral side of the glenohumeral joint lined up with the axis of the KINCOM.

b) the pad is placed proximal to the elbow joint on the posterior brachium.

c) a strap is placed around the subject's chest as in the flexion test.

d) the start angle for the test is at a comfortable position of shoulder flexion (approximately 90 degrees) and the return angle is set at the anatomical position (0 degrees).

3. Shoulder adduction

a) subject sits in chair with his back facing the KINCOM machine and his non-tested arm positioned against the back of the chair for stabilization.

b) the arm of the KINCOM is adjusted so that the pad is proximal to the elbow on the medial brachium.

c) a strap is placed around the subject underneath the arm that is being tested and is tightened around the chair in order to eliminate any lateral trunk flexion.

d) the arm is placed in a comfortable position of shoulder abduction (approximately 90 degrees) for the start of the test and is returned to a position where the pad is contacting the lateral side of the subject's body (approximately 10 degrees).

4. Shoulder abduction

a) subject sits in the chair as in the adduction test so that the axis of the machine is aligned with the sagittal axis of the glenohumeral joint.

b) the pad is placed on the lateral brachium proximal to the elbow joint.

c) the strap is placed around the subject as in the adduction test.

d) the arm is started from the anatomical position (0 degrees) and the return angle is set at a comfortable position of shoulder abduction (approximately 90 degrees).

5) Shoulder internal rotation

a) subject sits in chair facing forward with the axis of the KINCOM lined up with the long axis of the humerus and the glenohumeral joint.

b) the head of the KINCOM is tilted 15 degrees away from the subject so that the axis of the machine is now facing up toward the subject.

c) a strap is placed around the subject's chest which holds them against the back of the chair for stabilization.

d) the pad of the KINCOM arm is placed just proximal to the wrist on the anterior aspect of the forearm while the elbow is held in place near the axis of the machine with the KINCOM elbow pad.

e) the start angle is at a comfortable position of lateral rotation (approximately 90 degrees, with the forearm perpendicular to the floor), and the arm travels through approximately 90 degrees so that the arm is parallel with the floor at the return angle.

6. Shoulder external rotation

a) subject sits in chair with the long axis of the humerus and the glenohumeral joint lined up with the axis of the machine.

b) the head of the KINCOM is tilted away from the subject at 15 degrees.

c) the strap is placed around the subject as in the internal rotation test.

d) the pad of the kincom is placed just proximal to the wrist on the posterior aspect of the forearm with the elbow fit into the elbow pad.

e) the start angle is at a position where the arm is approximately parallel with the floor and the return angle is set with the arm being perpendicular to the floor, a movement of approximately 90 degrees.

7. Shoulder horizontal abduction

a) subject lies supine with their upper body on the KINCOM table and their lower body on an extension of another table so that the axis of the KINCOM is lined up with the longitudinal axis of the shoulder joint.

b) the arm is abducted to 90 degrees and the pad is placed on the posterior-lateral brachium just proximal to the elbow joint.

c) the subject is manually stabilized to ensure that the shoulders and chest remain on the table.

d) the start angle is at approximatley 90 degrees of horizontal adduction so that the brachium is perpendicular to the floor and the return angle is set at 0 degrees (when the brachium is approximately parallel with the floor).

8) Shoulder horizontal adduction

a) subject is positioned as in the horizontal abduction test with the axis of the KINCOM lined up with the longitudinal axis of the glenohumeral joint.

b) the pad is placed on the anterior-medial portion of the brachium just proximal to the elbow joint with the arm abducted to 90 degrees.

c) the subject is manually stabilized as in the horizontal abduction test with the tester using his body to eliminate any sliding movement of the subject on the table.

d) the start angle is at approximately 0 degrees (with the brachium parallel with the floor) and the arm is moved through approximately 90 degrees so that the brachium is perpendicular to the floor at the end position.

The KINCOM exercise device, as reviewed in an earlier section of this paper, has been shown to be capable of producing reliable and valid data (Farrell and Richards, 1986). Objectivity was not a problem in this study due to the nature of the testing and the data collection. The data which were collected, therefore, accurately represented the maximal strength that was exerted by the subjects on any given test.

3.5 DATA ANALYSIS

3.5.1 Peak Torque Values

At the conclusion of all of the testing, the data that were stored in memory on floppy disks were printed so that the peak concentric and eccentric strength scores for each test were displayed. This data was obtained using the torque versus angle option of the report mode located in the exercise program of the KINCOM software package. This program graphed the concentric and eccentric curves separately on one page and also determined the peak strength score on each graph. These graphs were edited in order to eliminate any torque overshoots that may have occurred by taking out the first several degrees of the curve if it was determined that a false peak had been obtained. An example of one of these graphs can be found in Appendix C.

The peak strength scores were then input into the Amdahl mainframe computer at the University of Manitoba. The SAS statistical package was used to carry out the data analysis.

The injured arm for each of the subjects in the injured group was used in the statistical analysis regardless of whether or not it was their dominant arm. The same number of dominant and non-dominant arms used in the injured group was also randomly selected from the healthy group in order to minimize the effects of arm dominance on the strength comparisons. The strength scores for these 40 limbs, 20 healthy and 20 injured, were then used in the data analysis.

3.5.2 Means and Comparisons

Mean values were calculated for each strength score and for other variables such as age, height, weight, time post-injury, dominant hand, and side of injury. Concentric scores were divided by eccentric scores for each peak torque measurement in each group to obtain a concentric/eccentric (CN/EC) strength ratio. These CN/EC ratios were then used to compare the healthy and the injured groups. A Student's two-sample t-test was used to determine the significance of the differences between groups, if any, for each of the variables. The alpha level was set with p<= .05 in this study although any significant findings beyond p<= .01 level of significance was reported.

Similar comparisons were then carried out to determine the relationships between agonist and antagonist movements. A Student's two-sample t-test was used to compare the agonist-antagonist (AG/ANT) ratios between the injured group and the healthy group. The significance of these comparisons were also calculated.

3.5.3 Reliability Testing

Reliability checks were carried out with the peak torque scores and the two ratios that were calculated. A t-test for paired comparisons was carried out with the results from the 10 control subjects chosen for this check for each of the three groups of scores listed above. The significance of the differences from one testing session to the next was determined for the peak strength scores, the CN/EC ratios, and the AG/ANT ratios.

3.5.4 Dominant versus Non-dominant Limbs

A comparison was also carried out between the strength of the dominant arm to the non-dominant arm for the 20 control subjects. Statistical analysis using the paired-comparisons t-test was carried out using the differences in mean peak torque values between the dominant and non-dominant limbs for all of the movements tested.

It is important to note that for all of the peak torque and strength ratio comparisons made in this study between the injured and control groups, the same number of dominant limbs as non-dominant limbs were used in the analyses. There were 14 subjects in the injured group with their AC separation occurring on their dominant side and 6 subjects with the injury on their non-dominant side. To compensate for this, 14 sets of data from the dominant limbs of the control group were randomly selected from the 20 sets of data collected. The other 6 sets of data were then taken from the non-dominant limbs of the remaining 6 control group subjects. This further decreased the possibility that dominant arm bias had an effect on the comparisons made between the injured and the control group.

Chapter IV

RESULTS AND DISCUSSION

4.1 INTRODUCTION

The contents of this chapter have been presented under the following headings: strength testing protocol; dominant versus non-dominant arm strength comparisons; reliability checks, for peak torque, concentric/eccentric ratios, and agonist/antagonist ratios; subject analysis; peak torque scores, including right versus left and injured versus uninjured limbs; and strength ratio comparisons for concentric/eccentric and agonist/antagonist ratios. The first two sections deal primarily with the analysis of the raw data collected for the two groups. The third and fourth sections are comparisons using only the control group to determine the differences, if any, between the dominant and the non-dominant limbs as well as between the test and retest reliability checks. The strength ratio comparisons examine both the control group alone as well as the differences between the control group and the injured group. The strength testing protocol section discusses some of the problems which arose in utilizing the newly developed protocol and offers some of the answers to these problems.

4.2 STRENGTH TESTING PROTOCOL

The discussion of this study would not be complete without a brief analysis of the strength testing protocol used to collect the data. The KINCOM dynamometer was used for all strength measurements carried out in this research and it proved to be a very reliable and valid measurement device. The reliability checks, although not perfect, did show that the protocol could be used to collect reliable data. This was evident in the fact that all of the major strength relationships such as the force-velocity relationship and the concentric-eccentric relationship held true for the majority of the data.

The means of positioning and stabilization delveloped for the tests carried out proved to be satisfactory. The KINCOM is quite adaptable in that the movement of the subject table and force arm head allows the researcher to place the subject in the best possible position to carry out most tests. The stabilization techniques offered by the manufacturers of the KINCOM are, unfortunately, far from adequate. The straps used for stabilizing subjects in this study had to be purchased from another company and the stabilization strategies were all designed from trial and error preliminary testing. The end result was that the subjects were fairly well stabilized by means of both the strapping techniques used and, in some movements, by manual stabilization. Stabilization is perhaps the most difficult test condition to control and there is still room for improvement in this area.

The standardization of the measurements including the order of testing, number of repetitions, and the rest intervals used was sufficient in most cases. The problems that did arise in this area involved the non-random test order and the rest interval between successive days. The movements carried out were kept in the same order for each subject to try and standardize the scores. This seemed to have some effect on certain movements, specifically on the shoulder flexion movements which were carried out first. There seemed to be a slight learning effect in some cases whereby the first few tests were not performed with a maximum effort. This is a very difficult problem to overcome but a longer training session before the actual testing session may have eliminated this minor problem.

The problem of rest between successive tests for the reliability check group may have also affected some of the test scores. As mentioned earlier, two or three of the 10 control subjects who were tested on two occasions complained of stiffness during the second test session. It is possible that a longer rest between the two test days would have been appropriate.

4.3 DOMINANT VERSUS NON-DOMINANT ARM STRENGTH COMPARISONS

A question which had to be answered before a comparison of the two groups could be made was the effect of arm dominance on the peak torque scores. The control group was analyzed to determine if there were indeed differences between the mean peak torque values of the dominant and the non-dominant limbs for all movements tested. A paired-comparisons t-test was carried out for each movement at each speed and contraction phase.

The analysis revealed that there were no significant differences ($P<.01$) between the shoulder peak torque scores of the dominant and non-dominant limbs. There were, however, a few significant differences with the alpha level set at $p<= .05$ that should be mentioned.

Shoulder extension in the eccentric slow test had a mean dominant to non-dominant peak torque difference of 6.35 Nm ($P=.0390$). A similar result was found in the eccentric fast test of shoulder extension where the difference was 6.85 Nm ($P=.0496$). This seems to indicate a slight difference in favour of the dominant limb in eccentric contractions of the shoulder extension movement.

Horizontal abduction of the shoulder was the only other movement in which there were questionable discrepancies between the mean peak torque scores of the dominant and non-dominant limbs. The concentric slow test showed a difference of 10.30 Nm in favour of the dominant limb (P=.0131). The eccentric slow test had a difference of 11.10 Nm between the dominant and non-dominant mean peak torque scores (P=.0302). This would suggest that there may be differences in favour of the dominant arm when comparing horizontal abduction at slow speeds. These results correspond somewhat with results reported by Walsh (1985). He reported findings of two unpublished studies which suggested that there were differences in favour of the dominant limb in horizontal abduction. It was pointed out, however, that these findings were not conclusive.

4.4 RELIABILITY CHECKS

One of the concerns in this study was to assure that the tests performed were reliable. The reliability and validity of the KINCOM dynamometer itself has been proven by Farrell and Richards (1986). The test protocols, however, were designed by the primary researcher and associates for use in this study and were never before used. This made it necessary to test the reliability of these newly designed protocols. The validity of the tests was shown simply by means of face validity tests where it was obvious as to which muscle groups were being tested in each of the movements.

The results of the 10 control group subjects who were randomly selected to take part in the reliability checks were compared in three separate analyses. First, the peak torque scores were compared for each test from the first session to the second session. Secondly, the concentric/eccentrtic ratios were compared between the two test sessions. Finally, the agonist/antagonist ratios were analyzed for differences between the two groups of data. In each of the three reliability checks a series of paired-comparison t-tests were carried out to determine if the differences from the original test and the retest were significantly different from zero. The three reliability checks will be dealt with separately below.

4.4.1 Peak Torque

The peak torque scores for each movement at both speeds and both contraction phases were compared for both the right and left shoulders. A total of 64 separate t-tests were carried out in order to check the reliability of each test.

There was one significant difference which occurred in the eccentric slow flexion test of the right shoulder ($P<.01$). In this comparison the first test was found to have higher peak torques with a mean peak torque difference of 19.50 Nm. The remainder of the 64 t-tests proved to be non-significant ($P<.01$). Thus, the tests were reliable when dealing with peak torque values. The one exception may be explained in that this was the first test carried out in each test session and there may have been a reluctance to exert a maximum force. A number of the test-retest subjects who were questioned after the second test session confessed that they were experiencing some stiffness during the first few tests.

4.4.2 Concentric/Eccentric Ratios

The concentric/eccentric ratios were calculated for each movement at each speed for both the original test and the retest. These 34 ratios were then compared using paired-comparison t-tests and no siginificant differences were found (P<.01). Thus, the concentric/eccentric ratios of the movements tested can be reliably reproduced between each successive test session.

4.4.3 Agonist/Antagonist Ratios

The agonist/antagonist ratios were calculated for four groups of movements. These included flexion/extension, adduction/abduction, internal rotation/external rotation, and horizontal adduction/horizontal abduction. Four ratios were calculated for each group of movements which included both speeds and both contraction phases. A total of 16 agonist/antagonist ratios were compared between the original test and the retest. There were no significant differences found between any of the test-retest comparisons (P<.01). This means that the agonist/antagonist ratios obtained from the peak torques in this study can be replicated and are therfore reliable. These ratios are compared later in this chapter with the agonist/antagonist ratios calculated for the injured group.

The peak torque scores themselves are liable to vary from day to day simply due to the motivation and the physical state of the subject on that particular day. These factors should not affect the two ratios compared in this study to any great extent because the test to test variance should not be as great as the day to day variance.

4.5 SUBJECT ANALYSIS

The present study included an injured and a control group which were standardized in their physical characteristics. Table 1 compares the average age, height and weight of the 20 injured and 20 control subjects as well as the standard deviation and range for each of the variables.

The average age of the two groups were calculated, with the mean age of the injured group (28.45) exceeding that of the control group (23.50) by 4.95 years. The average height and weight of the two groups were also similar with the control group being slightly taller and heavier. The control group had an average height of 176.78 cm. which was 3.78 cm. taller than that of the injured group with a mean of 173.00 cm.. The control group was slightly heavier than

TABLE 1

Physical Characteristics for the Injured and Control Group

	Injured			Control		
	Mean	SD	Range	Mean	SD	Range
Age (Yrs.)	28.45	9.62	17-50	23.50	3.65	19-32
Height (cm.)	173.00	8.19	151.2-184.0	176.78	9.15	151.2-191.5
Weight (kg.)	75.30	7.94	63.6-93.2	80.02	11.44	59.1-109.9

the injured group with the average of the control group (80.02 kg.) being 4.72 kg. greater than the injured group (75.30 kg.).

There were also several other similarities between the two groups. The 40 subjects tested were all considered to be recreational athletes. None of the subjects tested were considered to be specializing in weight lifting or strength training. This was important as a trained athlete may have biased the data in some way. This information was obtained through the administration of a lifestyle questionnaire, an example of which can be found in Appendix A.

4.6 PEAK TORQUE SCORES

There were 64 peak torque measurements obtained for each subject in this study. The shoulder movements included flexion, extension, adduction, abduction, internal rotation, external rotation, horizontal adduction, and horizontal abduction. Each of these movements was tested in both a concentric and an eccentric contraction phase at both a slow speed (50 d/s) and a fast speed (180 d/s concentrically; 90 d/s eccentrically). The mean peak torque values for the injured group can be found in Table 2 on the following page. The standard deviations and ranges for these scores can be found in Appendix D.

When referring to Table 2 it is notable that these are values obtained for the right and left shoulders regardless of which arm was injured. Analysis by injured and uninjured shoulders will be carried out later in this section. The peak torque values in Table 2 are offered as a means of comparing average strength values between the injured and the control group.

There were 20 control group subjects, 10 of which took part in the test-retest reliability analyses. The data from the first test session for these 10 subjects was used for all of the comparative analyses between the injured and control groups in order to eliminate any learning effect that might have taken place between the two test sessions.

TABLE 2

Mean Peak Torque Scores (Nm) of the Injured Group

	Right				Left			
	Con.		Ecc.		Con.		Ecc.	
	slow	fast	slow	fast	slow	fast	slow	fast
Flex.	64.20	60.30	77.45	80.65	62.60	58.10	72.50	76.90
Ext.	70.65	65.95	81.50	84.15	73.45	64.35	81.95	81.25
Add.	63.85	61.20	75.30	74.80	65.35	62.05	77.25	80.90
Abd.	50.75	47.20	55.45	55.40	51.70	50.35	61.55	58.70
In. Rot.	41.85	41.05	50.15	51.15	38.30	37.55	45.75	46.00
Ex. Rot.	27.30	24.80	31.05	29.20	28.85	25.35	34.00	32.35
H. Add.	59.95	56.15	67.85	64.50	56.65	55.10	66.30	68.25
H. Abd.	56.20	51.00	74.10	69.35	48.95	45.70	64.90	62.35

(KEY: Con.=concentric; Ecc.=eccentric; Flex.=flexion; Ext.= extension; Add.=adduction; Abd.=abduction; In. Rot.=internal rotation; Ex. Rot.=external rotation; H. Add.=horizontal adduction; H. Abd.=horizontal abduction)

This data was combined with the data from the other 10 control subjects and the mean peak torques for the control group were computed. The mean peak torque scores can be found in Table 3 and the remainder of the information for this analysis can be found in Appendix E.

Comparison of Table 2 and Table 3 shows that the control group was stronger in every test carried out. This is understandable as the injured group was recovering from a

TABLE 3

Mean Peak Torque Scores (Nm) of the Control Group

	Right				Left			
	Con.		Ecc.		Con.		Ecc.	
	slow	fast	slow	fast	slow	fast	slow	fast
Flex.	86.70	82.80	108.25	96.00	87.25	76.45	104.10	93.70
Ext.	95.35	83.30	114.75	108.30	90.65	85.00	104.15	100.35
Add.	89.05	76.50	100.40	100.60	80.10	76.70	95.55	94.80
Abd.	67.80	66.80	72.25	74.55	66.75	61.75	71.75	71.40
In. Rot.	49.15	47.85	59.65	59.50	53.15	47.50	58.10	56.85
Ex. Rot.	39.95	38.35	43.85	44.00	38.60	36.05	42.05	41.60
H. Add.	78.60	73.60	92.60	91.85	76.00	69.65	91.75	91.20
H. Abd.	80.45	61.75	95.75	83.60	66.60	58.90	80.90	77.80

(KEY: Con.=concentric; Ecc.=eccentric; Flex.=flexion; Ext.= extension; Add.=adduction; Abd.=abduction; In. Rot.=internal rotation; Ex. Rot.=external rotation; H. Add.=horizontal adduction; H. Abd.=horizontal abduction)

serious injury and as a result the strength of both limbs is most likely affected due to muscle damage and lack of exercise. Pain could have also been a factor in the lower peak torque scores although no test was stopped due to pain in the injured shoulder. The possibility cannot be ruled out that the control group was simply stronger since they were slightly taller and heavier. The fact that the injured group had lower peak torque scores, however, was not a major concern as it should not affect the other analyses carried out in this study.

Another observation was that shoulder extension was the strongest movement among the eight shoulder movements tested. This is due to the fact that the large and powerful latissimus dorsi and teres major muscles are being activated to produce the movement. External rotation of the shoulder was the weakest movement among the eight. This again is understandable as it is the smaller infraspinatis and teres minor muscles supplying the force for the movement. Further comparisons between the peak torque values of various movements will be conducted later in the section examining agonist/antagonist muscle ratios.

Regarding the speed of the movements, in almost all cases the slow movement had a greater peak torque as compared to the fast movement in both concentric and eccentric contraction phases for both the right and left shoulders. The few exceptions were found in the eccentric tests of the right arm for the movements of adduction, abduction and external rotation. The differences in these three tests, however, were only 0.20, 2.30, and 0.15 Nm respectively which were close enough to zero to disregard. This finding, therefore, supports the classic force-velocity relationship which suggests that higher torques are produced at slower testing speeds.

A final observation from Table 3 involves the concentric-eccentric relationships. For each movement (in both the right and left arms) the eccentric peak torque scores were greater than the concentric peak torque scores. This finding is again supported in the literature.

4.6.1 Injured versus Uninjured Limbs of Injured Group

As mentioned previously, Table 2 contains the peak torque scores for the right and left shoulder movements for the injured group. Table 4 shows the mean peak torque scores of the injured group separating the injured and the uninjured

TABLE 4

Mean Peak Torque Scores (Nm) of the Injured Group for Injured and Uninjured Shoulders

	Injured				Uninjured			
	Con.		Ecc.		Con.		Ecc.	
	slow	fast	slow	fast	slow	fast	slow	fast
Flex.	60.75	57.35	73.50	75.95	66.05	61.05	76.45	81.60
Ext.	70.35	65.55	81.00	84.10	73.75	64.75	82.45	81.30
Add.	60.15	57.85	70.85	72.85	69.05	65.40	81.70	82.85
Abd.	48.40	47.00	56.80	56.25	54.05	50.55	60.20	57.85
In. Rot.	39.80	38.75	47.65	48.75	40.35	39.85	48.25	48.40
Ex. Rot.	24.80	21.95	28.40	28.35	31.35	28.20	36.65	33.20
H. Add.	55.85	55.00	66.15	66.25	60.75	56.25	68.00	66.50
H. Abd.	54.00	49.65	72.00	68.25	51.15	47.05	67.00	63.45

(KEY: Con.=concentric; Ecc.=eccentric; Flex.=flexion; Ext.= extension; Add.=adduction; Abd.=abduction; In. Rot.=internal rotation; Ex. Rot.=external rotation; H. Add.=horizontal adduction; H. Abd.=horizontal abduction) limbs.

When comparing the injured to the uninjured limbs it is surprising to find that there was very little difference between the peak torque scores in the majority of the movements. Several of the scores obtained from the injured arm were actually higher in some movements when compared to the uninjured arm. Shoulder extension for both the concentric and eccentric contraction phases at the fast speed were two tests in which the injured arm was found to be stronger. Shoulder internal rotation for the eccentric fast test was also higher for the injured shoulder as compared to the uninjured arm although the difference was only 0.35 Nm. The most surprising result was in the horizontal abduction test in which all four tests, for both speeds and both contraction phases, resulted in the injured shoulder having greater mean peak torque scores.

It is important to note that none of these differences cited above in which the injured arm had higher peak torque values than the uninjured arm were significant ($P<.05$). These results do, however, raise some interesting questions. Horizontal abduction seems to be one movement which is certainly not adversely affected by a complete AC separation following a short recovery period. In fact, the incidence of this type of injury may enhance the strength in the movement of horizontal abduction over the period of rehabilitation. This could be the result of the patient having to use this muscle group while in a sling or it could possibly have something to do with the attempt to overtrain an injured limb while ignoring the training of the uninjured limb. The answer to these questions is not known but further study in this area is warranted.

There are a number of comparisons from Table 4 in which the peak torque values obtained from the injured shoulder were significantly lower than those of the uninjured shoulder. The mean peak torque difference for concentric slow adduction was 8.90 Nm which was significant (P<.01). The mean peak torque of the injured shoulder was 60.15 and the uninjured shoulder had a mean peak torque of 69.05 Nm. For concentric fast adduction the mean peak torque of the injured shoulder was 57.85 while the mean peak torque of the uninjured shoulder was 65.40. The mean difference of 7.55 Nm was found to be significant (P<.05). The eccentric slow adduction mean peak torques for the injured and uninjured shoulders were 70.85 and 81.70 Nm respectively. The mean difference was 10.85 Nm which was again found to be significant (P<.05). The eccentric fast adduction mean peak torque score for the injured limb was 72.85 Nm and for the uninjured limb was 82.85 Nm giving a significant mean difference of 10.00 Nm (P<.01). These comparisons are graphically represented in Appendix F.

From Table 4 it is obvious that the other movement which was weak following the separation was external rotation.

For the concentric slow movement the mean peak torque for the injured shoulder was 24.80 Nm. This was significantly less (6.55 Nm) than the mean peak torque of the uninjured shoulder which was 31.35 Nm ($P<.01$). The concentric fast mean peak torques were 21.95 Nm and 28.20 Nm. for the injured and uninjured limbs repectively. The resulting difference of 6.25 Nm was again found to be significant ($P<.01$).

Similar results were found for the eccentric phases of the external rotation movement. For the slow speed the mean peak torques were 28.40 Nm and 36.65 Nm and for the fast speed were 28.35 Nm as compared to 33.20 Nm for the injured and uninjured limbs. The mean differences were 8.25 Nm for the slow eccentric test and 4.85 Nm for the fast eccentric test which were both found to be significant ($P<.01$). The comparison of injured to uninjured shoulders for the external rotation movement is graphically represented in Appendix F.

The strength discrepancies between the injured and uninjured shoulders for the external rotation movement were even more dramatic than those found in the adduction tests. A possible explanation for these discrepancies lies in the fact that both of these movements require a large range in the shoulder joint. To be specific, adduction and external rotation movements place a great deal of strain on the injured area of the shoulder as the extreme ranges of these movements are achieved.

4.7 STRENGTH RATIO COMPARISONS

An important component of any strength comparison test is the analysis of strength ratios. The two most common ratios studied are the agonist/antagonist ratios and, more recently, the concentric/eccentric ratios. These ratios can help to explain a number of unanswered questions about the muscle groups involved in a certain movement. They can also be used as an indicator of injury or a possible threat of injury occurrance when clinically analyzed. The analyses below focus on these two ratios and the comparison bewteen the injured group and the control group for each ratio.

4.7.1 Concentric/Eccentric Ratios

The concentric/eccentric ratios for each movement at both speeds were calculated for both the injured group and the control group. The mean and standard deviation for each test is given in Table 5 along with the results of the two-sample t-tests which were carried out between the injured and the control group for each test.

A number of general observations can be made from table 5 regarding the concentric/eccentric ratios of the eight shoulder movements. The most obvious is that all of the ratios are below 1.00 which shows that eccentric contractions produce greater peak torque scores than concentric contractions. In the control group, the ratios

TABLE 5

Mean and Standard Deviation for the Concentric/Eccentric Ratios for Injured and Control Groups with Results of Two-Sample T-Tests

	Injured	Control	Significance
Flexion			
slow	.839 (.195)	.851 (.127)	NS
fast	.778 (.183)	.928 (.346)	NS
Extension			
slow	.899 (.179)	.849 (.118)	NS
fast	.843 (.246)	.770 (.123)	NS
Adduction			
slow	.889 (.194)	.870 (.099)	NS
fast	.819 (.137)	.763 (.141)	NS
Abduction			
slow	.880 (.147)	.957 (.138)	NS
fast	.917 (.472)	.935 (.194)	NS
Internal Rotation			
slow	.842 (.078)	.832 (.088)	NS
fast	.807 (.117)	.799 (.099)	NS
External Rotation			
slow	.887 (.185)	.923 (.107)	NS
fast	.795 (.189)	.880 (.085)	NS
Hor. Adduction			
slow	.851 (.170)	.873 (.116)	NS
fast	.900 (.328)	.796 (.096)	NS
Hor. Abduction			
slow	.759 (.091)	.830 (.079)	*
fast	.775 (.184)	.740 (.114)	NS

* = significant $P < .05$

range from a low of 0.740 in fast horizontal abduction to a high of 0.957 in slow abduction. The range for the injured group is from 0.759 in slow horizontal abduction to 0.917 in fast abduction. The highest ratios for both groups occurred in the abduction movements while the lowest ratios occurred in the horizontal abduction movements. This indicates that the deltoid and other abductors of the shoulder were not producing as great an eccentric force as a concentric force. The opposite was true for the muscles producing horizontal shoulder abduction, as the trapezius and rhomboids seemed to be able to provide a much greater eccentric contraction in comparison to the concentric force produced.

Another observation made from table 5 is that the ratios obtained in the fast movements were lower than those obtained at the slow speed for the same movement. This was especially true for the control group in which all of the movements except shoulder flexion followed this trend. Thus, it would seem that at slower speeds there was a tendency for the concentric peak torques to be much more similar to the eccentric peak torques than at faster speeds.

Table 5 also shows the comparison between the injured and the control groups. There was only one significant difference ($P<.05$) found when comparing the concentric/eccentric ratios between the two groups. This difference was for the slow horizontal abduction test in which the injured group had a mean concentric/eccentric ratio of 0.759 while the control group had a ratio of 0.830 for a mean difference of 0.071.

These results indicate that the loss in strength that occurred from a complete AC separation affected both the concentric and the eccentric contraction phases almost equally. If either the concentric or eccentric phase was more greatly affected than the other there would have been a number of significant differences found in the comparisons from table 5. The one minor difference is not enough evidence to suggest that the two contraction phases were not affected equally as a result of the injury.

4.7.2 Agonist/Antagonist Ratios

The agonist/antagonist ratios for four pair of movements were calculated for both the injured and the control group. The pairings were flexion/extension, adduction/abduction, internal rotation/external rotation, and horizontal adduction/horizontal abduction. For each pair of movements a ratio was calculated for the concentric slow, concentric fast, eccentric slow, and eccentric fast test conditions. Table 6 shows the mean and standard deviation for each movement as well as the results of the two-sample t-tests carried out between the two groups for each test condition.

There are several general observations which can be made from table 6. Regarding the relationships between agonists and antagonists, flexion was found to have lower peak torque values than extension. All of the ratios in this pairing are below 1.00 for all four test conditions in each group. These ratios range from 0.863 in the concentric fast test in the injured group to 0.994 in the same test of the control group.

TABLE 6

Mean and Standard Deviation for the Agonist/Antagonist Ratios for Injured and Control Groups with Results of Two-Sample T-Tests

	Injured	Control	Significance
Flexion/Extension			
con. slow	.896 (.413)	.986 (.255)	NS
con. fast	.863 (.205)	.994 (.195)	*
ecc. slow	.980 (.484)	.973 (.193)	NS
ecc. fast	.939 (.258)	.881 (.257)	NS
Adduction/Abduction			
con. slow	1.393 (.378)	1.381 (.404)	NS
con. fast	1.438 (.499)	1.196 (.265)	NS
ecc. slow	1.424 (.476)	1.500 (.388)	NS
ecc. fast	1.482 (.478)	1.455 (.319)	NS
Int. Rot./Ext. Rot.			
con. slow	1.670 (.459)	1.262 (.296)	**
con. fast	1.820 (.453)	1.297 (.430)	**
ecc. slow	1.724 (.458)	1.388 (.258)	**
ecc. fast	1.754 (.370)	1.409 (.362)	**
Hor. Add./Hor. Abd.			
con. slow	1.070 (.328)	1.041 (.219)	NS
con. fast	1.145 (.330)	1.216 (.160)	NS
ecc. slow	.950 (.283)	.995 (.227)	NS
ecc. fast	1.021 (.335)	1.128 (.172)	NS

NS = not significant
* = significant $P < .05$
** = significant $P < .01$

The adduction/abduction ratios were found to fall between 1.381 and 1.500, showing that the adductors were stronger than the abductors. This is not surprising as the strong pectoralis major muscle is responsible for adduction while abduction is produced by the smaller deltoid and supraspinatis muscles.

Internal rotation was found to produce greater peak torques than external rotation in both the injured and the control group. The ratios in the injured group ranged from 1.670 to 1.820 while the ratios in the control group ranged from 1.262 to 1.409. The force produced by the subscapularis and latissimus dorsi muscles is, therefore, greater than the combined force of the infraspinatis and teres minor muscles.

The horizontal adduction/horizontal abduction ratio was the only grouping in which there was a discrepancy regarding which movement produced the greater forces. The concentric slow, concentric fast, and eccentric fast tests for both groups produced ratios greater than 1.00. These ratios ranged from 1.021 to 1.216 which showed that the horizontal adductors of the shoulder produced slightly greater forces than the horizontal abductors. The opposite was true for the eccentric slow test for both the injured and the control groups. The horizontal adduction/horizontal abduction ratio for this test was 0.950 for the injured group and 0.995 for the control group. These ratios are, however, very close to 1.00 and this finding is most likely due to chance.

There are a number of differences between the agonist/antagonist ratios of the injured and the control group. The flexion/extension ratio for the concentric fast test was found to be significantly lower ($P<.05$) for the injured group (0.863) as compared to the control group

(0.994) with a difference of 0.131. The results from table 4 which compared the injured and uninjured limbs of the affected group would suggest that the ratio was lower due to the concentric fast extension test being very similar for both limbs. The concentric fast flexion test, however, was higher for the uninjured limb as compared to the injured limb. This may suggest that concentric flexion of the shoulder at a fast speed is affected by a complete AC separation to a greater extent than extension under the same conditions, as has been suggested by others (Walsh et al., 1985; Glick et al., 1977).

A more dramatic difference between groups was found for the internal rotation/external rotation ratios. For each of the four test conditions the injured group had significantly higher ratios as compared to the control group ($P<.01$). The concentric slow test produced ratios of 1.670 for the injured group and 1.262 for the control group with a significant difference of 0.408 ($P=.0019$). The ratios for the concentric fast test were 1.820 and 1.297 for the injured and control groups respectively with a significant difference of 0.523 ($P=.0006$). The eccentric slow ratio for the injured group was 1.724 which was 0.336 higher than the control group ratio of 1.388 which again was a significant difference ($P=.0070$). Finally, the eccentric fast ratio was 1.754 for the injured group and 1.409 for the control group with a significant difference of 0.345 ($P=.0049$). These comparisons are graphically represented in Appendix G.

The dramatic differences in the internal rotation/external rotation ratios represents a serious problem for the injured group. As was suggested earlier in this paper, an imbalance between antagonist muscles causes the weaker muscle group to be more vulnerable to stress (Grace et al., 1984). In this case it is the external rotators of the shoulder that are at risk. The results from table 4 clearly show that the peak torque in external rotation is significantly decreased due to the AC separation. This reduction creates a muscle imbalance between the subscapularis muslce and the infraspinatis and teres minor muscles.

Chapter V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 SUMMARY

The main purposes of this study were, first, to develop a protocol using the KINCOM dynamometer to evaluate isokinetic shoulder strength, and then to compare shoulder strength in injured and uninjured subjects. The protocol was implemented on 20 healthy individuals and 20 patients who were recovering from a third degree acromioclavicular separation to compare upper body muscle group strength. This comparison included peak torque measurements, concentric/eccentric ratios, and agonist/antagonist ratios. Testing was also carried out to check the reliability of the newly developed protocol.

The review of literature described the anatomy involved with a third degree AC separation and the implications of this injury on the strength measurements which were to be carried out. The relationships involving the concentric/eccentric and agonist/antagonist ratios were dealt with as they relate to muscular imbalances in the body. Some of the problems encountered in isokinetic strength testing were reviewed as well as some of the testing procedures necessary to develop a protocol to evaluate shoulder strength.

5.2 CONCLUSIONS

There are a number of conclusions which were reached in this study with the major conclusions listed below:

1. The protocol developed to test isokinetic shoulder strength was reliable.

2. The data collected reinforced the force-velocity and concentric-eccentric theories which were previously reported in the literature.

3. A third degree shoulder separation significantly reduces the strength in shoulder adduction and external rotation.

4. The concentric/eccentric ratios for all eight movements tested were not affected by the complete AC separation.

5. The flexion/extension ratio at the concentric fast speed was significantly decreased as a result of the injury.

6. The internal rotation/external rotation ratios at both speeds and both contraction phases were significantly increased as a result of the injury.

5.3 RECOMMENDATIONS

The following recommendations have been made on the basis of the current study and may be of benefit for patients recovering from a complete AC separation as well as to further research in this area:

1. A rehabilitation program for a patient recovering from a third degree AC separation should focus upon strengthening the shoulder adductors and especially the shoulder external rotators. This can be achieved through a program which includes both concentric and eccentric muscle contractions at an intensity that is safe yet beneficial to the patient. The flexion/extension and internal rotation/external rotation ratios should be back to normal values before the subject is allowed to return to normal activities to defend against the danger of reinjuring the shoulder.

2. The isokinetic shoulder strength protocol developed in this study should be utilized by individuals who are using the KINCOM dynamometer to test shoulder strength in both healthy and injured individuals.

3. Further improvements should be made to the existing shoulder strength protocol and new protocols should be established to test the other major joints in the body. This is the only way that test scores can be reliably and effectively utilized by all reserachers studying in this area.

4. Subjects should be given at least five to seven days to recover from a maximum strength test, such as the protocol used in this study, before administering a subsequent test.

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Appendix A

EXAMPLE OF THE PATIENT INFORMATION SHEET AND QUESTIONNAIRE

ACROMIOCLAVICULAR SEPARATION STUDY

PATIENT INFORMATION SHEET

1. NAME ______________________________ 2. AGE ________

3. DATE OF SURGERY ______________

4. METHOD OF INJURY ______________________________

5. DOMINANT HAND ______________

6. DO YOU PARTICIPATE IN WEIGHT TRAINING OR STRENGTHENING? How often?

   ALWAYS ________ SOMETIMES ________ NEVER ________

7. LIST THE SPORTS YOU ARE ACTIVE IN: How often?

   ________________________ ________________________

   ________________________ ________________________

   ________________________ ________________________

8. YOUR LAST X-RAY: DATE ______________________

   PLACE ______________________

9. Have you returned to your sports?

QUESTIONNAIRE

1) Rate the degree of pain you have with your shoulder.

   none ☐ ☐ ☐ ☐ severe

2) How would you describe your function?

   normal ☐ ☐ ☐ ☐ poor

3) Do you have stiffness?

   none ☐ ☐ ☐ ☐ severe

4) How is your strength?

   normal ☐ ☐ ☐ ☐ poor

5) How would you judge the cosmetic appearance of your shoulder?

   same as the other shoulder ☐ ☐ ☐ ☐ grossly deformed or scarred

6) What is the overall impression of your results?

   excellent ☐ ☐ ☐ ☐ poor

Appendix B

EXAMPLE OF THE INFORMED CONSENT FORM

Informed Consent and Release

Explanation of tests

The following data will be collected from each subject during the study:

1. height, weight, age

2. 16 strength measurements for each shoulder, including: flexion, extension, abduction, adduction, internal rotation, external rotation,horizontal abduction, horizontal adduction, at both a slow speed (50 degrees per second) and a fast speed (180 degrees per second).

3. 5 flexibility measurements at each shoulder, including: flexion, extension, abduction, internal and external rotation.

4. a questionnaire regarding the history of the injury.

The tests will be administered by trained personnel who will explain each test item in detail. All results will be kept confidential.

Risks

I have read the above and understand that I may request that the testing be stopped or delayed at any time if I so desire. The testing may also be terminated if the tester observes any symptoms of distress. The risk of injury is very minimal, and a qualified physician will be there at all times to monitor the testing.

Waiver and Release

I understand that in participating in this study, I do so at my own risk and I undertake to indemnify the University of Manitoba, its agents, officers and employees against any and all liability that may arise as a result of my participating.

____________________ ____________________

signature date

____________________ ____________________

witness date

Appendix C

EXAMPLE OF A TYPICAL KINCOM GRAPH

CON ——— ECC ———

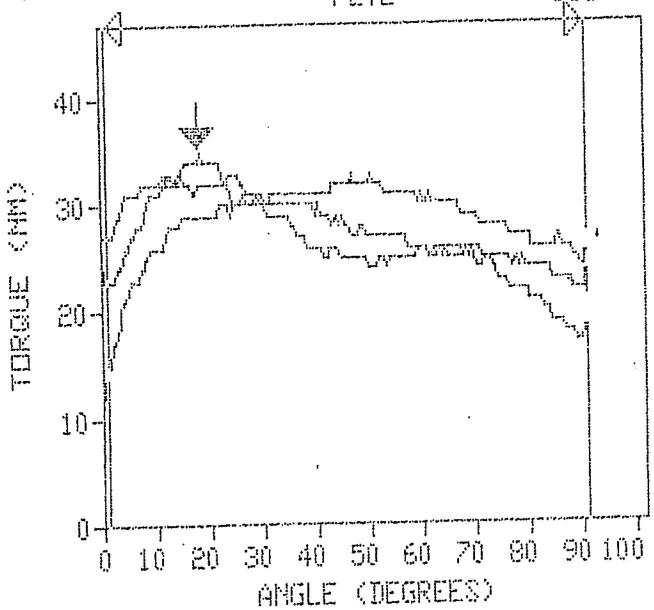
TORQUE VS ANGLE REPORT

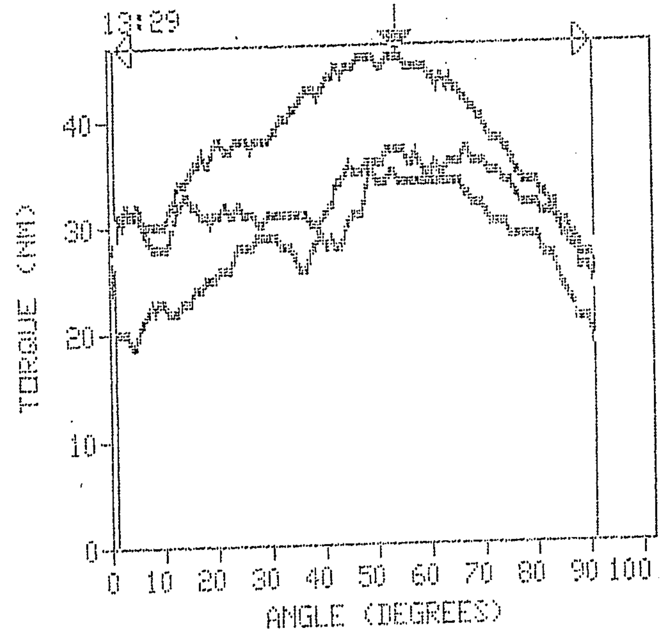
TORQUE CALCULATION
REGION ◁———▷
PEAK TORQUE ↓

JFLSER.50 JOHN FREJUK

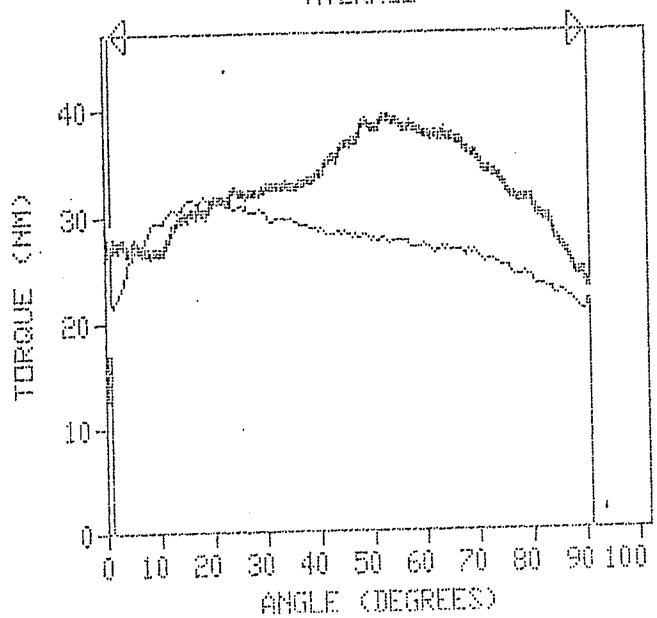
S ER L

PETE 111486 13:29





AVERAGE



TORQUE / MOTION	PEAK (NM)	AVG (NM)	% PEAK / AVG
CON	35 (@ 18°)	27	130
ECC	46 (@ 54°)	33	140
% CON / ECC	76	82	REGION: 1°- 91°

Appendix D

MEAN, STANDARD DEVIATION AND RANGE FOR PEAK TORQUE SCORES OF THE INJURED GROUP

SAS

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN	SUM	VARIANCE	C.V.
GRP=INJURED									
RFLCNSL	20	64.20000000	26.39896330	26.00000000	141.00000000	5.90298765	1284.0000000	696.9052632	41.120
RFLECSL	20	77.45000000	31.66182327	30.00000000	165.00000000	7.07979891	1549.0000000	1002.4710526	40.880
RFLCNFS	20	60.30000000	19.27938632	22.00000000	93.00000000	4.31100184	1206.0000000	371.6947368	31.972
RFLECFS	20	80.65000000	32.52897494	27.00000000	163.00000000	7.27369992	1613.0000000	1058.1342105	40.334
REXCNSL	20	70.65000000	24.39860867	22.00000000	124.00000000	5.45569476	1413.0000000	595.2921053	34.534
REXECSL	20	81.50000000	29.59818629	23.00000000	131.00000000	6.61835566	1630.0000000	876.0526316	36.317
REXCNFS	20	65.95000000	20.71479258	31.00000000	105.00000000	4.63196843	1319.0000000	429.1026316	31.410
REXECFS	20	84.15000000	35.16768104	28.00000000	162.00000000	7.86373254	1683.0000000	1236.7657895	41.792
RADCNSL	20	63.85000000	17.66136134	31.00000000	98.00000000	3.94920045	1277.0000000	311.9236842	27.661
RADECSL	20	75.30000000	25.89066078	39.00000000	129.00000000	5.78932775	1506.0000000	670.3263158	34.383
RADCNFS	20	61.20000000	16.36620395	35.00000000	94.00000000	3.65959446	1224.0000000	267.8526316	26.742
RADECFS	20	74.80000000	27.62836071	22.00000000	132.00000000	6.17788927	1496.0000000	763.3263158	36.936
RABCNSL	20	50.75000000	27.27805171	20.00000000	134.00000000	6.09955779	1015.0000000	744.0921053	53.750
RABECSL	20	55.45000000	30.68425792	21.00000000	147.00000000	6.86120866	1109.0000000	941.5236842	55.337
RABCNFS	20	47.20000000	21.11771519	14.00000000	91.00000000	4.72206467	944.0000000	445.9578947	44.741
RABECFS	20	55.40000000	29.94978253	22.00000000	146.00000000	6.69697497	1108.0000000	896.9894737	54.061
RIRCNSL	20	41.85000000	12.83201178	19.00000000	64.00000000	2.86932506	837.0000000	164.6605263	30.662
RIRECSL	20	50.15000000	15.75561721	20.00000000	77.00000000	3.52306311	1003.0000000	248.2394737	31.417
RIRCNFS	20	41.05000000	11.78078275	23.00000000	68.00000000	2.63426310	821.0000000	138.7868421	28.699
RIRECFS	20	51.15000000	15.46226306	24.00000000	84.00000000	3.45746713	1023.0000000	239.0815789	30.229
RERCNSL	20	27.30000000	8.90948637	9.00000000	48.00000000	1.99222172	546.0000000	79.3789474	32.635
RERECSL	20	31.05000000	10.05498044	13.00000000	47.00000000	2.24836198	621.0000000	101.1026316	32.383
RERCNFS	20	24.80000000	7.72283013	10.00000000	38.00000000	1.72687732	496.0000000	59.6421053	31.140
RERECFS	20	29.20000000	9.91330844	15.00000000	45.00000000	2.21668316	584.0000000	98.2736842	33.950
RHDCNSL	20	59.95000000	25.10499007	29.00000000	121.00000000	5.61364644	1199.0000000	630.2605263	41.877
RHDECSL	20	67.85000000	26.80391762	30.00000000	124.00000000	5.99353819	1357.0000000	718.4500000	39.505
RHDCNFS	20	56.15000000	13.98598923	35.00000000	84.00000000	3.12736227	1123.0000000	195.6078947	24.908
RHDECFS	20	64.50000000	23.66765503	27.00000000	112.00000000	5.29224855	1290.0000000	560.1578947	36.694
RHBCNSL	20	56.20000000	16.58026728	31.00000000	85.00000000	3.70746047	1124.0000000	274.9052632	29.502
RHBECSL	20	74.10000000	22.78942506	35.00000000	108.00000000	5.09587036	1482.0000000	519.3578947	30.755
RHBCNFS	20	51.00000000	13.45166787	30.00000000	75.00000000	3.00788438	1020.0000000	180.9473684	26.376
RHBECFS	20	69.35000000	24.14054244	29.00000000	110.00000000	5.39798939	1387.0000000	582.7657895	34.810
LFLCNSL	20	62.60000000	23.79385148	13.00000000	118.00000000	5.32046694	1252.0000000	566.1473684	38.009
LFLECSL	20	72.50000000	28.74662452	26.00000000	136.00000000	6.42794065	1450.0000000	826.3684211	39.651
LFLCNFS	20	58.10000000	24.99873681	18.00000000	124.00000000	5.58988749	1162.0000000	624.9368421	43.027
LFLECFS	20	76.90000000	33.78243081	25.00000000	171.00000000	7.55398117	1538.0000000	1141.2526316	43.930
LEXCNSL	20	73.45000000	24.52812564	23.00000000	117.00000000	5.48465563	1469.0000000	601.6289474	33.394
LEXECSL	20	81.95000000	32.46127247	27.00000000	138.00000000	7.25856119	1639.0000000	1053.7342105	39.611
LEXCNFS	20	64.35000000	20.09261451	27.00000000	106.00000000	4.49284519	1287.0000000	403.7131579	31.224
LEXECFS	20	81.25000000	34.24197947	26.00000000	153.00000000	7.65673938	1625.0000000	1172.5131579	42.144
LADCNSL	20	65.35000000	19.96912090	29.00000000	97.00000000	4.46523118	1307.0000000	398.7657895	30.557
LADECSL	20	77.25000000	28.81862519	30.00000000	124.00000000	6.44404049	1545.0000000	830.5131579	37.306
LADCNFS	20	62.05000000	17.62616178	28.00000000	90.00000000	3.94132959	1241.0000000	310.6815789	28.406
LADECFS	20	80.90000000	25.28344580	41.00000000	132.00000000	5.65355035	1618.0000000	639.2526316	31.253
LABCNSL	20	51.70000000	19.15614509	23.00000000	98.00000000	4.28344426	1034.0000000	366.9578947	37.053
LABECSL	20	61.55000000	25.35739278	24.00000000	112.00000000	5.67008540	1231.0000000	642.9973684	41.198
LABCNFS	20	50.35000000	19.37517402	19.00000000	104.00000000	4.33242062	1007.0000000	375.3973684	38.481
LABECFS	20	58.70000000	27.23793794	26.00000000	129.00000000	6.09058808	1174.0000000	741.9052632	46.402
LIRCNSL	20	38.30000000	9.95833425	19.00000000	55.00000000	2.22675123	766.0000000	99.1684211	26.001
LIRECSL	20	45.75000000	11.95110653	23.00000000	62.00000000	2.67234866	915.0000000	142.8289474	26.123
LIRCNFS	20	37.55000000	9.32723798	24.00000000	64.00000000	2.08563382	751.0000000	86.9973684	24.840
LIRECFS	20	46.00000000	13.06260230	25.00000000	70.00000000	2.92088667	920.0000000	170.6315789	28.397
LERCNSL	20	28.85000000	9.51052049	11.00000000	48.00000000	2.12661703	577.0000000	90.4500000	32.965

GRP=INJURED

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN	SUM	VARIANCE	C.V.
LERECSL	20	34.00000000	10.68693250	15.00000000	53.00000000	2.38967075	680.0000000	114.2105263	31.432
LERCNFS	20	25.35000000	8.79159287	14.00000000	44.00000000	1.96585993	507.0000000	77.2921053	34.681
LERECFS	20	32.35000000	10.47440489	18.00000000	55.00000000	2.34214814	647.0000000	109.7131579	32.378
LHDCNSL	20	56.65000000	18.55369165	19.00000000	92.00000000	4.14873158	1133.0000000	344.2394737	32.751
LHDECSL	20	66.30000000	22.34443296	29.00000000	119.00000000	4.99636710	1326.0000000	499.2736842	33.702
LHDCNFS	20	55.10000000	16.75488931	21.00000000	94.00000000	3.74650715	1102.0000000	280.7263158	30.408
LHDECFS	20	68.25000000	26.05838586	34.00000000	119.00000000	5.82683222	1365.0000000	679.0394737	38.181
LHBCNSL	20	48.95000000	13.70161343	25.00000000	81.00000000	3.06377390	979.0000000	187.7342105	27.991
LHBECSL	20	64.90000000	21.67438459	29.00000000	111.00000000	4.84653973	1298.0000000	469.7789474	33.397
LHBCNFS	20	45.70000000	12.29933674	30.00000000	85.00000000	2.75021530	914.0000000	151.2736842	26.913
LHBECFS	20	62.35000000	24.39213635	28.00000000	127.00000000	5.45424750	1247.0000000	594.9763158	39.121

Appendix E

MEAN, STANDARD DEVIATION AND RANGE FOR PEAK TORQUE SCORES OF THE CONTROL GROUP

GRP=NORMAL

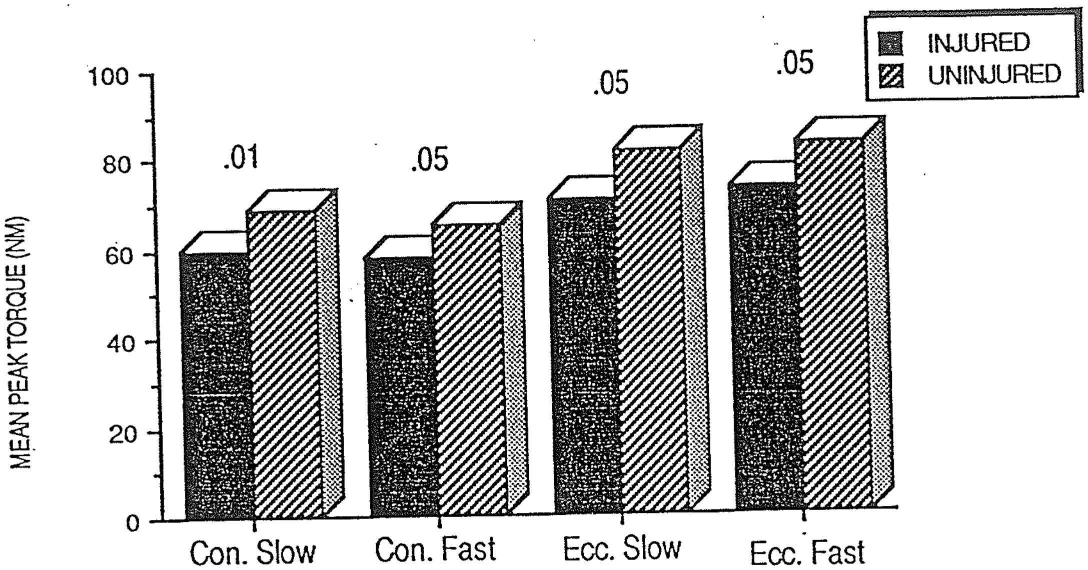
VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN	SUM	VARIANCE	C.V.
RFLCNSL	20	91.55000000	22.70051008	59.00000000	139.00000000	5.07598837	1831.0000000	515.3131579	24.796
RFLECSL	20	108.75000000	26.09269912	61.00000000	158.00000000	5.83450489	2175.0000000	680.8289474	23.993
RFLCNFS	20	81.50000000	22.26042039	47.00000000	126.00000000	4.97758132	1630.0000000	495.5263158	27.313
RFLECFS	20	96.55000000	36.33538945	32.00000000	173.00000000	8.12484008	1931.0000000	1320.2605263	37.634
REXCNSL	20	96.40000000	24.78836739	42.00000000	148.00000000	5.54284745	1928.0000000	614.4631579	25.714
REXECSL	20	114.65000000	31.18919347	60.00000000	181.00000000	6.97411568	2293.0000000	972.7657895	27.204
REXCNFS	20	82.10000000	15.21045347	46.00000000	107.00000000	3.40116079	1642.0000000	231.3578947	18.527
REXECFS	20	109.90000000	30.72612466	57.00000000	180.00000000	6.87057034	2198.0000000	944.0947368	27.958
RADCNSL	20	87.05000000	19.86394512	57.00000000	129.00000000	4.44171316	1741.0000000	394.5763158	22.819
RADECSL	20	101.00000000	25.20442735	63.00000000	164.00000000	5.63588129	2020.0000000	635.2631579	24.955
RADCNFS	20	75.35000000	13.44883090	49.00000000	104.00000000	3.00725001	1507.0000000	180.8710526	17.848
RADECFS	20	102.00000000	26.33388851	54.00000000	149.00000000	5.88843648	2040.0000000	693.4736842	25.818
RABCNSL	20	67.10000000	21.40806538	45.00000000	116.00000000	4.78698894	1342.0000000	458.3052632	31.905
RABECSL	20	71.60000000	25.56189598	44.00000000	127.00000000	5.71581371	1432.0000000	653.4105263	35.701
RABCNFS	20	66.80000000	23.54301774	41.00000000	138.00000000	5.26437881	1336.0000000	554.2736842	35.244
RABECFS	20	73.60000000	27.76480165	41.00000000	144.00000000	6.20839839	1472.0000000	770.8842105	37.724
RIRCNSL	20	49.40000000	12.76260986	32.00000000	86.00000000	2.85380632	988.0000000	162.8842105	25.835
RIRECSL	20	59.60000000	14.36882591	35.00000000	93.00000000	3.21296715	1192.0000000	206.4631579	24.109
RIRCNFS	20	47.50000000	11.24605194	28.00000000	75.00000000	2.51469366	950.0000000	126.4736842	23.676
RIRECFS	20	60.05000000	14.33609724	30.00000000	89.00000000	3.20564880	1201.0000000	205.5236842	23.874
RERCNSL	20	39.80000000	8.45172047	30.00000000	56.00000000	1.88986215	796.0000000	71.4315789	21.235
RERECSL	20	43.60000000	10.20526180	28.00000000	64.00000000	2.28196591	872.0000000	104.1473684	23.407
RERCNFS	20	38.75000000	10.05707397	22.00000000	59.00000000	2.24883011	775.0000000	101.1447368	25.954
RERECFS	20	44.05000000	10.85053964	28.00000000	66.00000000	2.42625442	881.0000000	117.7342105	24.632
RHDCNSL	20	79.85000000	20.37871697	53.00000000	123.00000000	4.55681964	1597.0000000	415.2921053	25.521
RHDECSL	20	93.00000000	27.90208443	63.00000000	151.00000000	6.23909575	1860.0000000	778.5263158	30.002
RHDCNFS	20	72.95000000	16.60841575	47.00000000	116.00000000	3.71375466	1459.0000000	275.8394737	22.767
RHDECFS	20	93.15000000	25.15065135	52.00000000	156.00000000	5.62385661	1863.0000000	632.5552632	27.000
RHBCNSL	20	79.35000000	23.81789464	49.00000000	134.00000000	5.32584315	1587.0000000	567.2921053	30.016
RHBECSL	20	96.15000000	28.66003085	53.00000000	155.00000000	6.40857772	1923.0000000	821.3973684	29.808
RHBCNFS	20	60.50000000	14.01315172	38.00000000	105.00000000	3.13343598	1210.0000000	196.3684211	23.162
RHBECFS	20	83.75000000	23.42485185	46.00000000	149.00000000	5.23795611	1675.0000000	548.7236842	27.970
LFLCNSL	20	89.80000000	27.59404970	52.00000000	161.00000000	6.17021709	1796.0000000	761.4315789	30.728
LFLECSL	20	103.70000000	34.29147508	54.00000000	180.00000000	7.66780693	2074.0000000	1175.9052632	33.068
LFLCNFS	20	74.45000000	16.36580196	44.00000000	110.00000000	3.65950457	1489.0000000	267.8394737	21.982
LFLECFS	20	94.10000000	27.99041189	53.00000000	163.00000000	6.25884637	1882.0000000	783.4631579	29.745
LEXCNSL	20	92.30000000	19.34207304	54.00000000	127.00000000	4.32501901	1846.0000000	374.1157895	20.956
LEXECSL	20	104.00000000	27.27443376	54.00000000	160.00000000	6.09874879	2080.0000000	743.8947368	26.225
LEXCNFS	20	83.65000000	18.31098319	51.00000000	117.00000000	4.09446031	1673.0000000	335.2921053	21.890
LEXECFS	20	100.65000000	29.22377367	51.00000000	160.00000000	6.53463445	2013.0000000	854.0289474	29.035
LADCNSL	20	79.80000000	10.60585737	54.00000000	97.00000000	2.37154180	1596.0000000	112.4842105	13.291
LADECSL	20	96.10000000	21.04106261	55.00000000	138.00000000	4.70492463	1922.0000000	442.7263158	21.895
LADCNFS	20	75.75000000	12.25120832	48.00000000	98.00000000	2.73945346	1515.0000000	150.0921053	16.173
LADECFS	20	95.85000000	20.86869981	57.00000000	138.00000000	4.66638314	1917.0000000	435.5026316	21.772
LABCNSL	20	65.40000000	20.63823738	33.00000000	120.00000000	4.61485017	1308.0000000	425.9368421	31.557
LABECSL	20	71.30000000	22.13618139	35.00000000	133.00000000	4.94980063	1426.0000000	490.0105263	31.047
LABCNFS	20	62.75000000	18.95666804	36.00000000	114.00000000	4.23883984	1255.0000000	359.3552632	30.210
LABECFS	20	71.85000000	18.05627169	37.00000000	114.00000000	4.03750509	1437.0000000	326.0289474	25.131
LIRCNSL	20	51.35000000	14.18774490	29.00000000	82.00000000	3.17247620	1027.0000000	201.2921053	27.629
LIRECSL	20	58.55000000	15.09783881	32.00000000	89.00000000	3.37597939	1171.0000000	227.9447368	25.786
LIRCNFS	20	47.25000000	11.52514414	32.00000000	70.00000000	2.57710057	945.0000000	132.8289474	24.392
LIRECFS	20	57.00000000	14.17930293	40.00000000	94.00000000	3.17058852	1140.0000000	201.0526316	24.876
LERCNSL	20	37.35000000	8.87500927	24.00000000	59.00000000	1.98451240	747.0000000	78.7657895	23.762

GRP=NORMAL

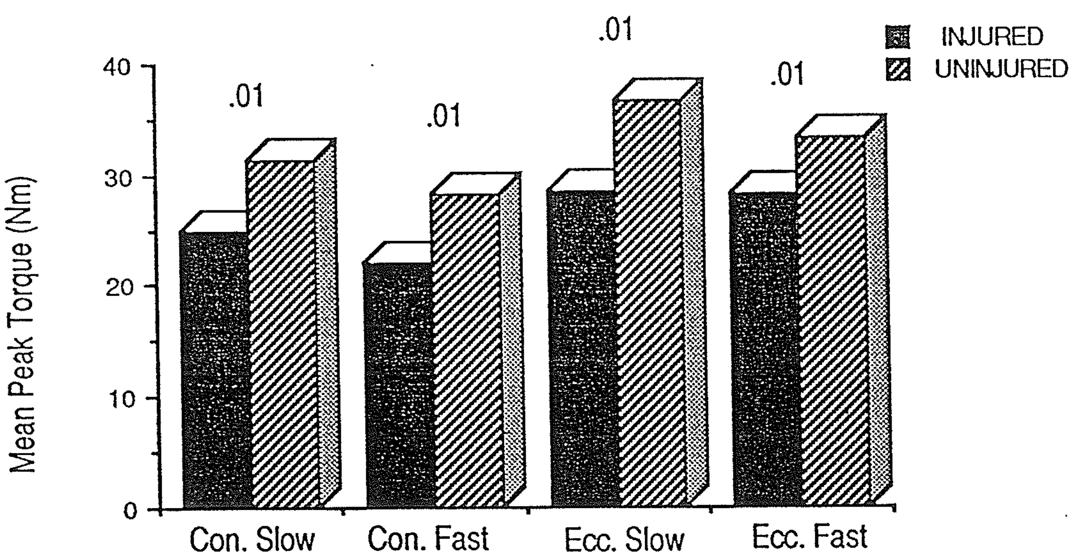
VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN	SUM	VARIANCE	C.V.
LERECSL	20	43.15000000	10.90762650	27.00000000	68.00000000	2.43901943	863.0000000	118.9763158	25.278
LERCNFS	20	35.60000000	8.48776209	23.00000000	52.00000000	1.89792130	712.0000000	72.0421053	23.842
LERECFS	20	41.60000000	11.14214380	24.00000000	72.00000000	2.49145909	832.0000000	124.1473684	26.784
LHDCNSL	20	76.90000000	21.36623012	50.00000000	142.00000000	4.77763430	1538.0000000	456.5157895	27.784
LHDECSL	20	92.25000000	28.37692725	41.00000000	163.00000000	6.34527383	1845.0000000	805.2500000	30.761
LHDCNFS	20	69.40000000	17.64086166	38.00000000	117.00000000	3.94461658	1388.0000000	311.2000000	25.419
LHDECFS	20	92.10000000	21.74469082	59.00000000	141.00000000	4.86226068	1842.0000000	472.8315789	23.610
LHBCNSL	20	66.65000000	19.28805193	42.00000000	102.00000000	4.31293953	1333.0000000	372.0289474	28.939
LHBECSL	20	81.35000000	18.46269354	52.00000000	115.00000000	4.12838378	1627.0000000	340.8710526	22.695
LHBCNFS	20	57.85000000	13.91808744	38.00000000	90.00000000	3.11217896	1157.0000000	193.7131579	24.059
LHBECFS	20	78.85000000	26.48589496	45.00000000	145.00000000	5.92242616	1577.0000000	701.5026316	33.590

Appendix F

GRAPHS OF MEAN PEAK TORQUE IN ADDUCTION AND EXTERNAL ROTATION FOR INJURED AND UNINJURED LIMBS OF INJURED GROUP



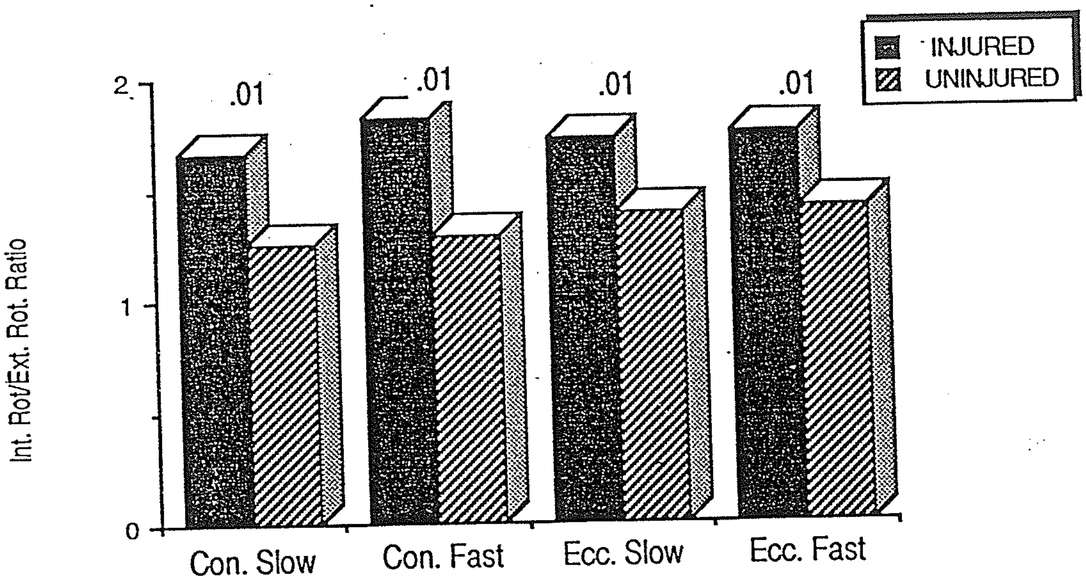
Mean peak torque in adduction of injured and uninjured limbs of 20 injured subjects



Mean peak torque in external rotation of injured and uninjured limbs of 20 injured subjects

Appendix G

GRAPH OF INTERNAL ROTATION/EXTERNAL ROTATION RATIOS FOR INJURED AND UNINJURED GROUPS



Internal rotation/external rotation ratios for injured and control groups