Shoulder Internal and External Rotation Strength in Impingement Syndrome

by

Lori Ann De Pauw

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SHOULDER INTERNAL AND EXTERNAL ROTATION STRENGTH IN IMPINGEMENT SYNDROME

BY

LORI ANN DE PAUW

A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University

of Manitoba in partial fulfillment of the requirements for the degree

of

MASTER OF SCIENCE

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I. Abstract

Purpose: Reduced ability of the rotator cuff to provide glenohumeral joint stabilization has been implicated in the etiology of shoulder impingement syndrome. During overhead motion the rotator cuff functions to provide glenohumeral joint stabilization primarily by eccentric muscle action. Eccentric muscle strength has not been previously studied in subjects with impingement syndrome. The purpose of this study was to evaluate concentric and eccentric strength of shoulder internal (IR) and external rotation (ER) in subjects with impingement syndrome and in a control group.

Subjects: Male subjects with impingement syndrome were obtained by referral from local physicians and physiotherapists and evaluated to ensure conformity with inclusion and exclusion criteria (n = 9, age; $\bar{x}$ = 32.1±6.9 SD years, mass; $\bar{x}$ = 84.2±7.0 SD kg). Diagnostic criteria included a positive impingement sign and negative relocation test. An asymptomatic age and sex matched control group was recruited for comparison (n = 23, age; $\bar{x}$ = 33.6±5.6 SD years, mass; $\bar{x}$ = 81.0±10.9 SD kg).

Methods and Materials: Isovelocity dynamometry (Kin-Com 500H) was used to test shoulder internal and external rotation strength with the shoulder positioned in the plane of the scapula. Three maximal effort concentric and eccentric contractions were performed at four testing speeds (45, 90, 135, 180°/s).

Analyses: Peak moment and work were derived for each test velocity and normalized for body mass. A 2D relief map (50 x 50 matrix) for 90° range of motion (ROM) and a ±180°/s velocity spectrum was generated for each subject for IR and ER using ISOMAP software (Isodyne Inc., Winnipeg). Split-unit multivariate ANOVA was performed.

Results and Conclusions: The impingement group exhibited a substantial ER eccentric deficit ($p<0.05$) at all velocities and a smaller concentric ER deficit for 2 of 4 speeds ($p<0.05$). Internal rotation (IR) values were not significantly different between the groups. Dynamic control ratios (peak concentric IR/eccentric ER) were significantly higher in the impingement group ($p<0.05$). The averaged ER strength relief map for the impingement group demonstrated a velocity and ROM matched deficit over 22% of the map area compared to the averaged control group map. Deficits were exhibited primarily within the eccentric region of the relief map, and within 0-50° ROM (forearm horizontal = 0°). We conclude that subjects with impingement syndrome exhibit neuromuscular patterns of shoulder strength which differ from those observed in subjects without shoulder pathology. Although it is unclear whether these differences represent a primary or secondary phenomenon, it is likely that this pattern would contribute to ongoing symptoms and predispose further injury. The eccentric ER deficit would result in a decreased ability to joint stabilize during IR motions.

Clinical Relevance: Rehabilitation programs directed at normalizing neuromuscular balance, primarily by addressing the specific ER eccentric deficits identified in this study, may benefit subjects with shoulder impingement syndrome.

II. Acknowledgements

There are many to whom I owe my heartfelt thanks on the completion of this thesis. To my best friend and husband, Philip Poon for his unwavering love and support. To my daughters, Lauren, Stephanie, and Alana for their patience and understanding. They are my "pride and joy" and their accomplishments have been a source of inspiration to me. To my family, especially my mother, for time spent caring for my children. To all the subjects who participated in this study, many of whom were friends and colleagues. To my committee members, Dr. J. Cooper and Dr. P. MacDonald, for contributing their time and knowledge. Finally, to my advisor, Dr. D. Kriellaars for his constant enthusiasm, encouragement and patience. His wisdom and teaching excellence are unequalled in my experience and it has been a very real privilege to have had the opportunity to work with him.

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V. Introduction

Establishing objective values of shoulder strength in the normal population is important in order to provide guidelines to assist in the evaluation and rehabilitation of patients with shoulder pathology. In addition, examination of the pattern of variation of shoulder strength in normal subjects and subjects with shoulder disorders may provide insight into pathophysiology and provide guidance in the design of exercise programs to promote recovery of function and prevention of further injury.

The production and control of human voluntary motion involves a complex interaction of neural, mechanical, and muscular factors (Enoka 1988). The operational domain of the neuromuscular system encompasses a vast range of angular velocities and a large range of joint angles for single and multisegmental motion. Most functional human motion requires rotation of body segments. Resultant joint moment (RJM) represents the rotational tendency exerted on a segment by the forces produced from all the tissues spanning a joint including muscles, ligaments and bones (Hay 1992). The ability to control the rotation of body segments is directly related to generation of RJM. The relatively recent introduction of isovelocity (isokinetic) dynamometry has allowed the objective quantification of RJM for concentric and eccentric muscle action over a large range of joint motion and at specific angular velocities. Strength assessment protocols using isovelocity dynamometers have been demonstrated to be capable of providing objective, valid and reliable estimations of resultant joint moment about the shoulder (RJM_S) (Greenfield et al. 1990, Hageman et al. 1989, Hellwig and Perrin 1991, Kuhlman et al. 1992).

Data on shoulder muscle strength for asymptomatic subjects has been provided by various authors using isovelocity dynamometers (Cahalan et al. 1991, Ivey et al. 1985, Kuhlman et al. 1992, Maddux et al. 1989, Nicholas et al. 1989, Otis et al. 1990, Reid et al. 1989). These studies have provided information on maximal concentric absolute mean moment values as well as mean maximal concentric agonist/antagonist shoulder strength ratios for groups of nonathletic male and female subjects. However eccentric muscle activity was not examined in any of these studies and peak moment was often the only parameter assessed (Cahalan et al. 1991, Ivey et al. 1985, Otis et al. 1990). Documentation of peak moment as the only measure of muscle strength may fail to capture important and clinically relevant information which can be obtained through more elaborate analysis of the moment-angle (M/θ) data (Kuhlman et al. 1992). Additionally, it is important to further our understanding of eccentric muscle action in asymptomatic subjects and those with specific shoulder pathology in order to gain insight into injury prevention, injury mechanism and progression, and optimal rehabilitation.

Studies employing isovelocity dynamometry which have examined the concentric moment angular velocity (M/ω) relationship have generally demonstrated a velocity dependent decrease in peak moment with increasing angular velocity (Cahalan et al. 1991, Ellenbecker 1988, Hageman et al 1989, Kuhlman et al. 1992, Ng and Kramer 1991, Soderberg and Blaschak 1987). However the eccentric/concentric relationship has not been widely studied and there is a paucity of information regarding the eccentric M/ω relationship for the shoulder musculature. In the few studies which have included examination of shoulder eccentric muscle action in subjects without shoulder pathology, maximal eccentric moment values have generally exceeded maximal concentric values at the specific velocities tested (Ellenbecker et al. 1988, Hageman et al. 1989, Hellwig and Perrin 1991, Ng and Kramer 1991). The one study which specifically investigated the eccentric M/ω relationship for shoulder musculature found that eccentric external rotation maximal peak moment generation increased with increasing speed in females and did not vary with angular speed in males (Hageman et al. 1989).

Shoulder impingement syndrome has been identified as one of the most commonly encountered musculoskeletal disorders (Craton 1992). It is associated with shoulder pain and disability in a broad spectrum of the population. The etiological factors related to the development of impingement syndrome and concomitant rotator cuff pathology have not been fully elucidated. Reduced ability of the shoulder musculature in providing glenohumeral joint stabilization has been proposed as one possible etiological component (Bowen and Warren 1991, Nirschl 1989, Perry 1983, Silliman and Hawkins 1991). Stability of the glenohumeral joint is dependent to a large extent on neuromuscular control which is provided primarily by action of the musculotendinous rotator cuff (Cain et al. 1987, Keating et al. 1993, Kronberg et al. 1990, Saha 1971).

Weakness of the rotator cuff as a result of contractile overload and fatigue (Nirschl 1989), disuse, cervical radiculopathy, suprascapular neuropathy (Matsen and Arntz 1990a) and altered muscle coordination due to pain (Poppen and Walker 1976) have been hypothesized to result in subacromial impingement due to inadequate humeral head depressor action of the rotator cuff during elevation of the arm.

Studies have also suggested that a relative "imbalance" in the moment generating capability of shoulder internal and external rotation may have a role in the development/persistence of shoulder impingement syndrome (Beasley and Chandler 1989, Burnham et al. 1993, Chandler et al. 1992, Cook et al. 1987, Fowler 1988, Hinton 1988, McMaster et al. 1991, 1992, Warner et al. 1990, Wilk et al. 1993). Recent investigations have employed isovelocity dynamometry to investigate shoulder internal and external rotation strength in athletic groups at high risk for developing shoulder pain. Many have demonstrated differences in the strength profile of shoulder internal and external rotation in groups at high risk for developing shoulder pain as compared to non-athletic populations. Increased concentric internal rotation/external rotation (IR/ER) ratios have been demonstrated in swimmers (Beasley and Chandler 1989, Fowler 1988, McMaster et al 1992), water polo players (McMaster et al. 1991), and from dominant to nondominant side in baseball pitchers (Chandler et al. 1992, Chandler et al. 1992, Hinton 1988, Wilk et al. 1993). The increased shoulder concentric IR/ER ratios, presumably attributable to training induced neuromuscular adaptations, were primarily the result of increased internal rotation RJM, while generally external rotation RJM was maintained or slightly decreased.

Despite the implication of shoulder muscle weakness and "imbalance" in the development/persistence of shoulder impingement syndrome few studies have investigated shoulder internal and external rotation strength in this population. Warner et al. (1990) demonstrated a significantly increased ratio of concentric shoulder internal/external rotation in subjects with impingement syndrome and a significantly decreased ratio in a group with instability compared to a control group. The differences observed in IR/ER ratios could not be ascribed to any absolute difference in peak moment or total work of either internal rotation or external rotation between the groups although the authors felt that a relative decrease of external rotation strength was a factor in impingement syndrome. Burnham et al. (1993) found that paraplegic wheelchair athletes with impingement syndrome had deficits of concentric internal rotation, external rotation and adduction RJM and a significantly higher concentric abduction/internal rotation and abduction/adduction ratio than paraplegic athletes without impingement syndrome. No significant differences were observed in the internal rotation/external rotation ratio between the groups. Beach et al. (1992) examined the relationship of shoulder flexibility, strength ratios and endurance to shoulder pain in competitive swimmers. Endurance ratios of external rotation, and abduction were demonstrated to correlate negatively with shoulder pain; as endurance ratios decreased the reported pain score increased. No other significant correlations were observed.

These studies have focused attention on muscle imbalance and decreased endurance as clinical features of impingement syndrome in the athletic population. However concentric peak moment (Burnham et al. 1993, Beach et al. 1992) and work (Warner et al. 1990) at one (Burnham et al. 1993) or two (Beach et al. 1992, Warner et al. 1990) angular velocities were the only parameters assessed. Additionally, information on the pattern of strength in athletic subjects and wheelchair athletes with impingement syndrome has limited applicability to the general population of subjects with impingement syndrome. A more comprehensive analysis of the concentric and eccentric M/ω relationship including several angular velocities may provide better insight into differences in the function of the neuromuscular system in subjects with and without shoulder pathology.

The purpose of this study was to provide a comprehensive analysis of the concentric and eccentric moment/angle/angular velocity relationship for shoulder internal and external rotation in a group of asymptomatic male subjects and a group of male subjects with shoulder impingement syndrome.

VI. Review of Literature

A. Glenohumeral Joint

The shoulder complex functions primarily to position the hand in space and is comprised of three synovial joints - the acromioclavicular (AC), the sternoclavicular (SC) and the glenohumeral joint - and the scapulothoracic articulation. The glenohumeral joint is the articulation between the head of the humerus and the glenoid fossa of the scapula. For the purposes of this paper "shoulder" will refer to the glenohumeral articulation. The glenohumeral joint when considered as a classical pin articulation, has three degrees of freedom of motion: flexion/extension, abduction and adduction, and internal and external rotation (Kent 1971). Internal and external rotation are described as taking place about a longitudinal axis through the shaft of the humerus (Kent 1971). Due to changes in the capsule length and orientation the degree of internal and external rotation varies with arm position. Approximately 180 degrees of internal and external rotation is possible with the upper limb positioned by the side, this diminishes to 90 degrees at 90 degrees of elevation. Only a minimal amount of internal and external rotation is possible with the arm in full elevation (Bechtol 1980). Arm elevation is the result of motion of the shoulder girdle (AC, SC, scapulothoracic articulation) as well as the glenohumeral joint and has been described in relation to the cardinal planes of the body. Flexion/extension takes place in the saggital plane. Abduction/adduction occur in the coronal plane. Description of elevation of the arm in relation to the plane of the scapula rather than the cardinal axes of the body has been suggested as a preferable method of describing glenohumeral motion (Johnston 1937). The plane of the scapula has been defined as 30-45 degrees anterior to the coronal plane with exact alignment determined by the contour of the thoracic wall (Bechtol 1980, Johnston 1937, Poppen and Walker 1976). Elevation of the arm with the humerus aligned in the plane of the scapula has been speculated to allow for lack of twisting of the glenohumeral joint capsule (Johnston 1937), optimal length-tension relationship of the shoulder musculature (Greenfield et al. 1990, Johnston 1937), and a relatively large degree of joint conformity (Poppen and Walker 1976). During scapular plane elevation in normal subjects there is less than 5mm of excursion of the humeral head on the glenoid and the humeral head rotates about a relatively fixed center (Poppen and Walker 1976).

The large degree of mobility available at the glenohumeral joint has been achieved at the expense of stability. Due to a lack of inherent bony stability, the glenohumeral joint relies upon other passive and neuromuscular restraints. Glenohumeral stabilization affords maximum congruency of joint surfaces and limits humeral head translations. Passive stabilization is provided by the fibrocartilaginous labrum, capsuloligamentous complex and negative intracapsular pressure (Hawkins and Mohtadi 1991). The capsuloligamentous constraints provide stability primarily at the extremes of range of motion (Lippitt and Matsen 1993). Neuromuscular stability of the glenohumeral joint is primarily provided for by the rotator cuff (Kronberg et al. 1990, Saha 1971) although the deltoid and other muscles of the shoulder girdle also provide a degree of stabilization. The rotator cuff musculature consists of the supraspinatus, infraspinatus, teres minor and subscapularis muscles. These four muscles take their origin from the scapula and insert into the proximal humerus blending with the capsule of the shoulder joint (Kent 1971). The function of the rotator cuff musculature has been investigated through electromyographic (EMG) analysis, cadaver studies and biomechanical analysis as well as through nerve block studies. EMG studies have demonstrated that the muscles of the rotator cuff are active continuously with varying intensities throughout simple elevation of the arm (Inman et al. 1944, Kronberg et al. 1990, Saha 1971, Shelvin et al. 1969, Sugahara 1974). EMG data in conjunction with information from anatomical and biomechanical studies have demonstrated that the role of the supraspinatus is to act with the deltoid to produce elevation of the arm and to assist with glenohumeral stability by compressing the head of the humerus into the glenoid fossa (de Luca and Forrest 1973, Inman et al. 1944, Kronberg et al. 1990, Perry 1983, Poppen and Walker 1978, Sugahara 1974). The infraspinatus, teres minor and subscapularis have orientations to the glenohumeral joint which allow them to assist with joint compression and provide caudal forces on the humeral head which act to counter the upward displacement of the humeral head on the glenoid which would otherwise occur with unopposed action of the deltoid during elevation of the arm (Inman et al., 1944, Poppen and Walker, 1976). Inman et al. (1944) described the combined action of the deltoid and the rotator cuff in producing a moment about the shoulder joint resulting in elevation of the arm as an "obligatory force-couple". However data provided through EMG analysis of high velocity multisegmental movements (i.e. during motions of baseball pitching, swimming) have failed to demonstrate the patterned activity of the deltoid and rotator cuff described by Inman. The activation of the rotator cuff muscles during the baseball pitch seem more related to their function in providing glenohumeral joint stabilization and internal and external rotation shoulder joint moments rather than their function in producing elevation of the arm in concert with the deltoid (Bradley and Tibone 1991, Glousman 1993, Jobe et al. 1984, Perry 1983). The integral role of the rotator cuff in producing joint moments which act to maintain maximal glenohumeral joint congruency and limit translations of the humeral head during a wide range of glenohumeral joint movements have been emphasized in previous (Saha 1971) and more recent EMG and anatomical studies (Cain et al. 1987, Kronberg et al. 1990).

Internal rotation of the humerus on the glenoid fossa is produced by the subscapularis, pectoralis major, latissimus dorsi, and teres major muscles (Kronberg et al 1990, Sugahara 1974). Teres minor and infraspinatus are the primary external rotators of the glenohumeral joint (Kronberg et al. 1990, Sugahara 1974). Kronberg et al. (1990) also include supraspinatus as a muscle capable of providing an external rotation joint moment about the shoulder..

B. Shoulder impingement syndrome

Shoulder impingement syndrome has been described as "an ill-defined term for a variety of disorders of the shoulder that manifest as anterior shoulder pain, especially during overhead activities" (Fu et al. 1991). While the term "shoulder impingement syndrome" refers to the mechanism by which pain is produced, the pathological changes associated with this clinical entity are observed in the rotator cuff tendons. The subacromial bursa is thought to be involved secondarily (Hawkins and Abrams, 1987).

The etiology of shoulder impingement syndrome has been attributed to factors extrinsic and intrinsic to the rotator cuff muscle tendon complex (Fu et al. 1991). Extrinsic causes of rotator cuff disorders result from forces acting outside the rotator cuff musculature leading to impingement of the contents of the subacromial space beneath the coraco-acromial arch. Primary impingement is thought to result from an outlet stenosis (decrease in the opening between the acromion, coracoacromial ligament, coracoid, acromioclavicular joint and the glenoid) due to alterations in or inherited slope and shape of the acromion (Neer 1972). Neer attributed 95% of all tears of the rotator cuff to primary impingement against the anterior one third of the acromion. Neer (1983) described three stages of rotator cuff disease according to the pathophysiology of cuff degeneration. Stage 1, edema and hemorrahage, primarily occurs in those under 25 years of age and is reversible with conservative treatment. Stage 2, characterized by fibrosis and tendinitis, typically occurs in 25-40 year olds and is treated surgically if not amenable to conservative treatment. In Stage 3, tears of the rotator cuff, biceps rupture and bone changes occur primarily in the over 40 age group. Stage 3 lesions are treated surgically. The finding of an association between acromial morphology and cuff tears in cadaver and a patient-based series supported primary impingement as a major etiological factor in the development of rotator cuff disease (Bigliani et al., 1991). While inherited acromial morphology, thickness of the coracoacromial ligament, or shape of the coracoid process (Gerber et al. 1985) may play a role in the development of impingement syndrome in some subjects, it is now commonly accepted that acromial degenerative changes (i.e. cystic and sclerotic changes and osteophyte formation) associated with impingement syndrome generally are a secondary rather than primary phenomenon. Consistent with this, intratendinous and articular side partial thickness as opposed to bursal side rotator cuff tears have been demonstrated to occur with frequency (Ogata and Uhthoff 1990, Ozaki et al. 1988). In addition, Ogata and Uhthoff (1990) demonstrated in 76 cadaver shoulders at autopsy that although the incidence of rotator cuff tears increased with age, there was no correlation between aging and degenerative changes of the undersurface of the acromion.

Intrinsic rotator cuff disorders can be defined as those arising from forces within the rotator cuff muscle-tendon complex (Fu 1991). Intrinsic disorders have been attributed to age related degenerative changes (Brewer 1979, Ozaki et al. 1988) hypovascularity of the cuff (Lohr and Uhtoff 1990, Rathbun and MacNab 1970, Rothman and Parke 1965), and intrinsic tendon overload (Leadbetter 1992, Nirschl 1989, 1990 Woo and Tkach 1990). However the age related changes and hypovascularity as a cause of rotator cuff tendinitis have been challenged by recent investigators who have demonstrated adequate vascularity of the cuff in the so called "critical zone" (an area corresponding to the region in which most tendon ruptures occur - approximately 1 cm proximal to the bony insertion of the supraspinatus tendon), and have failed to detect any distinct age related changes (Brooks et al. 1992, Clark and Harryman 1993). In an extensive review of literature on the vascularity of the rotator cuff Chansky and Iannotti (1991) reported that in symptomatic patients with impingement syndrome the "critical zone" of the supraspinatus tendon, demonstrates hypervascularity. They concluded that the area of hypovascularity in the supraspinatus tendon demonstrated in cadaver studies may have been the result of a technical artifact or an age related process associated with asymptomatic degenerative changes in the rotator cuff.

Current thinking in the area of chronic tendon injury tends to support the theory of repeated small tendon fiber failures due to intrinsic tendon overload as a primary etiological component (Leadbetter 1992, Nirschl 1989, 1990 Woo and Tkach 1990). Leadbetter (1992), in his extensive review of tendon injuries, stated that in the development of intratendinous degeneration "focal load influences on cell matrix metabolism may play as great a role as any proposed diminished vascularity " (pg 566). Woo and Tkach (1990) attributed the etiology of chronic tendon injury to intrafibrillar sliding beyond the elastic limit apparently due to high forces arising from muscle contraction, likely isometric or eccentric in nature. With repeated microtrauma the healing processes are not adequate and a weakened tendon results.

Nirschl (1989) contended that 90% of rotator cuff disease results from multiple contractile "overload" of the tendons (primarily eccentric in nature) which occur during occupational, athletic or daily living activities. He characterized the pathological changes which occur in the rotator cuff as angiofibroblastic hyperplasia - an invasion into the normally orderly tendon fibers by fibroblasts and vascular granulation-like tissue without any evidence, in chronic stages, of any inflammatory cells. Likewise Nixon and DiStefano (1975) in a review of rotator cuff disease found a loss of the normal organization of the tendon fibers, an increased granularity and lack of evidence of repair processes. This pathological process has been termed tendinosis to denote the lack of any well-defined inflammatory response within the tendon which the term "tendinitis" implies. Tendinosis is defined as "intratendinous degeneration due to atrophy (aging, microtrauma, vascular compromise, etc.) " (Leadbetter, 1992 pg 545). It is postulated that microtrauma within the rotator cuff eventually leads to weakness/imbalance of the rotator cuff musculature resulting in loss of stabilization of the glenohumeral joint with subsequent anterior/superior migration of the humeral head and secondary impingement of the rotator cuff beneath the coracoacromial arch (Matsen and Arntz 1990a, Nirschl 1989, Perry 1983).

In recent years the concept of subtle “functional” glenohumeral instability has been proposed as a primary etiological factor in impingement syndrome in the young athletic population. This condition has been attributed to attenuation of the passive stabilizers of the glenohumeral joint (Jobe and Bradley 1988, Jobe and Kvitne 1989), and/or alterations of the neuromuscular activation pattern of the muscles of the glenohumeral or scapulothoracic complex (Garth et al. 1987, Glousman et al. 1988, Jobe and Kvitne 1989, Jobe et al. 1983, Kibler et al. 1992, Pappas et al. 1985, Warner et al. 1990). Any of these conditions may result in decreased ability to maintain optimal positioning of the humeral head within the glenoid cavity during segmental and multisegmental motion subsequently leading to secondary impingement. Ability to joint stabilize during activities requiring static positioning of the glenohumeral joint would also be affected by altered neuromuscular patterns.

Jobe and co-workers (Jobe and Bradley 1988, Jobe and Pink 1993) have recently presented a categorization of soft-tissue injuries of the shoulder. They hypothesize that in subjects over the age of 35 shoulder symptomatology is primarily due to age-related degenerative changes. In the younger athletic population (18-35 years) shoulder disorders are conceptualized as an instability/impingement continuum. The classification scheme includes four categories. Group I encompasses subjects with isolated impingement and no instability. This is most likely to occur in the older recreational athlete and be associated with bursal side rotator cuff lesions. Group II represents subjects with glenohumeral instability and secondary impingement. The degree of glenohumeral instability in this group may be very subtle and difficult to detect on clinical examination. This group is comprised primarily of young overhead athletes. It is speculated that microtrauma of the muscular, ligamentous and capsular structures as a result of the repetitive high stresses applied to these structures in many overhead sports may lead to a decreased ability to provide joint stabilization. Jobe and Pink (1993) report that the pathological findings at surgery in this group are evident in the posterosuperior labrum and the undersurface of the supraspinatus, infraspinatus and teres minor apparently due to anterior subluxation of the humeral head and attendant encroachment of the humeral head against the posterosuperior labrum. Group III consists of athletes who present with generalized ligamentous laxity and glenohumeral instability. The pathological lesions are similar to those observed in group II. Group IV demonstrate glenohumeral instability as a result of a single traumatic event, and do not have clinical signs of impingement. Pathology observed at surgery includes evidence of a Bankart lesion and erosion of the posterior humeral head.

The prevalence of symptomatic impingement syndrome in the general population has not been reported in the literature. However the incidence of impingement syndrome has been reported to be particularly high in athletes involved in overhead activities (Jobe and Bradley 1988, Kibler et al. 1988, Richardson et al. 1980). Impingement syndrome has also been demonstrated in surgical series to occur with frequency in "sedentary" workers (Neer 1988) and manual labourers (Post and Cohen 1986). Herberts et al. (1984) have documented increased incidence of shoulder impingement syndrome in subjects whose jobs demand sustained overhead work. In the majority of cases cumulative trauma rather than an acute injury precipitates the onset of symptoms (Matsen and Arntz 1990a). From a review of patients with rotator cuff impingement and tears at surgery it appears that these conditions are more common in men than women and in the dominant as opposed to the nondominant arm (Hawkins et al. 1985, Neer 1988, Norwood et al. 1989, Post and Cohen 1986). The occurrence of rotator cuff tears is rare before the fifth decade (Brewer 1979, Ellman 1990, Hawkins et al. 1985, Neer 1988, Post and Cohen 1986).

Chronic rotator cuff injuries are generally initially managed conservatively. If there is no response to 6-12 weeks of conservative treatment further investigations (arthrogram, ultrasonography, MRI etc.) are recommended in order to rule out a rotator cuff tear. When a tear is present, repair is generally recommended. In active subjects with acute tears, the initial period of conservative treatment is bypassed and repair is recommended as soon as possible (Cofield 1985, Matsen and Arntz 1990b). In subjects with chronic rotator cuff disease in which further investigations have failed to detect a tear, 6-12 months of conservative treatment is generally recommended before surgical intervention is considered (Cofield 1985, Ellman 1990, Hawkins and Abrams 1987, Matsen and Arntz 1990a, Miniaci and MacDonald 1991, Neer 1972, Wolf 1992). Conservative treatments include relative rest, nonsteroidal anti-inflammatory medications, steroid injection, various physiotherapy modalities, and strength training with emphasis on the rotator cuff (Brewster and Moynes Schwab 1993, Ellenbecker and Derscheid 1989, Hawkins and Abrams 1987, Hawkins and Kennedy 1980, Jobe and Moynes 1982, Kamkar et al. 1993, Kibler et al. 1992, Matsen and Arntz 1990a, Nicholson 1989, Nirschl 1989, Pappas et al. 1985, Silliman and Hawkins 1991, Wilk and Arrigo 1993, Wolf 1992). Stretching of the tissues spanning the glenohumeral joint is also often advised as these patients tend to have limited motion in horizontal adduction, and internal rotation which has been attributed to posterior capsular tightness (Kibler et al. 1992, Matsen and Arntz 1990a, Pappas et al. 1985, Warner et al. 1990).

Although conservative treatment has been reported to be capable of reducing symptoms in the majority of patients with stage 1 and 2 rotator cuff disease (Cofield 1985, Ellman 1990, Hawkins and Abrams 1987, Neer 1972, Nirschl 1989), controlled studies evaluating specific treatment measures have rarely been performed. Two studies were found which evaluated outcome following conservative treatment for impingement syndrome. Chard et al. (1988) retrospectively reviewed 137 patients with a clinical diagnosis of impingement syndrome who had a variety of treatments including relative rest, active range of motion exercises, local corticosteroid injection, and unspecified "physiotherapy". Review was done a mean of 17.9 months following initial presentation at which time 26% continued to have "active" tendinitis, 29% had residual symptoms and 39% had no symptoms. Factors distinguishing the group of patients with resolved symptoms from the others included earlier presentation following onset of symptoms and onset of symptoms unrelated to their occupation. In the group with resolved symptoms, the majority were improved within 3 months. Brox et al. (1993) in a prospective randomized blinded study compared the effects of a physiotherapist-supervised exercise program to arthroscopic acromioplasty followed by physiotherapy for treatment of stage II impingement syndrome. A control group was included which received placebo treatment of detuned soft laser. The supervised exercise regime included range of motion exercises and gradually progressed to strengthening of the "short rotator muscles and scapular stabilising muscles". The Neer shoulder score was the outcome measure used for evaluation at an average of 6 months following treatment. Results demonstrated no differences between the surgical and exercise groups however both were significantly improved compared to the placebo group ($p < 0.001$). Although improvement in pain and function scores were demonstrated in the active treatment groups it should be noted that time of absence from work was not reduced compared to the placebo group. It is apparent from these studies that shoulder impingement syndrome is not a self-limiting ailment and that treatment with a specific exercise program may be at least as beneficial as surgical intervention. There remains however considerable scope for improvement in defining the most effective and efficient rehabilitation treatment protocol.

C. Strength

The evaluation of human muscular strength is a subject of considerable interest to those in the field of rehabilitation. In order to investigate human strength a precise definition of the term is required. There is an extensive amount of literature devoted to investigating human strength however the definition of strength has varied in these papers or in many has not been defined at all.

Strength has been defined as "the maximum force or tension generated by a muscle" (McArdle, Katch, Katch 1991 pg. 452). This definition is useful when determining strength in vitro however does not allow for the simple determination of strength in vivo. Atha (1981), in his extensive review on muscle strengthening, defined strength as "the ability to develop force against an unyielding resistance in a single contraction of unrestricted duration" (pg. 7). While allowing for the measurement of strength clinically (isometric measurement at a given joint position), defining strength in terms of an isometric contraction fails to consider the many other circumstances (eccentric and concentric contractions through a range of motion and velocity spectrum) under which muscles act in daily activities. Sale (1992) provided a broader definition of strength as "the peak force or torque developed during a maximum voluntary contraction under a given set of conditions (e.g., contraction type and velocity)" (pg. 21). While considerably broader in scope, this definition restricts the information obtained to one point during a dynamic muscle action (i.e. the point at which peak moment is achieved) and therefore fails to capture all of the available information. It is felt that an operational definition which best encompasses all facets of strength is "the ability to control rotation of body segments" (Kriellaars, 1993). The performance of most actions within the human body requires rotation of body segments and therefore the strength of a subject is directly related to the ability to control this rotation by generation of a muscular moment about the joint. The moment generating capability of a muscle is a complex interaction between intrinsic muscular properties (physiological cross-sectional area and length), the degree of neural activation (recruitment and modulation of discharge frequency), activation history, the velocity of contraction of the muscle and the muscle moment arm (Enoka 1988, Herzog et al. 1991). The muscle moment arm (the perpendicular distance from the line of action of the force to the axis of rotation) varies with the joint angle. It follows therefore that the most global and informative approach to quantifying human strength for single segment motion may be one which estimates the joint moment/angle/angular velocity relationship.

Resultant joint moment (RJM) represents the rotational tendency exerted on a segment by the forces produced from all the tissues spanning a joint including muscles, ligaments and bones. The ability to control the rotation of body segments is directly related to generation of RJM. Isovelocity dynamometers can provide an objective, valid and reliable estimate of resultant joint motion for concentric, eccentric and isometric muscle action over a substantial range of joint motion and for specified angular velocities. Isovelocity dynamometers are electromechanical or electrohydraulic devices which contain speed controlling mechanisms which will accelerate to a predetermined angular velocity when any force is applied. The resistance provided by the machine varies to match the force applied by the subject throughout the range of motion. The term "isovelocity" is preferred to "isokinetic" when referring to these machines. Kinetics is the branch of dynamics which deals with relationships among the forces (White and Panjabi 1978) and "iso" means same or equal, therefore the term "isokinetics" erroneously implies that the same relationship occurs between the forces. Isovelocity (constant angular velocity) is a more appropriate term to describe the type of motion performed on these dynamometers. The moment generated by an individual can be recorded during isometric (constant joint angle), or constant velocity eccentric or concentric muscle action.

The most consistently reported isovelocity measure of muscle strength in the literature is peak moment, although with the availability of computer software programs other values including average moment, total work, average power, angle specific moment, angle of peak moment and "peak torque acceleration energy" have also been used for evaluation. The use of peak moment alone in quantifying strength has been justified most notably by Kannus (1988a, 1988b), Kannus and Jarvinen (1990), Kannus and Yasuda (1992) who have demonstrated good correlation ($r = .70$ - 98) at any given velocity between peak moment and total work, peak angular impulse, average power, and angle specific moment measurements and therefore argue that there is little to be gained from more elaborate analysis of the data. Kannus et al. obtained their data by examination of the quadriceps and hamstrings in subjects with and without knee ligament pathology. Notwithstanding the work of Kannus and his co-investigators, there is support in the literature for more comprehensive analysis of moment profiles especially when evaluating more complex joints such as the shoulder. Perrin et al. (1987) compared bilateral knee and shoulder peak moment, total work, "torque acceleration energy" (defined by Perrin et al. (1987) as the work performed in the first one-eighth second of torque production), and average power in a group of college baseball pitchers, a group of swimmers and a group of nonathletic subjects. They found that for the knee and most of the shoulder muscle groups examined, the results were consistent regardless of the parameter used for evaluation, however there were exceptions. Analysis of total work, "torque acceleration energy", and average power revealed significantly greater strength on the right (dominant) side in baseball pitchers' internal rotation whereas analysis of peak moment measurements demonstrated no significant difference. The authors concluded that a consistent relationship between peak moment and the other parameters measured could not be assumed for all muscle groups and suggested that consideration of other parameters may be even more important when evaluating patients with pathology. There is some support for this suggestion in the work of Kuhlman et al. (1992) who evaluated peak moment and total work of shoulder external rotation and abduction pre and post suprascapular nerve block in four normal male subjects. The post nerve block decreases for external rotation were significantly greater for total work than for peak moment and demonstrated much less variability. The post nerve block decrease in total work for abduction was also greater than the mean decrease in peak moment although this difference was not statistically significant. Both Kuhlman and Perrin's studies suggest that assessment of parameters such as total work is warranted and may be a more sensitive measure of changes in muscle strength.

Other investigators have recommended that evaluation of peak moment alone should not be considered in isolation of the angle at which peak moment occurs (Baltzopoulos and Brodie, 1989). Reid et al. (1989) tested shoulder strength in 40 athletic males and females for the purpose of providing normative data for this population. Data were included, in this study, on the angle of peak moment occurrence, the arc of maximum strength (defined as the arc of motion during which maximum moment was maintained within 2 newton meters of the peak moment) and the preferential start and finish angles (defined as the points at which measurable moment commenced and ceased respectively). Reid et al. (1989) suggested that this information would be especially relevant when assessing changes in strength due to pathology of following a treatment intervention. Reid et al. (1989) during their investigation observed large standard deviations associated with the measurement of the angle of occurrence of peak moment. Variability in the angle of peak moment occurrence between subjects had also been noted previously by Ivey et al. (1985). In addition Kuhlman et al. (1992) in an investigation of shoulder muscle strength demonstrated poor test-retest reliability of the measure of the angle at which peak moment was obtained. They attributed this poor reliability to errors in positioning of the subject or in setting of the reference angles, however it may be that change in the angle of peak moment occurs due to changes in the neural activation of the muscle on separate testing trials. Other investigators have demonstrated that the angle of maximum moment changes with angular velocity (Baltzopoulos and Brodie, 1989).

A number of investigators have provided data on shoulder muscle strength in the asymptomatic nonathletic population (Cahalan et al. 1991, Ivey et al. 1985, Kuhlman et al. 1992, Maddux et al. 1989, Nicholas et al. 1989, Otis et al. 1990, Reid et al. 1989). These studies have generally found that there are several subject-specific factors which significantly influence shoulder muscle strength including age, gender, hand dominance, specific training, and exercise patterns. Shoulder strength is generally found to decrease with increased age (Kuhlman et al. 1992, Murray et al. 1985). Murray et al. compared the strength of shoulder flexion/extension, abduction/adduction, and internal/external rotation in a group of younger men (age 26-36, mean = 31) to older men (age 56-66, mean = 62) and found that the older men had significantly decreased mean moment values ($p < .01$) in all muscle groups tested except the shoulder extensors. The older men had mean moment values ranging from 75-92% of the younger men. Kuhlman et al. (1992) compared isovelocity peak moment and total work of shoulder external rotation and abduction in twenty-one younger men ages 19-31 (mean = 21 years) and nine older men ages 51-65 (mean = 58 years) and also found that the younger men were significantly stronger ($p < 0.001$) in all parameters examined. The older men had mean peak moment and total work values of 68-80% that of the younger men. It should be noted however that all of the younger men and none of the older men participated regularly in sporting activities. Ivey et al. (1989) reported that in their investigation of male and female subjects between the ages of 21 and 50 (mean = 27 years) the effect of age on shoulder strength was not significant when normalized for exercise pattern. They stated that "age had no general effect on individual strength, and strength was found to be directly related to exercise patterns, individuals who exercised their upper extremity regularly obtaining a higher torque than those who did not" (pg. 385). These studies are in agreement with other studies which have examined the effect of aging on strength in other upper and lower limb muscles. Vandervoort et al. (1986) in a review paper on strength and endurance in the elderly stated that an average decrease of 20% in maximal isometric contractions has been demonstrated to occur by the seventh decade compared to young adults. Maximal strength tends to peak between 20-30 years of age depending on gender, the specific muscle tested and strength measurement technique (Malkia 1993) and then plateau for at least 30 years (Vandervoort et al. 1986).

All studies which compared strength differences due to gender found that women generate lower absolute isovelocity moment shoulder values than men and several authors (Cahalan et al. 1991, Maddux et al. 1989, Nicholas et al. 1989) found that these differences continued to be significant even when the data was normalized for lean body mass. Ivey et al. (1985) however found that gender differences in shoulder strength were not significant when the data were normalized for both lean body mass and exercise pattern.

The results of the studies on the effect of hand dominance on shoulder muscle strength have also varied. Although Maddux et al. (1989), Reid et al. (1989) and MacDonald et al. (1988) found no statistically significant difference between the dominant and nondominant side in shoulder measurements in normals, Ivey et al. (1985) stated that in their group of 31 subjects there was a trend for the dominant side to have greater values and others have found dominance to have a significant effect on the values obtained in at least some of the shoulder movements studied (Cahalan et al.1991, Perrin et al. 1987, Walker et al. 1987, Warner et al. 1990). Studies of athletic populations have more consistently found a dominance effect on shoulder muscle strength in athletes involved in unilateral upper extremity activities (Alderink and Kuck. 1986, Brown et al. 1988, Chandler et al. 1992, Cook et al. 1987, Ellenbecker 1991, Hinton 1988, Wilk et al. 1993).

The strength of shoulder internal and external rotation in various upper extremity athletic groups has been investigated by several researchers. The "normal" strength ratio of the internal and external rotators of the shoulder has been reported by several authors to be approximately 3:2 (Cahalan et al. 1991, Ivey et al. 1985, Reid et al 1989). The ratio of internal rotation/external rotation (IR/ER) in athletes has been reported to differ from those obtained in nonathletic populations. Changes in the IR/ER ratio have been demonstrated in swimmers (Beasley and Chandler 1989, Fowler 1988, McMaster et al. 1992), water polo players (McMaster et al. 1991), and from dominant to nondominant side in baseball pitchers (Chandler et al. 1992, Cook et al. 1987, Hinton 1988, Wilk et al. 1992). These changes have been theorized to have an eitological role in the development of shoulder pathology.

The positioning of the glenohumeral joint during isovelocity measurements of the shoulder IR and ER has varied in the literature. It has been shown by several investigators (Greenfield et al. 1990, Hageman et al. 1989, Soderberg et al. 1987, Walmsley et al. 1987) that positioning of the glenohumeral joint has a significant effect on the isovelocity internal and external rotation values obtained. Much of the published literature has reported on values obtained with the glenohumeral joint positioned in 90 degrees of abduction in the frontal plane or 90 degrees of flexion in the sagittal plane. However testing in this position has been found to be poorly tolerated in patients with shoulder pathology (Elsner et al. 1983, Rabin and Post 1990), and place the patient in the "impingement position" (Neer, 1972).

Several authors (Greenfield et al. 1990, Hellwig and Perrin 1991, Kuhlman et al. 1992, Warner et al. 1990) have advocated testing IR and ER with the humerus positioned in the plane of the scapula which has been defined as 30-45 degrees anterior to the frontal plane (Johnston 1937, Poppen and Walker 1976). Benefits of testing with the humerus aligned in the plane of the scapula include: lack of twisting of the glenohumeral joint capsule (Johnston 1937), optimal length-tension relationship of the shoulder musculature (Greenfield et al. 1990, Johnston 1937), a relatively large degree of joint conformity, (Poppen and Walker 1976) and subject comfort (Kuhlman et al. 1992, Warner et al 1990). With the humerus aligned in the plane of the scapula and > 45 degrees of elevation the glenohumeral joint is in a relatively "loose-packed" position which allows for efficient joint nutrition and lubrication and unrestricted joint kinematics (Greenfield et al 1990). In addition, the position of impingement would be avoided thereby decreasing the possibility of iatrogenic damage to the rotator cuff. Based upon these observations it has been suggested that the scapular plane should be the preferred position of isovelocity testing for the glenohumeral joint.

Measurements of internal and external rotation shoulder joint moment ($SJM_{IR/ER}$) in the asymptomatic population obtained with the humerus positioned in the plane of the scapula have been provided in a limited way by only a few investigators (Greenfield et al. 1990, Hellwig and Perrin 1991, Kuhlman et al. 1992, Warner et al. 1990). Greenfield et al. (1990) reported concentric peak moment measurements expressed as a percentage of body weight of IR and ER tested at 60 °/s with the glenohumeral joint elevated 45 degrees in the plane of the scapula (30 degrees anterior to frontal plane) in a group of 14 females and 6 males with a mean age of 25.3 years. The subjects were tested in the standing position. Hellwig and Perrin (1991) recorded concentric and eccentric peak moment measurements of IR and ER at 60 °/s in 21 males (mean age = 21.4 years) with the glenohumeral joint positioned in 90 degrees of elevation in the plane of the scapula (40 degrees anterior to frontal plane). The subjects were tested in the seated position. It is difficult to compare directly the results of the two studies due to the various differences in testing protocol, in terms of positioning of the subjects and the use of "gravity correction" (correction for moment of the weight of the actuator arm and the weight of the arm). Both found test/re-test reliability to be good. Kuhlman et al. (1992) reported on isovelocity concentric values of peak moment, total work and angle at peak moment as well as on isometric measurements at various angles for shoulder ER and abduction taken with the arm in the plane of the scapula (30 degrees anterior to frontal plane). No mention was made of "gravity correction". Measurements of ER were obtained with the glenohumeral joint in 45 degrees of elevation in the plane of the scapula with the patient positioned supine. They tested a group of 21 younger men (mean age 24) all of whom were regularly involved in sport activities, a group of 9 sedentary older men (mean age 58) and a group of 9 sedentary older women (mean age 56) at 90 and 120 °/s. They found age (when comparing the older to younger men) and gender (when comparing the older men to older women) to have a significant effect on values obtained during isometric and isovelocity measurements. High test-re-test reliability for peak moment and total work isovelocity measurements (r = .80 -.86) and some isometric measurements was demonstrated. The eccentric and concentric moment angle (M/θ) and moment angular velocity (M/ω) and the eccentric/concentric relationship has not been widely studied for shoulder musculature. The most extensive investigations of the M/ω and eccentric/concentric relationships have been conducted on the knee and elbow musculature. Baltzopoulos and Brodie (1989) reported in their review article on isokinetic dynamometry that, in general, concentric peak moment output decreases with increasing velocity. However they also reported that several investigators have observed a plateauing of the knee extensor concentric moment output at lower velocities. These findings are at variance with the concentric force-velocity curve obtained by testing isolated muscle preparations (Hill 1938) in which the concentric force-velocity relationship is hyperbolic in nature such that force decreases rapidly as the velocity of shortening increases. It has been suggested that the observed plateauing of maximal concentric knee extension moment at lower velocities during isovelocity testing may be attributed to neural inhibition limiting muscle tension at the lower velocities (Perrine and Edgerton, 1978), however it is also possible that the observed results may be due to the testing protocol used. RJM about the knee for maximal eccentric knee flexion and extension has been observed to increase, decrease or remain the same with increasing angular velocity (as reported in Griffin et al. 1993).

Examination of M/ω relationships for RJM about the elbow for flexion have also yielded conflicting results. Concentric peak moment has been reported to decrease initially and then plateau (Rodgers and Berger, 1974) and to decrease with increasing velocity (Griffin 1987, Griffin et al 1993). Maximal eccentric peak moment has been reported to increase and then decrease with increasing velocity (Griffin 1987, Rodgers and Berger 1974) and to remain unchanged with increasing velocity (Griffin et al. 1993). Average eccentric moment values were consistently found to be greater than concentric values (Griffin 1987, Griffin et al. 1993, Hortobagyi and Katch 1990, Rodgers and Berger 1974).

The conflicting results noted in these studies may be as a result of several factors. The methodology used, including the separation period between the concentric and eccentric muscle action, the testing velocities, and the type of dynamometer used, may have affected the results. In addition, there is some evidence that subject-specific factors including gender, age and strength levels may contribute to differences in the results obtained. Hortobagyi and Katch (1990) investigated the M/ω relationship obtained by testing elbow flexion and extension in a group of 40 male subjects at 0.52, 1.57 and 2.09 rad/s (approximately 30, 90 and 120 °/s). The subjects were separated into a high strength and low strength group based on their summed maximal concentric and eccentric moment scores. The high strength group consisted of competitive athletes and recreational weight-lifters. The low strength group consisted of recreational athletes who did not participate in specific weight training. They found that although the eccentric peak moment and constant angle moment output exceeded concentric in both groups ($p<0.05$) the M/ω relationship differed between the low strength and high strength groups. In the low strength group concentric moment plateaued at low velocities and eccentric moment plateaued at high velocities. In contrast, in the high strength group, concentric moment decreased with increasing angular velocity and eccentric moment increased with increasing angular velocity ($p > 0.05$). The authors of this study discussed the role of neural inhibition as well as intrinsic muscular properties (fiber typing, muscle size, muscle architecture and degree of muscle extensibility) as possible factors contributing to the differences in the observed shape of the M/ω curve in the low strength and high strength subjects.

Griffin et al. (1993) investigated the M/ω relationship in different muscle groups and between male and female subjects. They examined concentric and eccentric knee flexion and extension and elbow flexion at 30 and 120 °/s in a group of 50 untrained men and 40 untrained women. They found similar M/ω relationship for all muscle groups regardless of gender. Eccentric peak moment was not statistically significantly different between velocities tested. Concentric peak moment decreased with increased velocity ($p > 0.01$). The eccentric/concentric ratio increased with increased velocity in all muscle groups. Women had significantly higher ($p > 0.01$) eccentric/concentric ratios than men in all muscle groups tested. This difference in the eccentric/concentric relationship due to gender had been previously demonstrated by Colliander and Tesch (1989). However Griffin et al. (1993) noted that in their study differences in age between the male and female subjects may have been a confounding factor (female subjects were older than male subjects).

Investigators had previously shown that age has a significant effect on the observed M/ω relationship (Poulin et al. 1992, Vandervoort et al. 1990). Poulin et al. (1992) compared elbow and knee extension peak moment in a group of young and older male subjects and demonstrated that although the older subjects in general had decreased strength, greater deficits were found in concentric than eccentric peak moment ($p < 0.01$).

Only three published papers (Ellenbecker et al. 1988, Hageman et al. 1989, Hellwig and Perrin 1991) could be found which provided information regarding the eccentric/concentric moment-angular velocity relationship of shoulder musculature.

Ellenbecker et al. (1988) compared concentric and eccentric internal and external rotation isovelocity strength training in 22 male and female college aged (ages not specified)tennis players. Although not subjected to statistical analysis, isovelocity pre-testing demonstrated that eccentric peak moment values for internal and external rotation exceeded concentric at all velocities tested (60, 180, and 210 °/s). In general the eccentric/concentric peak moment and peak moment to body weight ratios increased with increasing angular velocity. The average external rotation peak moment eccentric/concentric (E/C) ratio was 1.68 before and 1.41 after training. The eccentric/concentric ratio for internal rotation was a mean of 1.65 before and 1.38 after training. These shifts in the E/C internal and external rotation ratios after training reflected the greater overall concentric strength gains achieved in both the concentrically and eccentrically trained group ($p < 0.005$). Significant eccentric strength gains were obtained only in the concentrically trained group with significance varying depending on the velocity tested ($p < 0.05$ and $p < 0.005$).

Hageman et al. (1989) used isovelocity dynamometry to compare shoulder internal and external rotation concentric and eccentric peak moment values. These were obtained at 60 and 180 °/s with the glenohumeral joint positioned in 45 degrees elevation in the frontal and the saggittal plane respectively in a group of 18 male and female subjects. Eccentric moment was observed to exceed concentric moment for all movements and at both velocities tested. Only concentric internal rotation in males and eccentric external rotation in females were found to vary significantly with velocity. Concentric internal rotation in males decreased significantly at the higher velocity ($p < 0.0001$). Eccentric external rotation increased significantly at the higher velocity in females ($p < 0.003$). The lack of a consistent relationship may have been due to the relatively small sample size and the testing protocol used. Positioning of the glenohumeral joint was found to have a significant effect on the peak moment values of internal and external rotation obtained in this study. Eccentric and concentric peak moment values were found to be higher in the position of 45 degrees of glenohumeral abduction compared to the 45 degrees of glenohumeral flexion position in all occasions when significance was found. Concentric and eccentric external rotation peak moment in male and female subjects and eccentric internal rotation peak moment in the female subjects were all significantly higher in the position of 45 degrees of glenohumeral abduction ($p < 0.01$).

Hellwig and Perrin (1991) used the Kin-Com dynamometer to investigate the effect of glenohumeral positioning on concentric and eccentric internal and external rotation. They tested gravity corrected internal and external rotation at 60 °/s in the frontal and scapular planes in a group of 21 normal male subjects. They reported that eccentric values were significantly greater than concentric peak moment values for internal and external rotation at 60 °/s ($p < 0.05$). In this study positioning of the shoulder joint was not found to have a significant effect on shoulder joint moment.

It is apparent that there is a paucity of information available regarding the M/θ and M/ω relationship for the shoulder. Different muscles groups may demonstrate unique M/θ and M/ω relationships based on architectural design and percentage of muscle fiber type. Notwithstanding this, examination of the available data on the shoulder and extrapolation of the data obtained from knee and elbow testing would seem to indicate that in a group of normal male subjects with similar ages and activity levels it can be expected that in general, concentric moment values will decrease with increasing velocity of testing and eccentric values will increase or plateau with increasing velocity of testing. Eccentric moment values would be expected to exceed concentric values.

D. Strength in subjects with soft-tissue shoulder disorders

Few isovelocity dynamometry investigations of SJM in subjects with soft-tissue disorders have been conducted and those that have been performed have only included information regarding concentric muscle action over a limited number of angular velocities.

Warner et al. (1990) evaluated shoulder strength and flexibility in a group of normal subjects, a group with primary instability and a group with primary impingement. The authors defined the patient groups by means of physical examination and supportive radiographic, arthrographic or arthroscopic findings. The physical examination included impingement tests as described by Neer (1972) and Hawkins and Kennedy (1980), stability tests including those described by Rockwood (1975) Gerber and Ganz (1984) as well as generalized ligamentous laxity tests as described by previous authors. Patients with voluntary instability or Stage III rotator cuff disease were excluded. Strength testing was performed on the Biodex Dynamometer with subjects in standing and the shoulder positioned in approximately 25 degrees of scapular plane abduction. The ratios of concentric internal rotation/external rotation total work and peak moment measured at 90 and 180 °/s were compared between the 3 groups. Preliminary testing of the dominant and nondominant arms in the group of normals found significant ($p < 0.001$) differences in the internal rotation/external rotation (IR/ER) ratio as a result of higher internal rotation peak moment and total work on the dominant side. Absolute values are not reported in the study but the authors found significant differences when evaluating the dominant arm in peak moment and work ratios ($p< 0.001$). There was no significant difference between the velocities tested. The normal subjects had IR/ER ratios of 120-150%, the instability group approximately 100% and the impingement group 200% suggesting a relative weakness of the external rotation in the impingement group and internal rotation in the instability group although these shifts in the ratios could not be attributed to any specific absolute strength deficits. The authors suggested that this information could be used when testing with an isovelocity dynamometer to differentiate the two groups of patients and to establish exercise guidelines to correct the relative strength deficits. Flexibility testing demonstrated that the impingement group had a statistically significant limitation of active and passive internal rotation and cross-chest adduction compared to the instability group ($p < 0.001$). Although the findings are interesting, several comments can be made with regard to the study design. First, there was no mention of the reliability or validity of the tests used to assess shoulder stability. Second, the reliability of specific strength testing protocol used was not evaluated. The validity of the results could have been improved by matching the control group with respect to gender and activity levels with the instability and impingement groups. Finally, Jobe (1990), in a commentary on this study suggested that delineation of the instability and impingement patient groups could have been improved by the use of the apprehension test followed by the relocation test. The relocation test is performed by placing the patient supine with the arm off the table at 90 degrees of abduction and external rotation. "The examiner will push anteriorly as his fingers grasp the humeral head, then the humeral head will be pushed posteriorly. Any anterior subluxation is considered pathologic and typically is painful. The important observation while pressing posteriorly is that the pain is relieved and the examiner may be able to feel the sudden relocation of the humeral head" (Jobe and Bradley 1989 pg. 425-426). Jobe and Bradley's interpretation of the test was that apprehension observed during anterior translation of the humeral head represented a previous dislocation, while provocation of pain in this position indicated an anterior subluxation. Relief of pain with posterior translation of the humeral head was considered a positive relocation test. In the most recent description found of the anterior instability and relocation tests Silliman and Hawkins (1993) stated that pain alone in the absence of apprehension in anterior instability testing should not be considered a sign of anterior instability and that the relocation test should be considered positive only with disappearance of the apprehension. As there have been no published studies on the reliability or validity of the relocation test to date, the most prudent approach to the interpretation of the test would seem to be that of Silliman and Hawkins (1993).

Beach et al. (1992) in a study examining the relationship of shoulder flexibility, strength, and endurance to shoulder pain in 32 male and female competitive swimmers failed to find any significant differences in ER/IR or abduction/adduction peak moment ratios or flexibility tests between those swimmers with and without shoulder pain although external rotation and abduction endurance were negatively correlated with shoulder pain (p

≤ 0.001). There was no attempt in this study to delineate the cause of the shoulder pain and those swimmers with shoulder pain were identified by a survey only. Nevertheless the finding of a relationship between poor endurance and shoulder pain is significant and lends credence to the clinical impression of Jobe (1990) that shoulder dysfunction increases with fatigue.

Burnham et al. (1993) evaluated concentric shoulder abduction/adduction and internal/external rotation peak moment ratios at 60 °/s in a group of normal athletic males and a group of male wheelchair athletes with and without shoulder impingement syndrome. The wheelchair athletes were found to significantly stronger than the able-bodied subjects in all muscle groups tested, however evaluation of the abduction/ adduction ratio revealed relative weakness of shoulder adduction in the paraplegic group. When comparing the paraplegic athletes with (26%) and without impingement syndrome, the impingement group was significantly weaker in adduction, and internal and external rotation but not in abduction. Evaluation of the strength ratios demonstrated a relative weakness of the adductors compared to the abductors (more pronounced than in the paraplegic group as a whole), and of the internal rotators compared to the abductors. No significant difference was found in the external rotation/internal rotation ratio. The authors suggested that the strength imbalances found in the paraplegic group with and without impingement were a factor in the development of shoulder impingement syndrome and used the results of this study to make recommendations regarding strengthening programs for this group.

An abstract by Saboe et al. (1993) reported on absolute and ratio values for SJM during abduction, adduction, external and internal rotation in a group of athletic subjects with and without shoulder subluxation. They found bilateral absolute and relative strength deficits in subjects with unilateral symptoms of shoulder subluxation compared to the group without shoulder pathology. The strength deficits occurred in all motions tested except external rotation measured in the "apprehension position". As well, subjects with unilateral subluxation had higher abduction to internal rotation and external to internal rotation ratios bilaterally. The authors concluded that the asymptomatic arm in subjects with unilateral subluxation may not be normal and would benefit from an exercise program. In addition this study indicates that regardless of any dominance effect on strength, the contralateral shoulder in these subjects should not be used as a control.

Eccentric data were not included in any of the studies evaluating shoulder strength of subjects with impingement or instability despite the fact that eccentric muscle action is a common occurrence during human motion. During many functional movements a conbination of concentric and eccentric muscle action occurs (Oberg 1993) and concentric muscle action generally is eventually followed by eccentric muscle action of the same muscle (Newham 1993). Additionally eccentric muscle action has been implicated in the development of muscle and tendon injuries (Curwin and Stanish 1984, Friden and Lieber 1992, Garrett 1990, Jensen and DiFabio 1989) and eccentric neuromuscular training has been advocated as a means of treatment for tendinitis (Curwin and Stanish 1984). Isovelocity dynamometry studies have demonstrated that strength differences between groups have varied depending on the muscle action (concentric or eccentric) evaluated (Beasley and Chandler 1989, MacDonald et al. 1988). Additionally eccentric deficits have been observed to be more pronounced than concentric in subjects with joint and tendon pathology (Bennett and Stauber 1986, Niesen-Vertommen et al. 1992). MacDonald et al. (1988) evaluated eccentric and concentric isovelocity peak moment during various shoulder movements as part of an analysis comparing shoulder function in subjects treated surgically and nonsurgically following third degree acromioclavicular separation. A control group of asymptomatic subjects was included in the study. Strength testing was performed on the Kin-Com Dynamometer and included concentric and eccentric peak moment data during flexion, extension, abduction, adduction, internal rotation, external rotation, horizontal abduction and horizontal adduction at 50 and 180 °/s. Comparison of the dominant and nondominant side in the control group demonstrated no statistically significant differences ($p < 0.05$). When comparing the two treatment groups, the nonsurgical group demonstrated increased eccentric abduction (180 degree/sec) and concentric external rotation (50 degree/sec) peak moment values on the affected side as opposed to the unaffected side compared to the surgical group. All other strength comparisons between the two treatment groups were not statistically significant.

Beasley and Chandler (1989) compared the concentric and eccentric IR/ER peak moment ratios in a group of 15 college level female swimmers to a group of 15 nonathletic female subjects at velocities of 60 and 90 °/s. The only significant finding was that of a statistically significant difference ($p < 0.05$) in concentric IR/ER peak moment ratios between the two groups. They concluded that female swimmers exhibited a relative weakness of shoulder external rotation compared to internal rotation. No differences were observed in eccentric IR/ER ratios between the swimmer and control group. As the results were reported in an abstract the exact methodology used in this study is not known, however it is possible that it would influence the results obtained.

Bennett and Stauber (1986) evaluated concentric and eccentric muscle action for knee extension in 131 subjects with a variety of knee disorders. The eccentric exercise treatment group included only those subjects that demonstrated eccentric but no concentric peak moment deficit. An eccentric peak moment deficit was defined as a 15% deficit in eccentric moment compared to the eccentric peak moment of the symptomatic knee, or a 15% deficit in eccentric compared to the concentric peak moment values of the ipsilateral knee. Forty-one of the subjects tested fit this criteria and all of them were diagnosed as having "anterior knee pain syndrome". Thirty-nine of the 41 subjects improved in two to four weeks with eccentric muscle training in terms of pain relief, function and eccentric peak moment values. However due to the lack well-defined outcome measures and lack of inclusion of a control group these findings are viewed cautiously.

Neisen-Vertommen et al. (1992) compared the effect of concentric versus eccentric strength training in 17 subjects with achilles tendinitis over a twelve week period. Evaluation consisted of determination of ankle plantarflexion concentric and eccentric peak and mean moment at 30 °/s and 50 °/s. It was found that concentric plantarflexion peak and mean moment values were consistently greater than eccentric at all testing sessions (0, 4, 8, and 12 weeks). Unfortunately there was no control group included in this study so it is difficult to speculate on the reason for this eccentric deficit. While both groups of subjects demonstrated increased strength, there was no significant difference between the two treatment groups. However the group which trained primarily eccentrically did have a significantly greater decrease in the pain rating ($p < 0.01$) averaged over the 12 weeks.

A few studies have used isovelocity dynamometers to assess shoulder strength following repair of the rotator cuff (Kirschenbaum et al. 1993, Rabin and Post, 1990, Walker et al. 1987, Walmsley et al. 1992). All used the nonoperative side for comparison. Although the percentages differ slightly, all studies reported significant weakness of the shoulder external rotation, abduction and flexion for up to one year post-operatively with flexion being the most affected. It should be noted in the context of these studies, that follow-up of patients after rotator cuff repair has frequently found recurrent rotator cuff defects (Matsen and Arntz 1990b). Harryman et al. (1991) used ultrasonography to investigate the integrity of the rotator cuff an average of five years following rotator cuff repair in 105 operations in 89 patients. In this series 35% of patients were found to have a recurrent defect in the rotator cuff. It was found that function of the shoulder (in terms of range of motion, subjective rating of comfort, examination of 16 functional arm activities, and strength measurement with a hand-held dynamometer) correlated significantly better with the integrity of the cuff at follow-up than with the size of the initial tear.

Two authors attempted to evaluate shoulder strength pre-operatively with limited success. Rabin and Post (1990) tested shoulder strength pre-operatively on an isovelocity dynamometer in patients with various shoulder pathologies. Only 33% of patients could initiate the testing preoperatively and only 13% could complete the test. Kirschenbaum (1993) evaluated patients with rotator cuff tears preoperatively following subacromial injection of lidocaine. Prior to the injection none of the patients was able to generate sufficient moment for testing. Following injection values of concentric peak moment on the affected side averaged 37%, 36% and 33% for abduction, external rotation, and forward flexion respectively compared to the unaffected side.

In summary, shoulder impingement syndrome is a very commonly occurring musculoskeletal disorder. The etiological factors related to impingement syndrome continue to be the subject of considerable investigation and while conservative methods are advocated for treatment, the optimal rehabilitation program has not been defined.

Recently, functional instability of the glenohumeral joint, presumably due in part to muscular imbalances has been speculated to have a role in the development of this syndrome. Support for this as a possible cause of impingement syndrome has been provided by isovelocity dynamometry studies which have demonstrated altered concentric IR/ER strength ratios in these subjects (Beasley and Chandler 1989, Warner et al. 1990). However the study by Beasley and Chandler was performed using wheelchair athletes and therefore has limited applicability to able bodied subjects due to neuromuscular training adaptations specific to this population. Warner and co-workers' impingement group was comprised primarily of an overhead sport athletic population and the control group was not well matched to the impingement group. There is a need for a well controlled study of the neuromuscular patterns of shoulder strength in the recreational athletic and nonathletic subject with impingement syndrome. Finally, there has been limited previous investigation of the concentric/eccentric moment/angle/angular velocity relationship for shoulder internal and external rotation in subjects with and without shoulder pathology. A comprehensive evaluation of resultant joint moment about the shoulder during shoulder internal and external rotation including both concentric and eccentric muscle action may provide insight into the etiology of shoulder impingement syndrome and assist in defining the most effective and efficient rehabilitation program for this population.

VII. Objectives

Primary Objective

1. To determine and compare concentric and eccentric strength of shoulder internal and external rotation in a group of male subjects with stage 1 and 2 impingement syndrome (Neer, 1983) and a control group of asymptomatic male subjects, through analysis of the moment/angle/angular velocity relationship.

Secondary Objectives

2. to assess shoulder range of motion in the control and impingement groups.
3. to assess the reliability of a specific strength testing protocol using the Kin-Com dynamometer.
4. to determine the relationship between shoulder pain and isovelocity strength parameters.

VIII. General Hypotheses

1. The impingement syndrome group will demonstrate concentric and eccentric external rotation strength deficits. The eccentric strength deficits will be greater than the concentric.
2. Internal rotation strength measurements will not be significantly different between the two groups.
3. The impingement syndrome group will demonstrate limitation of internal rotation and horizontal adduction range of motion.
4. Eccentric measurements will exceed concentric measurements for both internal and external rotation.

5. Eccentric measurements will increase with increasing speed and concentric measurements will decrease with increasing speed.
6. The self-reported shoulder symptom scores will not demonstrate a significant correlation with internal or external rotation isovelocity strength parameters.

IX. Delimitations

The study examined male subjects, 20-45 years of age and included only individuals who did not participate in any specific upper extremity strengthening programs at a frequency greater than 3 times per week. The impingement group subjects included only those with chronic stage 1 or 2 (Neer 1983) disease and excluded those subjects exhibiting signs and symptoms of glenohumeral subluxation.

Isovelocity measurements were delimited to those taken with the glenohumeral joint positioned in 45 degrees of scapular plane abduction. Velocity spectrum testing was delimited to the testing velocities of 45, 90, 135, and 180 °/s and examined only the movements of external and internal rotation.

X. Limitations

Some limitations in this study result from the isovelocity dynamometry protocol which was chosen in order to reduce the possibility of iatrogenic damage. Measurements taken in the plane of the scapula will not provide information about neuromuscular performance during external and internal rotation in other joint positions. Moment analysis during single segment motion is not necessarily representative of neuromuscular activity during multisegmental motion. The velocity spectrum tested, while more extensive than has previously been documented, represents only a small portion of the range of concentric and eccentric angular velocities observed during functional activities. Isovelocity testing is dependent on maximum effort voluntary muscular contractions of the subject.

Impingement group subjects were not required to have an arthrogram or MRI in order to be able to exclude those with small rotator cuff tears.

XI. Assumptions

The primary assumption in this study is that the moment measured on the dynamometer is an accurate quantification of resultant joint moment about the shoulder joint. This assumes that several criteria were met including co-axial alignment of the instantaneous axis of rotation of the shoulder joint and that of the dynamometer, adequate subject stabilization, lack of relative movement between and rigidity of the limb segment and actuator arm, force application perpendicular to the actuator arm force transducer, and absence of inertial effects.

The study further assumes that the impingement and control group subject population was representative of the general population of male subjects between the ages of 20-45 years.

XII. Methodology

A. Subjects

The number of subjects required for the study was determined by a power analysis with the power index set at 3.28 (0.05 alpha, 0.05 beta) (Appendix A).

1. Inclusion Criteria

Male subjects between the ages of 20-45 were included in the study. Subjects were included in the impingement group if they had had pain in the shoulder region for at least 12 weeks, a Nirschl tendinosis pain phase rating of I-VI (Nirschl 1992, Appendix B), a positive impingement sign (Hawkins and Kennedy 1980, or Neer 1983), and at least one of the following: 1) tenderness to palpation over the greater tuberosity, lesser tuberosity, or anterior edge of the acromion, 2) painful arc on abduction, 3) pain on resisted shoulder abduction, forward flexion or external rotation.

2. Exclusion Criteria

Subjects were excluded if they had any known cardiovascular disease or any other medical condition which would preclude involvement (i.e. history of arthritis, other conditions affecting the neck, elbow, wrist, or hand). Exclusion criteria also included current contralateral upper extremity injury or disease and current participation in upper extremity weight training at a frequency greater than 3 times/week. Control group subjects were excluded if they had any history of injury or disease affecting the right shoulder or right upper extremity.

Subjects in the impingement group were excluded if they had a history of prior shoulder dislocation, cortisone injection to the affected shoulder within eight weeks prior to the study, and /or greater than three cortisone injections to the affected shoulder in the past. At the time of the screening examination subjects were excluded if they reported a Nirschl tendinosis pain phase rating greater than VI in combination with a visual analogue scale (VAS) greater than 5, or demonstrated any of the following signs: a positive relocation test

(Silliman and Hawkins, 1993), a positive drop arm test (Jobe and Bradley, 1989), or restriction of glenohumeral external or internal rotation to less than 50 degrees (measured with the glenohumeral join in the adducted position at the side of the body).

3. Recruitment

The control subjects consisted of a sample of convenience recruited through word of mouth throughout the Bannatyne campus of the University of Manitoba.

The subjects with impingement syndrome were recruited through letters sent to physiotherapy clinics, and physicians practising in the field of family medicine, rehabilitation medicine, orthopaedics, or sports medicine in the Winnipeg area (Appendix C).

4. Selection

After being recruited for the study, the appropriateness of the subject's inclusion into the study was determined. Both the control and the impingement groups were assessed by the primary investigator to ensure conformity with the inclusion/exclusion criteria of the study (Appendices E, F, G for assessment forms).

5. Informed Consent

All subjects were required to sign an informed consent form prior to participation in the study (Appendix D). This study was approved by the University of Manitoba Faculty of Medicine Committee on the Use of Human Subjects in Research.

B. Instruments

1. Dynamometer

Isovelocity dynamometers have been shown to be capable of providing objective, valid, and reliable measurements of shoulder muscle strength using various testing protocols and for both concentric and eccentric muscle action (Frisiello et al. 1994, Greenfield et al. 1990, Hageman et al. 1989, Hellwig and Perrin 1991, Kuhlman et al. 1992).

The Kinetic-Communicator (Kin-Com, 500 H, Chattecx Corporation, Hixson, TN.) isovelocity dynamometer was used in this study to evaluate strength of the external and internal rotators of the shoulder. The Kin-Com is a microcomputer-controlled hydraulic instrument. The subject applies a force against the actuator arm of the Kin-Com dynamometer and the parameters of force, arm angular velocity, and angular displacement are detected by the Kin-Com via a strain-gauge transducer, tachometer, and potentiometer respectively. The mechanical reliability of the Kin-Com has been established (Farrell and Richards, 1986) to range from .948 to .999 depending on the variable examined. Hageman et al. (1989) and Hellwig and Perrin (1991) both demonstrated good reliability (r =.76 - .93) of their protocol when testing the shoulder internal and external rotation on the Kin-Com in both the concentric and eccentric mode, however the reliability of the specific test protocol used in this study had not been previously determined.

2. Goniometer

High intra-examiner reliability of the goniometer in measurements of active shoulder range of motion in healthy subjects has been previously documented (Boone et al. 1978, Greene and Wolf 1989). In addition, intra-tester intraclass correlation coefficients (ICC) ranging from .87 to .99 for passive shoulder range of motion in a patient population was demonstrated by Riddle et al.(1987). It is generally accepted that passive range of motion is more difficult to measure accurately than active (Gajdosik and Bohannon, 1987).

3. Visual Analogue Scale (VAS)

Visual analogue scales consist of a line usually 10 centimetres long. At the ends of the line are descriptive phrases relating to the extremes of pain intensity. VAS's for rating pain intensity have been shown to be a valid and sensitive measure of pain intensity (Jensen and Karoly, 1992). VAS scores may be treated as ratio data for the purposes of statistical analysis (Jensen and Karoly, 1992).

C. Procedure

Subjects accepted into the study were given uniform instructions regarding the testing procedure and equipment. Measurements of body mass and height were taken. Range of motion was tested prior to strength testing in all subjects. The VAS was completed before and after strength testing as a means of assessing pain intensity. All testing was performed by the primary investigator.

1. Strength testing

Positioning and Alignment: Subjects were seated beside the dynamometer with their shoulder joint in 25 ° of scapular plane abduction. The plane of the scapula was defined as 30 degrees anterior to the frontal plane (Poppen 1976, Saha 1971, Johnston 1937). The elbow joint was positioned in 90 degrees of flexion in the V-pad attachment, with the forearm in neutral pronation/supination. Subjects gripped the handle of the dynamometer with their wrist in the neutral position. The head of the dynamometer was rotated 45 degrees from the vertical so that the longitudinal axis of the humerus was approximated to the rotational axis of the dynamometer. The height of the dynamometer head was adjusted so as to maintain the shoulders level. Shoulder position was assessed with a hand-held goniometer.

Stabilization of the testing chair was achieved by means of weights and a tethering strap. Subjects were stabilized in the chair with straps placed horizontally around the waist and diagonally around the contralateral hip and ipsilateral shoulder region. The subjects' contralateral arm rested in their lap and their feet were unsupported. The elbow was secured to the V-pad with velcro straps.

Range of motion for testing was restricted to 90 degrees, with the forearm horizontal position designated as zero. Concentric external rotation moved the arm towards the forearm vertical position. During eccentric external rotation the forearm was returned to the forearm horizontal position. The opposite occurred for internal rotation, i.e. during concentric internal rotation the forearm moved toward the forearm horizontal position while during eccentric internal rotation the forearm was returned toward the vertical position. Seat height, length of the moment arm, height of the dynamometer head and order of testing were recorded.

Testing Protocol: The dynamometer's medium acceleration setting was used. Prior to testing, each subject completed a session of 15 submaximal repetitions using the passive mode of the dynamometer. During these passive mode repetitions, the actuator arm of the dynamometer moved the upper limb without requiring a minimum level of force to be generated on the force transducer. This served as a general warm-up and to familiarise the subject with the isovelocity machine. Subjects were then instructed to perform 3 submaximal repetitions followed by 3 maximum reciprocal concentric and eccentric repetitions at each velocity with a three second pause between contractions. Subjects were not allowed to view the dynamometer monitor during testing. During the maximal effort contractions the verbal commands "pull" and "resist" were given during concentric and eccentric contractions respectively. No other verbal encouragement was given. Testing speeds were 45, 90, 135, 180°/s. There was a 1.5 minute rest given between each velocity tested. Subjects were systematically allocated to one of four testing order categories such that they began testing with either the slow (45 and 90 °/s) or fast (135 and 180 °/s) velocities and either internal rotation or external rotation. A five minute rest was given between testing internal rotation/external rotation.

Moment values were not corrected for the moment of the weight of the forearm and hand in this study. The magnitude of the moment of the weight of the forearm and hand for an 80 kg man was recorded using the passive mode on the dynamometer, and estimated using body segment parameter data (Chandler et. al. 1975). Using the specific test protocol of this study (i.e. shoulder abducted 45°, in the plane of the scapula, 90 degree ROM, axis of rotation of machine approximating the glenohumeral joint, 0° = forearm horizontal, dynamometer head @ 45° tilt) the predicted variation of the moment of the weight of the forearm and hand due to different subjects would not be greater than 1 Nm.

Reliability testing: Intrarater test-retest reliability was determined for the strength testing protocol used in this study. Five subjects were re-tested within 10 - 14 days of the original procedure. They were asked to maintain their usual activity level between testing sessions. Pearson's product moment correlation coefficient and the intra-class correlation coefficient (ICC) (Fleiss, 1985) were calculated for each movement and contraction type i.e. concentric internal rotation, eccentric internal rotation, concentric external rotation, eccentric external rotation for peak torque and total work (Table 1).

	Pearson		ICC	
	Peak	Work	Peak	Work
External Rotation				
concentric	0.97	0.98	1.00	0.97
eccentric	0.94	0.92	0.86	0.80
Internal Rotation				
concentric	0.94	0.92	0.99	0.99
eccentric	0.87	0.90	0.77	0.84

Table 1 Test-retest reliability of concentric and eccentric external and internal rotation for peak moment and total work

2. Range of motion testing

All subjects had active shoulder range of motion measured prior to initial strength testing. The right shoulder was tested in all control subjects. The affected shoulder was tested in the shoulder impingement group. The movements tested were: shoulder flexion and abduction, internal rotation and external rotation with the arm positioned in 90 degrees of abduction, external rotation with the arm positioned by the side, cross chest horizontal adduction, and combined internal rotation/adduction/extension. Testing was performed in the order given above for each subject. Shoulder movements, with the exception of combined internal rotation/adduction/extension, were measured with a standard universal goniometer. The alignment of the goniometer on the subject was as described by Norkin and White (1985) and the subject was positioned in the supine position for all tests except when measuring external rotation with the arm in the neutral position, and combined internal rotation/adduction/extension. These were tested in the seated position. Combined internal rotation/adduction/extension was determined by the most cranial posterior bony anatomical landmark (i.e. vertebral level) reached by the radial styloid process of the individual.

D. Data Collection, Reduction and Analysis

1. Strength Parameters

The Kin-Com dynamometer transducers are interfaced with an on-board computer equipped with an A/D converter which samples the generated signals at a frequency of 100 Hz. The moment arm of the machine (the distance from the normal axis of the force transducer sensor to the axis of rotation of the dynamometer) was input to the computer by the investigator. The raw data of time, angular displacement, angular velocity, moment arm and force were exported from the on-board computer into individual ASCII text files for each test velocity. The raw data was then processed by means of Isomap Dynamometry Software (Isodyne Inc., Winnipeg, Manitoba). Shoulder Joint Moment (Nm) ($SJM_{(IR/ER)}$) was calculated as the product of force (N) and moment arm (m). Angular acceleration was derived from the unfiltered angular velocity waveform by numerical differentiation.

Regions of flatline data (rest periods between contractions) were removed using a velocity threshold of 2 °/s. A velocity threshold of 15 °/s was utilized to mark the beginning and end of each concentric and eccentric contraction. Figure 1 is a typical external rotation moment/angle plot generated for a control subject.

Figure 1 Graph of External Rotation Shoulder Joint Moment (Nm) versus Shoulder Joint Angle for a representative control subject. Three reciprocal eccentric (top three curves) and concentric contractions were performed at the highest angular speed (180°/s) Concentric contractions commenced at a shoulder joint angle of zero (forearm horizontal). Eccentric contractions commenced at a shoulder joint angle of 90° (forearm vertical).

The conversion program compiled report files with summary statistics regarding the data. The report files contained the strength parameters of peak moment, angle of peak moment occurrence, average moment and work for each test velocity. Determination of these parameters was restricted to regions of isovelocity data using an acceleration threshold of 300 °/s^2. The strength parameter report files were imported to a spreadsheet program

(Quattro Pro Version 6.0). Internal rotation and external rotation data were analyzed separately. The body mass normalized arithmetic mean of the three maximal concentric and eccentric contractions at each velocity was used for analysis of the strength parameters of peak moment, average moment, total work and angle of peak moment occurrence. Dynamic control ratios (DCR) were determined for each subject at each test velocity. The dynamic control ratio (Dvir et al. 1989) was calculated by dividing body mass normalized mean maximum eccentric external rotation moment by body mass normalized mean maximum concentric internal rotation moment for each specific velocity.

2. Strength Relief Maps

Strength relief maps depict the moment generating capability about a joint throughout a sampled range of motion and velocity spectrum. This three dimensional moment/angle/angular velocity relationship is expressed in the form of a two-dimensional relief map by mapping the z-axis moment values to a colour code. Strength relief maps provide for easy visual analysis of the sampled strength data and allow objective quantification of the entire sampled strength domain.

Internal rotation and external rotation strength relief maps were generated for each subject by use of the ISOMAP software program. For each subject the converted ASCII text files for each test velocity, including all repetitions, were converted into a single file. ISOMAP uses a bicubic interpolating spline to fit all the moment data to a 50X50 velocity/angle matrix. X-axis velocity values were plotted with concentric velocities designated as positive (0 to + 180 °/s and eccentric velocities designated as negative (0 to – 180 °/s). Angle values were plotted on the Y-axis from 0 - 90 degrees. The z-axis moment values were normalized to maximum for each subject, and each relief level (colour) depicted a ten percent decrement from maximum. The volume (J) (area under the moment/angle/angular velocity curve) was calculated for each individual relief map for internal rotation and external rotation. For analysis, volume values were normalized for body mass (J/kg).

The individual external rotation and internal rotation relief maps for each subject were used to generate an average internal rotation and external rotation relief map for each group (control and impingement). An internal rotation and external rotation "difference" map was then generated by subtracting the average impingement map from the average control map. Generation of difference maps allowed for regional event detection analysis of the moment data in terms of angle and angular velocity.

E. Statistical Analysis

1. All statistical analysis was performed using the statistical software program SYSTAT Version 5.0 for Windows. The level of significance was assessed at an alpha level of 0.05.

2. The VAS pain scores were analyzed for the impingement group before and after testing by means of a paired *t* test.

3. Goniometric range of motion testing was analyzed by means of an independent *t* test for each movement tested. Internal rotation results measured in regard to posterior boney landmarks were analyzed by means of the Mann-Whitney *U* test.

4. The isovelocity parameters of maximum moment, mean moment, angle of maximum moment occurrence and work were analyzed by means of a split-unit repeated measures two-way analysis of variance (ANOVA). Tukey's multiple comparison test was used for post-hoc analysis. For this calculation the sample size ("n" value) was determined using the harmonic mean of the "n" size of the two groups (control and impingement) (Hassard, 1991). Concentric velocities were designated as positive and eccentric velocities were designated as negative for a total of eight velocity measures. Each movement (internal and external rotation) and each contraction type (concentric and eccentric) were analyzed separately using this method. This was repeated for each of the isovelocity parameters evaluated.

5. The volume of the moment/angle/angular velocity graph for internal rotation and external rotation was subjected to a one-tailed independent *t* test to determine differences between the control and impingement groups.

6. The dynamic control ratios (DCR) were analyzed by means of independent *t* tests utilizing a Bonferonni correction.

7. The relationships between the self-reported shoulder symptom scores and the volume of the external rotation strength relief map were analyzed by means of the Pearson product moment correlation coefficient and linear regression.

XIII.Results

1. Subjects

A total of thirty-two subjects participated in the study; twenty-three in the control group and nine in the impingement group. Group demographics are outlined in Table 2.

	Control	Impingement
Number	23	9
Age (yrs)	33.6±5.6	32.1±6.9
Body Mass (kg)	81.0±10.9	84.2±7.0
Hand Dominance (R/L)	21:2	6:3
Side Affected (Dominant:Non-dominant)	n/a	7:2
Upper Extremity Weight Training (%)	57	78

Table 2 Group demographics of control and impingement groups. Mean and standard deviation are shown where applicable.

No significant differences were observed between groups for age and body mass. Although the impingement group demonstrated a higher percentage of weight training activity the difference was not statistically significant ($\chi2 = 0.52$, N.S.). One subject in the impingement group was a member of a university volleyball team. No other subjects in the control or impingement groups were involved in any competitive/professional sports activities. Table 3 summarizes the self-reported shoulder symptom ratings for the impingement group.

Pre-test VAS (cm)	1.94±1.8
Post-test VAS (cm)	2.44±2.1
Nirschl Tendinosis Score	4.44±1.8
Duration of Symptoms	
years	3.31 ± 2.8
range	0.25 - 7

Table 3 Impingement group shoulder symptom ratings.

The impingement group VAS scores were significantly higher post-test than pre-test (paired t-test, $p < 0.034$). All of the control group subjects had VAS ratings of zero both before and after strength testing. Pearson's product moment correlation coefficient and linear regression analysis were used to assess the relationship between the shoulder symptom ratings and the volume (J/kg) of the external rotation strength relief map for the impingement group. The volume of the external rotation strength relief map was selected to assess this relationship as it provides a single value which encompasses all of the sampled moment data. There was a small negative and nonsignificant correlation between the Nirschl tendinosis rating and volume of the external rotation strength relief map ($r = -0.127$, N.S.). There was a small positive and nonsignificant correlation between the strength relief map external rotation volume (J/kg) and the pre and post VAS scores ($r = 0.35$, N.S. for both) and the duration of symptoms ($r = 0.091$, N.S.).

Range of Motion

The shoulder range of motion results are presented in Table 4. Analysis of active shoulder range of motion data demonstrated that the only statistically significant difference between the control and impingement group was for shoulder internal rotation measured in the ninety degree abducted position. The impingement group had significantly less (mean difference = 8.6°) active shoulder internal rotation than the control group (independent *t*-test, $p < 0.012$).

	Control	Impingement	p value
Forward Flexion	166.9 ±7.7	164.4 ±7.3	0.42
Abduction	179.4 ±2.4	178.9 ±3.3	0.62
External Rotation (neutral)	61.11 ±13.5	56.67 ±13.5	0.42
External Rotation (abducted)	92.5 ±10.0	91.1 ±8.2	0.72
Horizontal Adduction	30.27 ±5.8	30.0 ±5.0	0.90
Internal Rotation (abducted)	45.00 ±8.4	36.4 ±5.9	0.012*
Internal Rotation (posterior) (vertebral levels)	10.39 ±1.5	11.1 ±1.9	0.304

Table 4 Range of motion data (degrees) for control and impingement groups (mean and standard deviation). Internal rotation (posterior) was measured in terms of vertebral levels and analyzed by Mann-Whitney *U*-test. * significant at < 0.05 level.

B. Strength Data

1. Peak Moment

The moment/angular velocity relationship for external rotation and internal rotation for the control and impingement groups is graphically illustrated in Figure 2 and Figure 3. A statistically significant correlation was observed for body mass to peak moment for IR ($r = 0.461$, $p < 0.001$) and ER ($r = 0.371$, $p < 0.001$). The body mass normalized peak moment values (Nm/kg) are plotted with standard error bars at each testing velocity. Eccentric velocities are designated as negative and concentric velocities are designated as positive.

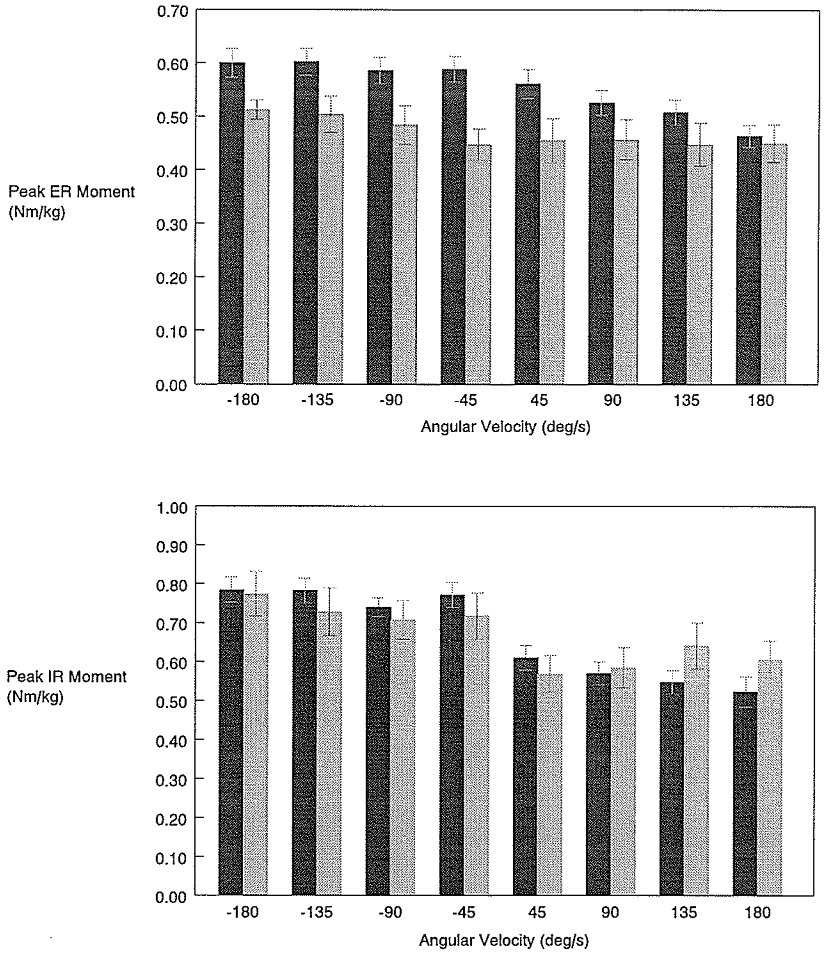

Figure 2 Moment/angular velocity relationships. Control group - solid bar, Impingement group - gray bar. Figure 2A illustrates the data for external rotation for both the control and impingement groups. Figure 2B illustrates the data for internal rotation for both the control and impingement groups.

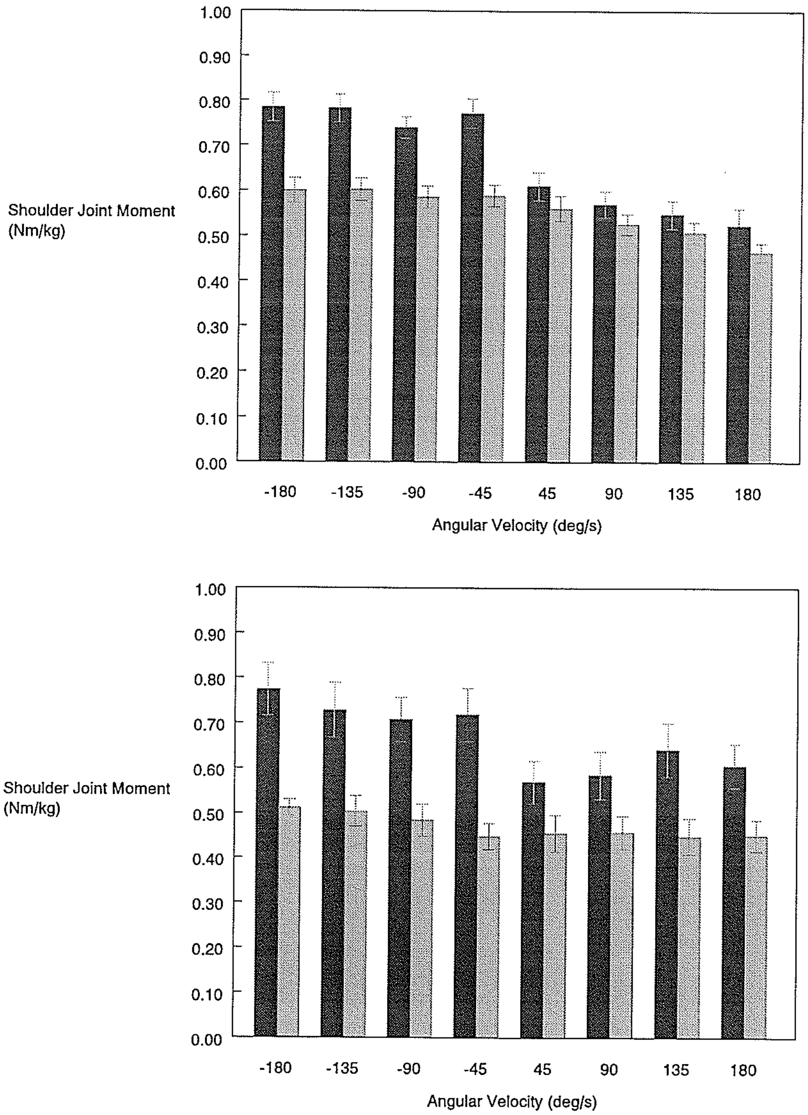

Figure 3 Moment/angular velocity relationships. Control group - solid bar, Impingement group - gray bar. Figure 3A. Internal and external rotation moment angular velocity relationships for the control group. Figure 3B. Internal rotation and external rotation moment angular velocity relationship for the impingement group.

An ANOVA table presenting the statistical analysis of the results of external rotation concentric peak moment data is displayed in Table 5. The outline of this ANOVA table is identical to that used in the analysis of each of the other parameters evaluated (i.e. peak moment, work, angle of peak moment occurrence for internal and external rotation, concentric and eccentric values).

	SS	DF	MS	F	p
Between Subjects		31			
Between Groups	0.100	1	0.100	2.212	0.147
Error	1.360	30	0.045		
Within Subjects		96			
Between Velocities	0.036	3	0.012	7.194	0.000
Group x Velocity	0.028	3	0.009	5.547	0.002
Error	0.151	90	0.002		
Total		127			

Table 5 Example ANOVA table summarizing results for concentric external rotation peak moment (Nm/kg).

As summarized in Table 5, analysis of the peak moment results obtained for concentric external rotation demonstrated statistically significant between velocity differences ($p < 0.001$). The group by velocity interaction was also statistically significant ($p < 0.002$). Tukey's multiple comparison test was used for post-hoc analysis of the group by velocity interaction effect. As illustrated in Figure 2A concentric external rotation peak moment for the impingement group was statistically significantly lower than the control group at 45, and 90°/s. There was no significant difference between the control group mean concentric peak moment at 135 and 180 °/s and the impingement group mean peak moments. There was no statistically significant effect of velocity on concentric external rotation peak moment for the impingement group. Mean peak moment was observed to decrease with increasing velocity for the control group. The mean peak moment at 180 °/s was significantly less than the mean at 90 and 45°/s but not statistically significantly different than the mean peak moment at 135°/s. There was no statistically significant difference between the mean peak moment observed at 45 °/s and 90 °/s for the control group.

As illustrated in Figure 2A there was a significant difference between groups on analysis of peak moment values for eccentric external rotation ($p < 0.013$). Statistically significantly lower magnitude of eccentric peak moment in the impingement group at all velocities was observed as evidenced by separation of standard error bars at all eccentric velocities. A significant between velocity effect was also demonstrated ($p < 0.031$). For the impingement group the mean peak moment at 45 °/s was significantly lower than the mean peak moment obtained at 135 and 180 °/s but not significantly different from the mean at 90 °/s. There was no statistically significant effect of velocity on the eccentric peak moment values for the control group.

Internal rotation concentric and eccentric peak moment data analysis demonstrated no statistically significant differences except for the group by velocity interaction for concentric peak moment ($p < 0.001$). Post-hoc analysis of concentric internal rotation demonstrated that the control group had significantly higher mean peak moment at 45 °/s than at 180 °/s. There were no other statistically significant differences observed.

2. Work

The work/angular velocity relationships for internal rotation and external rotation for both the control and impingement groups were similar to the relationship observed for peak moment. On analysis of concentric external rotation work data, the only statistically significant effect observed was the group by velocity interaction ($p < 0.010$). Mean work values observed for the impingement group were significantly lower than the control group mean work values at 45 and 90 °/s. The mean work at 135 and 180 °/s for the control group was not significantly different than the impingement work means. There was no significant effect of velocity on mean work in the impingement group, however for the control group, mean work at 180 °/s was significantly less than that observed at 45 °/s.

There was a significant between groups effect observed on analysis of eccentric external rotation work data ($p < 0.038$) with separation of standard error bars at all velocities. The velocity and group by velocity effects were not significant.

The only statistically significant effect observed for internal rotation concentric and eccentric work was the concentric group by velocity interaction ($p < 0.004$). The control group had higher mean concentric internal rotation at 45 °/s than at 135 °/s. There were no other statistically significant differences.

3. Angle of Peak Moment Occurrence

Figure 4 graphically illustrates the results obtained for angle of peak moment occurrence. The angle of peak moment occurrence (°) was determined at each velocity tested and plotted with standard error bars. Concentric velocities were designated as positive and eccentric velocities as negative.

As illustrated in Figure 4A there was a significant velocity effect on the angle of peak moment occurrence for concentric external rotation ($p < 0.001$). For both the control and impingement groups concentric peak moment occurred later in the range of motion with increasing velocity. The mean angle of peak concentric moment occurrence was significantly higher (i.e. occurred later in the range of motion) at 135 and 180 °/s than at 45 or 90 °/s for both groups. There was no statistically significant difference observed for either group between the angle of peak moment occurrence at 45 and 90 °/s or of that between 135 and 180 °/s. No significant group or group by velocity interaction effects were observed on analysis of concentric external rotation.

A statistically significant group ($p < 0.016$) and velocity ($p < 0.005$) effect was observed for eccentric external rotation angle of peak moment occurrence. At 45 °/s the impingement group achieved peak eccentric moment significantly earlier in the range of motion than the control group. There were no other significant between group differences. There was no significant effect of velocity on the angle of peak eccentric moment occurrence for the control group. Peak moment in the impingement group was achieved earlier in the range of motion at 45 °/s than at 90 or 180 °/s.

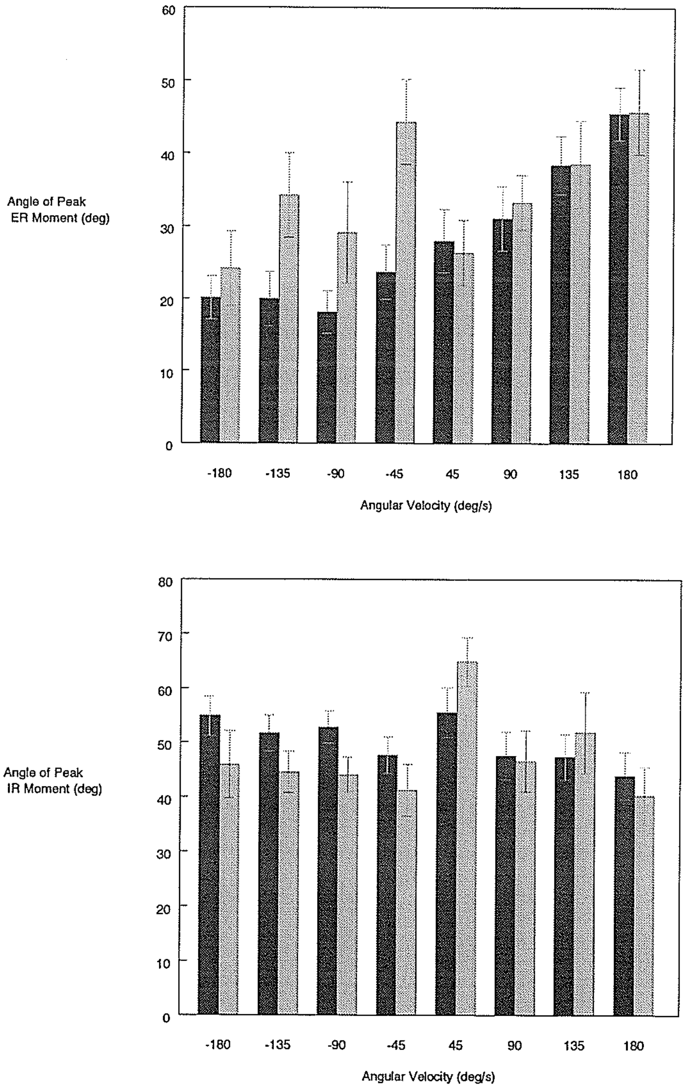

Figure 4 Angle of peak moment occurrence/angular velocity relationship. Control group - solid bar, impingement group - gray bar. Figure 4A. External Rotation for control and impingement groups. Figure 4B. Internal Rotation for control and impingement groups.

As shown in Figure 4B, concentric peak moment tended to occur later in the range of motion with increasing velocity for both the control and impingement groups (between velocity $p < 0.001$). For the control group the difference was significant only between the angle of peak moment occurrence at 180 °/s and 45 °/s. For the impingement group the angle of peak moment occurrence was significantly higher at 45 °/s than at any of the other velocities and also significantly higher at 135 °/s than at 180 °/s.

Summary statistics for external rotation and internal rotation are shown in Tables 6 and 7.

	Group	Velocity	Group X Velocity
Peak Moment (Nm/kg)			
concentric	0.147	0.000	0.002
eccentric	0.013	0.031	0.245
Angle (°)			
concentric	0.974	0.000	0.907
eccentric	0.016	0.005	0.131
Work (J/kg)			
concentric	0.194	0.179	0.010
eccentric	0.038	0.095	0.170

Table 6 Summary of statistical analysis of external rotation strength data.

	Group	Velocity	Group X Velocity
Peak Moment (Nm/kg)			
concentric	0.513	0.373	0.001
eccentric	0.473	0.093	0.711
Angle (°)			
concentric	0.748	0.000	0.132
eccentric	0.139	0.155	0.953
Work (J/kg)			
concentric	0.450	0.291	0.004
eccentric	0.264	0.103	0.264

Table 7 Summary of statistical analysis of internal rotation strength data.

4. Dynamic Control Ratio

The dynamic control ratio results are graphically illustrated in Figure 5. The dynamic control ratio (DCR) was calculated by dividing body mass normalized mean peak eccentric external rotation moment by body mass normalized mean peak concentric internal rotation moment for each subject. When averaged over speed the DCR was statistically significantly higher in the impingement group than in the control group ($p < 0.000$). Post-hoc testing employing a Bonferonni correction to compare each velocity demonstrated statistical significance only at 135°/s.

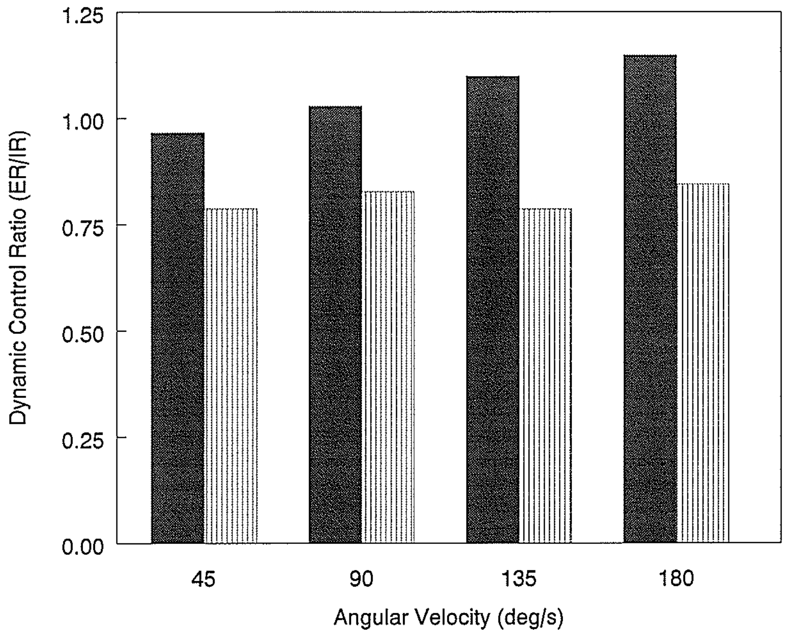

Figure 5 Dynamic Control Ratios. Dynamic control ratios (DCR) were calculated for each testing for both the control and impingement group. The p-values obtained at each velocity are 45°/s, 0.02; 90°/s, 0.08; 135°/s, 0.01; 180°/s, 0.05. The control group is solid bars, impingment group are vertical striped bars.

Strength Relief Maps.

Strength relief maps were generated for internal and external rotation for each of the subjects. The volume (J) (area under the moment/angle/angular velocity curve) of each individual internal rotation and external rotation strength relief map was calculated and normalized for body weight (J/kg). The mean volume (J/kg ± SD) of the external rotation strength relief maps for the impingement group (3.3 ± 0.6 J/kg) was significantly less than the mean volume of the control group strength relief maps (4.0± 0.8 J/kg) ($p < 0.026$). There was no significant difference between the mean volume of the control (4.8 ± 1.0 J/kg) and impingement group (4.6 ±0.9 J/kg) internal rotation strength relief maps ($t = 0.683$, N.S.).

The individual strength relief maps for internal rotation and external rotation for each subject were utilized to generate an "average" internal rotation and external rotation relief map for the control and impingement groups. "Difference" maps were generated by subtracting the average control map from the average impingement map for both internal and external rotation. The averaged strength relief maps and difference maps generated from absolute moment (Nm) and body mass normalized moment (Nm/kg) for IR and ER are displayed in Figure 6 and Figure 7.

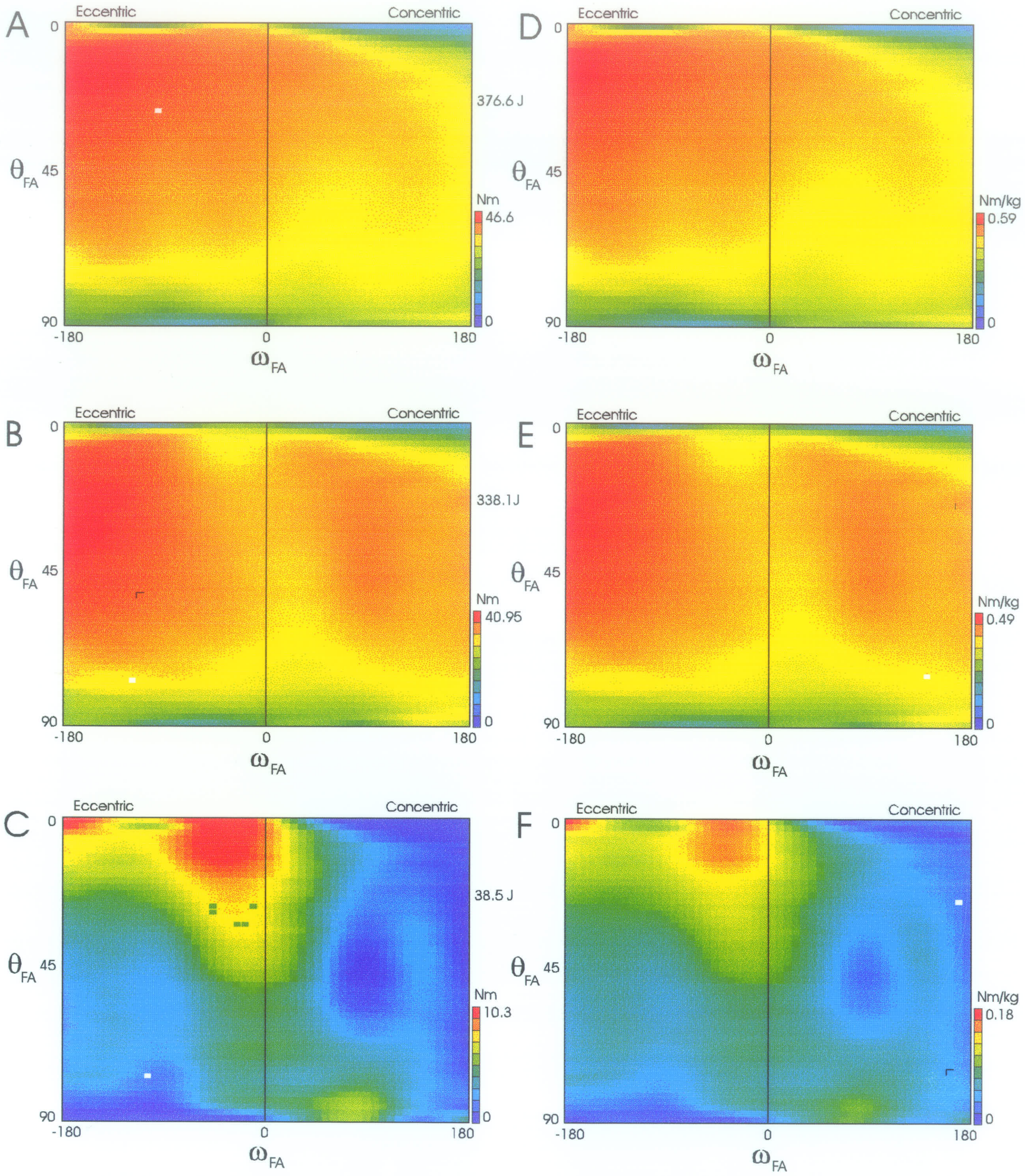

Figure 6. Average external rotation strength relief maps. A. Control map. B. Impingment map. C. Difference map (control - impingement. D. Body mass normalized control map. E. Body mass normalized impingement map. F. Body mass normalized difference map (control - impingement). The horizontal axis is the angular velocity of the forearm and the vertical axis is the angle of the forearm corresponding to the amount of internal/external rotation at the shoulder.

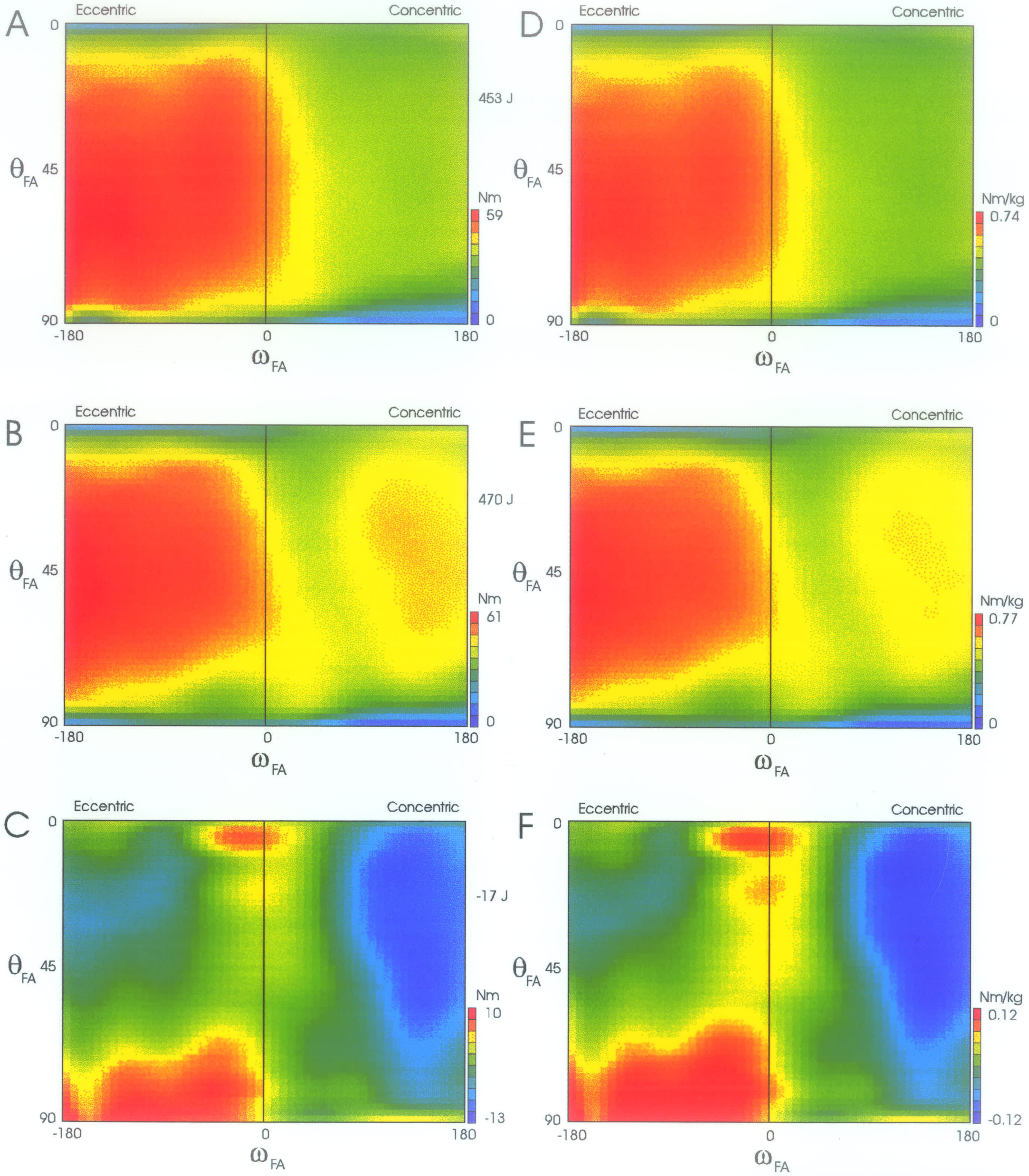

Figure 7. Average internal rotation strength relief maps. A. Control map. B. Impingement map. C. Difference map (control - impingement). D. Body mass normalized control map. E. Body mass normalized impingement map. F. Body mass normalized difference map (control - impingement). Horizontal axes - forearm angular velocity (deg/s). Vertical axes - forearm angle (deg) corresponding to shoulder int/ext rotation. Total work (J) for each non-normalized map is shown. The color-coded scale bars are calibrated in Nm or Nm/kg as indicated.

The external rotation difference map analysis revealed an angle and velocity matched peak moment difference of 12.83 Nm. Regional event detection analysis was performed using a 5Nm threshold value. An angle and velocity matched external rotation moment deficit in the impingement group was demonstrated over 22% of the map using this technique. The deficit was localized to two regions. The first region (region 1) comprised 21.2% of the map area and was sustained over the 0-50° angle spectrum and -180 to + 40°/s angular velocity spectrum. The second region (region 2) comprised 0.8% of the map area and occured within the 84-90° range of motion and 62-92°/s velocity spectrum. Regional event detection analysis of the body mass normalized difference map was performed with a threshold of 0.07Nm/kg (approximately 5.7Nm). The pattern observed in the difference map generated using absolute moment was preserved in the body mass normalized difference map but was more extensive. The impingement group deficit increased to comprise 39.8% of the map area. The area of region 1 comprised 36.6% of the map surface encompassing a 0 - 72° range of motion and -180 - +70°/s velocity spectrum. Region 2 included 3.2% of the map area encompassing the 72-90° range of motion and -18 to 121°/s angular velocity spectrum. Analysis of the internal rotation difference map revealed an angle and velocity matched peak moment difference of 10.7 Nm. Regional event detection analysis revealed that 10.9% of the map area had angle and velocity matched moment differences greater the 5 Nm. A 4 Nm difference or greater was observed over 17% of the map area. The volume of the internal rotation difference map was 7.9 J. Qualitative analysis of the difference map revealed that the impingement group internal rotation deficit occurred in the eccentric region of the map. These differences were sustained across all eccentric velocities in the range of motion between approximately 0 and 25 degrees. The impingement group also demonstrated a concentric region of increased internal rotation moment generation. This region was revealed on examination of both the absolute and mass normalized difference map but was more extensive in the mass normalized map and encompassed the 0-60° range of motion and 135-180 °/s angular velocity spectrum.

XIV. Discussion

This study examined shoulder internal and external rotation moment angular velocity relationships in a group of male subjects with impingement syndrome and a control group of asymptomatic male subjects. This results of this study indicate that male subjects with impingement syndrome have patterns and magnitudes of shoulder strength at variance with those observed in subjects without known shoulder pathology. As hypothesized, the impingement group demonstrated concentric and eccentric SJM_{ER} strength deficits. The magnitude of SJM_{ER} in the impingement group was less than the control group at all eccentric speeds and at three out of four concentric speeds. There were no significant differences in SJM_{IR} between the two groups based on peak moment and work data. As hypotheisized, assessment of active range of motion demonstrated decreased internal rotation in the impingement group however contrary to the hypothesis no difference was demonstrated in horizontal adduction between the groups.

Isovelocity testing was chosen to examine shoulder internal and external rotation strength. The test-retest reliability of the strength testing protocol utilized in this study was very high. The ICC's for peak moment ranged from 0.77 (eccentric IR) to 1.00 (concentric ER). Previous investigators have reported comparable reliability, as assessed by peak moment, of similar isovelocity testing protocols for shoulder internal and external rotation tested in both the concentric and eccentric modes for healthy subjects (Frisiello et al. 1994, Hageman et al. 1989, Hellwig and Perrin 1991). The intraclass correlation coefficicents reported in these studies ranged from 0.76 - 0.93. It is recognized that the degree of reliability demonstrated in healthy subjects cannot be generalized to subjects with shoulder pathology. However, the testing protocol in this study did not vary between control and impingement groups, and all impingement group subjects were observed to perform and complete the test without difficulty. This suggests that the impingement group subjects were capable of producing reliable isovelocity strength measurements using the protocol designed for this study.

The results of the present study support the findings of Warner et al. (1990) but are in conflict with those of Leroux et al. (1994). Warner et al. (1990) documented significantly increased concentric peak moment and total work IR/ER ratios in subjects with impingement syndrome when compared to a control and instability group. No absolute ER or IR differences were observed between groups. The authors concluded that "a relative weakness of the external rotators is an important feature of the impingement process" (pg 373). Although we did not statistically analyze concentric $SJM_{IR/ER}$ ratio data between the groups in this study, (the dynamic control ratio was considered a more relevant ratio), in agreement with the results of Warner et al., the observed mean peak moment ratios for the impingement group (1.28-1.45) were higher at all velocities than the mean control group ratios (1.1 - 1.2). This upward shift in the concentric IR/ER ratios could be attributed in the present study to a significant decrease in external rotation strength as no difference in SJM_{IR} was observed.

The decreased active shoulder joint internal rotation observed in the impingement group in the present study has been previously demonstrated to be a feature of impingement syndrome (Warner et al. 1990) and has commonly been reported to be part of the clinical manifestation (Matsen and Arntz 1990a, Pappas et al. 1985). The present study did not however, demonstrate limitation of the movements of combined internal rotation/adduction and cross chest adduction in the impingement which has been previously observed (Warner et al. 1990). This may have been due to the relative difficulty in accurately assessing these movements.

The pattern of limitation of shoulder range of motion observed clinically in subjects with impingement syndrome has been speculated to be due to the presence of posterior capsular tightness (Pappas et al. 1985) as a result of reactive fibrosis due to repetitive stresses and microtrauma. It has been suggested that posterior capsular tightness may result in superior humeral head translation and impingement during arm elevation (Matsen and Arntz 1990a). Support for this theory has been provided by Harryman et al. (1990). They demonstrated in a cadaver model that operative tightening of the posterior capsule results in increased anterior humeral head translation during glenohumeral joint flexion and cross body adduction and superior head translation during flexion. Certainly posterior capsular tightness is a possible cause of the demonstrated limitation of shoulder internal rotation in the impingement group in the present study. Whether restricted active internal rotation represents a primary factor in the development of impingement syndrome or is a secondary phenomenon has not been ascertained.

The strength results of the present study are in conflict with those reported by Leroux et al. (1994). Leroux and co-workers investigated bilateral concentric $SJM_{IR/ER}$ in a control group ($n = 15$), a group with chronic impingement syndrome ($n = 15$) and a group of impingement subjects following arthroscopic anterior acromioplasty ($n = 15$). Peak moment and average power were examined at 60 and 180 °/s. No significant peak moment or average power concentric IR/ER differences were identified between the dominant and nondominant shoulders in the control group or between the affected and nonaffected shoulder in the impingement groups. In contrast to our results and those of Warner et al., IR/ER ratios were significantly *lower bilaterally* ($p < 0.005$) in the operated and nonoperated impingement groups compared to the control group. Absolute deficits of both internal and external rotation compared to the control group were demonstrated in the nonoperated impingement group ($p < 0.01$) with a relatively greater deficit of internal rotation. The IR/ER ratios were not significantly different between the operated and nonoperated impingement group. Due to the bilateral nature of the findings and the lack of correlation of strength deficits with duration of symptoms, a primary association between the identified IR/ER differences and impingement syndrome was suggested.

There are several possible explanations for the lack of agreement between the present study and that of Leroux and co-workers. Several methodological flaws in the study reported by Leroux et al. (1994) may have affected the results obtained. Firstly, the control and impingement groups were not balanced with respect to gender. It is well documented that women generate lower magnitudes of shoulder joint moment than men (Cahalan et al. 1991, Hageman et al. 1989, Ivey 1985, Kuhlman et al. 1992, Maddux et al. 1989, Nicholas et al. 1989, Reid et al. 1989). In the study by Leroux et al. the impingement group had a female/male ratio of 2:1 and the control group had a 1:2 ratio. Given that the moment values were not adjusted for body mass, the lower IR and ER moment and power magnitudes observed in the impingement group may be attributed partially to the larger female/male ratio in the impingement group. Interpretation of the power data is also confounded by failure to standardize testing range of motion. The mean control group test range of motion was larger than the impingement group which may have contributed (depending on the method of calculation) to increased power magnitudes in the control group. Finally, the method of data analysis (multiple student's *t* tests without employing a correction factor) may have resulted in the erroneous conclusion of significance where none existed.

The conflicting IR/ER ratio values are more difficult to explain. No statistically significant difference in IR/ER ratios has been demonstrated between male and female subjects (Tata et al. 1993). Similar shoulder positioning (25-45 degrees of scapular plane shoulder abduction), and testing protocols (by Leroux et al. and Warner et al.) were employed. Differences in the activity levels of the populations studied was cited as a possible explanation by Leroux et al. for the discrepancy between their results and those of Warner et al. Several investigators have demonstrated increased concentric IR/ER ratios in various overhead athletic groups (Beasley and Chandler 1989, Fowler 1988, McMaster et al 1992). One hundred percent of the impingement group subjects in the study by Warner et al. participated in overhead sports or jobs involving repetitive overhead work, as compared to only 31% in their control group. Although degree of subject participation in overhead activity is not reported by Leroux et al., it is implied in the discussion section that few (if any) of the impingement group subjects took part in overhead sports. It is conceivable that this resulted *prima facie* in increased IR/ER ratios in the impingement group in the study by Warner et al. However, this was not the case in the present study. The control and impingement groups in this study were well matched with regard to overhead activity. Only one of the impingement group subjects and none of the control group subjects regularly participated in overhead sports activities. Although in our study the impingement group had a higher percentage of subjects participating in upper extremity weight-training (78%) compared to the control group (57%), the difference was not statistically significant.

Leroux et al. examined an older age group (impingement group mean = 48.8 yrs, post-operative impingment group = 50.2 yrs.) than either Warner et al. (impingement group mean = 31 yrs.) or the present study (impingement group mean = 32.1 yrs.). Although age related changes in the relationship between internal and external rotation shoulder joint moment has not been previously examined it is possible that the IR/ER strength profile associated with impingement syndrome varies with age. It is certainly probable that shoulder joint activity patterns change with age and that these alterations differentially affect internal and external rotation shoulder joint moment generation capacity.

Finally, it is possible that the impingement groups between studies were not homogeneous with regard to the underlying etiology. Warner et al. (1990) demonstrated significant differences in IR/ER strength ratios between subjects with anterior shoulder instability and those with impingement syndrome, with the instability group exhibiting a significantly decreased ratio compared to controls. Additionally they observed that 63% of the instability subjects had signs of impingement. As no mention was made by Leroux et al. regarding exclusion of subjects with glenohumeral joint instability it is possible that the impingement groups between studies were not homogeneous in this regard. In the present study an attempt was made to identify and exclude subjects with overt or subtle shoulder instability through inquiry into the history of shoulder complaints and clinical examination including the apprehension and relocation tests. The impingement subjects in the present study were therefore composed of subjects who did not exhibit any detectable clinical instability. Notwithstanding the above, it is also possible that the subjects in the study by Leroux et al. represented a group with primary mechanical impingement. Primary impingement is more likely in an older age group (Jobe and Bradley 1989). Additionally pain relief was reported to have been obtained in subjects post arthroscopic acromioplasty which lends support to primary mechanical impingement as the underlying pathology. The possibility in the present study that the impingement group contained subjects with very minor clinical instability cannot be ruled out.

Examination of the moment angular velocity relationship, as hypothesized and in agreement with previous studies investigating shoulder internal and external rotation in normal subjects (Cahalan et al. 1991, Ellenbecker 1988, Hageman et al 1989, Kuhlman et al. 1992, Mayer et al. 1994, Mikesky et al. 1995, Ng and Kramer 1991, Soderberg and Blaschak 1987), demonstrated a decrease in concentric moment magnitude with increasing velocity in the control group.

Evaluation of the eccentric moment angular velocity relationship in the control group in this study failed to demonstrate a change in moment generation capacity with increasing angular velocity for either internal or external rotation. There has not been general agreement in the few previous studies that have provided information on eccentric muscle action over a velocity spectrum for shoulder internal and external rotation. Hageman et al. (1989) investigated concentric and eccentric muscle action at 60 and 180°/s. They reported that eccentric ER moment increased significantly ($p < 0.003$) with increasing speed in females, but remained constant in males. Internal rotation eccentric moment did not change significantly with speed in males or females. Mikesky et al. (1995) investigated dominant and nondominant concentric and eccentric muscle action of shoulder internal and external rotation and elbow flexion and extension in 25 baseball pitchers at 90, 180 and 300 °/s. Although the velocity effect was not subjected to statistical analysis, on examination of their data a trend for external rotation moment to be maintained or decrease with increasing speed, and internal rotation moment to increase with increasing speed was observed. The discrepancy observed between these results and the present study is likely due to differences in testing protocol and procedure. The most extensive data to date on shoulder moment angular velocity relationships has been provided by Mayer et al. (1994). They examined concentric (60, 180, 240, 300°/s) isometric and eccentric (60, 120, 180, 240°/s) SJM for flexion, extension, abduction, adduction, external rotation and internal rotation movements. As observed in the present study, a trend was demonstrated for eccentric moment to be maintained across the velocity spectrum. The present study, in agreement with previous studies conducted in nonathletic populations, (Hageman et al. 1989, Hellwig and Perrin 1991, Mayer et al. 1994), baseball pitchers (Mikesky et al. 1995) and tennis players (Mont et al. 1994, Ng and Kramer 1991) demonstrated that for the control group maximal eccentric resultant $SJM_{IR/ER}$ exceeded velocity matched concentric values. Mayer and co-workers observed that maximal isometric moment generation exceeded or equalled eccentric moment for all movements tested with the exception of eccentric IR at 60°/s which slightly exceeded the observed isometric $\mathrm{SJM}_{\mathrm{IR}}$. Although isometric $\mathrm{SJM}_{\mathrm{IR/ER}}$ was not examined in the present study, observations in this laboratory on resultant joint moment about the knee ($\mathrm{RJM}_{\mathrm{K}}$) have demonstrated a similar relationship for maximal voluntary moment production i.e. isometric > eccentric > concentric (Webber and Kriellaars 1996).

Absolute $\mathrm{SJM}_{\mathrm{IR/ER}}$ values are difficult to compare between studies due to differences in subject characteristics, dynamometer type, testing position and protocol including familarization of subject, use of "gravity correction", etc. Notwithstanding this, the control group resultant concentric and eccentric $\mathrm{SJM}_{\mathrm{IR/ER}}$ in the present study is within the range reported in the literature. External rotation concentric and eccentric peak moment was generally noted to be higher (concentric 37.3 - 45.3, eccentric 47.2 - 48.5) than those reported for male nonathletic subjects (concentric 20.0 - 30.6 Nm, eccentric 26.0 - 43.1 Nm) (Hageman et al. 1989, Hellwig and Perrin 1991, Mayer et al. 1994, Dvir 1995) and lower than those reported for male professional athletes (concentric 53.2 - 62.1 Nm, eccentric 63.0 - 66.6 Nm) (Mikesky et al. 1995). Internal rotation concentric and eccentric peak moment (concentric 42.8 - 49.3 Nm, eccentric 59.9 - 63.74 Nm) was also slightly higher than reported in the literature for nonathletic subjects (concentric 34.0 - 48.0 Nm, eccentric 41.0 - 54.1 Nm) (Hageman et al. 1989, Hellwig and Perrin 1991, Mayer et al. 1994, Shklar and Dvir 1994), and lower than those reported for athletic subjects (concentric 96.3 - 108.7 Nm, eccentric 84.0 - 96.5 Nm) (Mikesky et al. 1995).

Significant differences have been reported between resultant $\mathrm{SJM}_{\mathrm{IR/ER}}$ obtained with the humerus positioned in the plane of the scapula as opposed to the frontal plane position (Greenfield et al. 1990), with significantly higher $\mathrm{SJM}_{\mathrm{ER}}$ observed with scapular plane positioning. In agreement with previous investigations which examined $\mathrm{SJM}_{\mathrm{IR/ER}}$ in the scapular plane and 45 degrees of glenohumeral abduction (Greenfield et al. 1990, Tata et al. 1993), relatively low concentric IR/ER ratios were observed for the control group in this study (1.10 - 1.21). The relatively higher ER values obtained with testing in the scapular plane has been hypothesized to be due to the attainment of optimal length tension relationship for the external rotators (Greenfield et al. 1990) in this position.

Examination of the impingement group moment/angle/angular velocity relationship revealed patterns and magnitudes at variance with the control group. Significantly decreased magnitudes of eccentric SJM_{ER} were observed in the impingement group compared to controls at all testing speeds. The magnitude of the external rotation eccentric deficit (maximum mean difference = 9.5 Nm @ 45°/s) was greater than the concentric deficit (maximum mean difference = 7.3 Nm @ 45°/s) at all speeds tested. The differences in ER peak moment observed at 45°/s represent a 20% eccentric and 16% concentric deficit in the impingement group. In contrast to the control group, a velocity dependent change in concentric SJM_{ER} was not demonstrated, however an increase in eccentric SJM_{ER} with velocity was observed. These findings are considered to be reflective of the tendency in the impingement group to demonstrate a relatively greater deficit of moment generation at low velocities for both IR and ER. In addition, while SJM_{IR} eccentric values exceeded concentric values in the impingement group (Figure 3A), external rotation eccentric peak moment and work did not exceed the velocity matched concentric values. The altered moment angle angular velocity relationship demonstrated in the impingement group is readily appreciated on examination of the control and impingement ER strength relief maps. The flattened overall surface of the ER relief map in the impingement group is immediately apparent (Figure 6B and 6E). On examination of the body mass normalized ER difference map the regions exhibiting the external rotation deficit are easily visualized (Figure 6F). This deficit (throughout 40% of the map area) occurred primarily in the range of motion within 50° of the forearm horizontal for eccentric velocities and in the near vertical forearm position in the low velocity concentric region of the map. Examination of the internal rotation difference map revealed patterns in variance with the control group that were not detected on evaluation of peak moment and work data (Figure 7). An internal rotation eccentric deficit was observed corresponding to end range of motion (70-90°, near forearm vertical). Conversely, the impingement group displayed *increased* concentric moment generation capacity in region of the strength relief map corresponding to 0-45° range of motion and 135-180°/s angular velocity. It is striking that the deficit of eccentric external rotation and the relatively increased concentric internal rotation moment generation capacity in the impingement group demonstrated in the relief maps (and on analysis of the DCR) occur within the same range of motion (i.e. closer to the forearm horizontal position). Differences in internal rotation and external rotation moment generation between the control and impingement group are also apparent in the angular position as the forearm approaches the near vertical position. In this range of motion deficits of eccentric internal rotation and concentric external rotation are observed.

Analysis of the angle of peak moment demonstrated that for both the control and impingement group concentric IR and ER peak moment occurred later in the range of motion with increasing velocity (Figure 4). This pattern has been observed on examination of concentric RJM_K for flexion and extension movements (Baltzopoulos and Brodie 1989). However others have failed to demonstrate velocity dependent change in angle of peak moment occurrence in studies which have examined shoulder (Ivey et al. 1985) and elbow RJM (Horotobagyi and Katch 1990) and Kuhlman et al. (1992) demonstrated that for SJM_{ER} angle of peak moment occurred slightly earlier in the range of motion with increasing velocity. Angle of peak moment occurrence for IR and ER eccentric muscle action did not demonstrate a velocity dependency for either the control or impingement group. The large variability in angle of peak moment occurrence between subjects observed in the present study has been previously demonstrated (Ivey et al. 1985, Kuhlman et al. 1992, Mayer et al. 1994, Reid et al. 1989) and may partially account for differing results between studies. Differences in the neural activation strategy between subjects may account for the large variability in this parameter as well as the observed change in angle of peak moment with velocity.

Significant differences were observed in the angle of peak moment occurrence for eccentric external rotation between the control and impingement group. The impingement group developed peak moment significantly earlier in the range of motion than the control group at the three lower velocities. This may represent a neural regulatory mechanism limiting sustained moment generation at low ER eccentric velocities and preventing attainment of peak moment at the optimal joint angle as governed by muscular length-tension and moment arm.

A neural regulatory mechanism limiting motor unit activation may also explain the observed suppression of eccentric external rotation and low velocity eccentric internal rotation moment generation capacity in the impingement group as compared to the control group. In the impingement group this regulatory mechanism seems to act to limit the relatively high magnitude moment generation associated with eccentric and slow velocity concentric neuromuscular activity. Certainly pain and nocioceptive activity could be a factor influencing neuromuscular activation patterns in the impingement group. The impingement group did demonstrate higher VAS scores post-test than pre-test, however none complained of pain during testing and the post-test sensation was described primarily as discomfort or fatigue rather than pain. In addition there was no correlation observed between the volume of the external rotation strength relief map and the Nirschl tendinosis pain scale rating or the pre or post VAS scales. It is also possible that the neural inhibitory influence may be related to an attempt to limit high magnitude moment generation in order to preserve joint stability. The neuromuscular IR and ER strength patterns demonstrated for the impingement group in this study would be expected to adversely affect glenohumeral joint stability. The rotator cuff musculature have an integral role in providing glenohumeral joint stabilization (Inman et al. 1944, Kronberg et al. 1990, Poppen and Walker 1976, Saha 1971). The role of the rotator cuff in preventing upward translations of the head of the humerus during humeral abduction has been demonstrated by several investigators (Inman et al. 1944, Kronberg et al. 1990, Poppen and Walker 1976,1978, Sharkey and Marder, 1995). Saha (1971) and more recently others (Cain et al. 1987, Itoi et al. 1994, McKernan et al. 1990) have demonstrated the role of the posterior rotator cuff (infraspinatus and teres minor) as a neuromuscular component responsible for providing anterior glenohumeral joint stabilization (Cain et al. 1987, Itoi et al. 1994, McKernan et al. 1990). Cain et al. speculated that the posterior rotator cuff had the capacity to decrease strain on the anterior structures of the glenohumeral joint by generating a posterior translation force on the humeral head during external rotation of the shoulder. EMG has provided additional insight into the function of the rotator cuff. Studies of the pitching motion have demonstrated peak activity of the infraspinatus and teres minor in late cocking (abduction and maximum external rotation) when they are acting to generate a external rotation moment about the glenohumeral joint and provide stabilization (Jobe et al. 1983). The posterior cuff muscles are also highly active during the follow-through phase (after release of the ball) when they are acting to generate eccentric moments to slow the upper arm segment and maintain joint stability (Jobe et al. 1983). EMG activity of pectoralis major, subscapularis and latissimsus dorsi has been shown to be substantial during late cocking when they are generating eccentric moments to slow external rotation. These muscles are also highly active during the acceleration (from late cocking position until release of the ball), and follow-through phase of the baseball pitch when they are acting to generate a concentric internal rotation moment about the shoulder joint. Activities in which the internal rotator musculature is working to accelerate the upper arm and the external rotators are acting to decelerate the upper arm occur not only during the extreme conditions of a baseball pitch, but are common in many sporting (swimming, tennis, volleyball, martial arts) and work-related activities (hammering, grocery bagging etc.). The present study has demonstrated an "imbalance" between the maximal moment generation capacity during concentric internal rotation and eccentric external rotation. The strength relief maps reveal that these changes occur primarily in the 45° range of motion prior to the forearm horizontal position. Given the functional roles of the internal and external rotation musculature, the demonstrated decreased DCR (eccentric ER/concentric IR) in the impingement group would result in a decreased ability to maintain glenohumeral joint stability during internal rotation movements. The deficit of concentric external rotation and eccentric internal rotation moment generation in the forearm vertical position may be related to pain mediated neural inhibition in this relative "position of impingement". It may also represent a compensatory mechanism in an attempt to control joint stability.

It has previously been speculated that anterior and superior translation of the humerus on the glenoid fossa resulting from decreased neuromuscular joint stabilization capability, may lead to cuff tendon impingement against the coracoacromial arch (Perry 1983, Matsen and Arntz 1990a). Recently Jobe and Pink (1994) have reported impingement of the undersurface of the supraspinatus and infraspinatus against the posterosuperior glenoid labrum in the young overhead throwing athlete. Jobe and Pink attribute this "inside impingement" to anterior capsule laxity and the effect of action of the posterior deltoid unopposed by the rotator cuff. The results of this study would support decreased neuromuscular stabilization of the humeral head as a possible factor leading to rotator cuff impingement.

XV. Conclusion

The purpose of this study was to determine resultant shoulder joint moment for internal and external rotation ($SJM_{IR/ER}$) through a velocity spectrum and range of motion in a group of asymptomatic male subjects and group of male subjects with impingement syndrome. This study concludes that subjects with impingement syndrome exhibit neuromuscular patterns and magnitudes of shoulder internal and external rotation strength at variance with those observed in asymptomatic subjects.

Strength assessment was performed using an isovelocity dynamometer (Kin-Com, Kin-Com, 500 H, Chattecx Corporation, Hixson, TN). The specific strength testing protocol designed for this study proved to be highly reliable in providing reproducible results in the control group. The impingement group was able to complete the strength testing without difficulty, and tolerated it well. The strength parameters of peak moment, work and angle of peak moment occurrence, as well as a 2D relief map depicting moment generation for a range of motion and ± 180°/s velocity spectrum were utilized for analysis. These strength relief maps provided additional insights into the pattern and magnitude of strength differences between the control and impingement groups throughout the sampled range of motion and velocity spectrum. The strength relief maps allowed for rapid visual assessment as well as quantitative analysis of the sampled strength domain.

Conclusions of this study are as follows:

1. The impingement syndrome group exhibited concentric and eccentric SJM_{ER} strength deficits. The SJM_{ER} eccentric deficit was greater in magnitude and scope than the concentric deficit. Strength relief map analysis identified a SJM_{ER} deficit throughout 40% of the difference map area. The deficit encompassed slow concentric and all eccentric velocities. The eccentric deficit was maintained throughout the 0 - 70° range of motion.

2. The impingement syndrome group did not demonstrate a SJM_{IR} strength deficit on analysis of peak moment and work data. Analysis of the strength relief maps identifed a

region of increased concentric strength and decreased eccentric strength in the impingement group.

3. The impingement syndrome group demonstrated a decreased dynamic control ratio (eccentric SJM_{ER} /concentric SJM_{IR}). The strength relief maps demonstrated that the regions of decreased eccentric SJM_{ER} and increased SJM_{IR} were overlapping in terms of the range of motion in which they occurred.

4. Eccentric SJM_{IR} substantially exceeded concentric moment in both the control and impingement group. Eccentric SJM_{ER} equalled (at slow velocities) or exceeded (at high velocities) concentric moment for the control group. For the impingement group eccentric SJM_{ER} did not exceed concentric moment.

5. The control group demonstrated a decrease in magnitude of concentric $SJM_{IR/ER.}$ with increasing angular velocity. Eccentric SJM_{ER} in the control group was maintained across velocity. The impingement group did not demonstrate a velocity dependent decrease of concentric SJM_{ER} with increasing angular velocity. A velocity dependent increase of eccentric SJM_{ER} with increasing angular velocity was identified in the impingement group.

6. Angle of peak moment occurrence increased (i.e. occurred later in the range of motion) with increasing concentric angular velocity for internal and external rotation for both the control and impingement group. Angle of peak moment occurrence was maintained across the eccentric velocity spectrum for the control and impingement group for internal rotation and control group external rotation. The impingement group showed a tendency for the angle of peak moment occurrence to be achieved later in the range of motion with increasing eccentric angular velocity. Eccentric external rotation angle of peak moment occurred earlier in the range of motion for the impingement group than the control group.

7. The impingement group demonstrated limitation of active shoulder internal rotation range of motion.

XVI. Future Recommendations

Although this study has not determined whether the strength differences observed in subjects with impingement syndrome represent a primary or secondary phenomenon, it is probable that the persistence of these neuromuscular patterns will contribute to ongoing symptoms and predispose the individual to further injury. It is felt a rehabilitation program designed to address the specific strength and range of motion deficits identified in this study will benefit subjects with impingement syndrome. The goal of the rehabilitation program should be to achieve functional dynamic (neuromuscular) stability of the glenohumeral joint primarily by addressing the external rotation (posterior rotator cuff) eccentric strength deficit. Stretching of the posterior capsule may be beneficial. It is recommended that the strengthening program include both concentric and eccentric modes of muscle action and progress to encompass several planes of shoulder joint motion. Force progression should be in keeping with the demonstrated moment angular velocity relationship for voluntary contractions (i.e. maximum isometric > eccentric > concentric). Finally, the program should be carefully progressed to match as closely as possible the functional demands of the individual. The principles of specificity of training dictate that the strengthening program should include activities that are similar in the speed of motion, range of motion, mode of contraction, pattern of muscle activation, and number and sequence of moving body segments to the desired functional activity.

Although significant differences were detected between the control and impingement groups in this study, the power of the study could be improved by increasing the impingement group sample size. It is felt the differences between groups in terms of magnitude and scope of the external rotation deficit would become more apparent with an increase in power thereby adding weight to the conclusions of the study. It is also possible that the difference in internal rotation strength detected on analysis of the strength relief maps would be detected on analysis of the peak moment and work data with a more powerful study.

Fatigue data for shoulder internal and external rotation was not included in the present study. Beach et al. (1992) have demonstrated a correlation between decreased endurance ratios of shoulder abduction and external rotation and shoulder pain. In addition Jobe (1990) has made the clinical observation that pitchers with shoulder instability experience greater dysfunction with fatigue. Fatigue data may therefore be an important to consider in the evaluation of patients with shoulder pathology. Assessment of endurance ratios during various shoulder movements in subjects without shoulder pathology has not been widely studied and has been reported only for concentric muscle action (Maddux 1989, Nicholas et al. 1989). There is a need to establish reliable endurance protocols and to provide more baseline information regarding endurance values for both concentric and eccentric muscle action. The correlation of the various endurance values to objective tests of function would also be an area for future research.

The present study has identified neuromuscular patterns of shoulder strength in subjects with impingement syndrome at variance with those observed in subjects without shoulder pathology. A prospective, therapeutic intervention study designed to address the observed strength deficiencies in the impingement group would provide information which would assist in the delineation of the most effective and efficient rehabilitation program for this group.

Shoulder pain and disability is commonly encountered in the athletic population (i.e. baseball pitchers, swimmers, tennis players) (Jobe and Bradley 1988, McMaster and Troup 1993) and an increased prevalence of shoulder disability has been demonstrated in certain occupational groups (Sommerich et al. 1993). An examination of shoulder strength in these high risk populations using the comprehensive strength analysis employed in the present study, may be able to identify shoulder strength patterns which are likely to predispose the development of impingement syndrome. Based on this information, a prospective study could be performed to evaluate the effect of a preventative exercise program in a group at high risk for developing shoulder impingement syndrome.

XVII.References

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XVIII. Appendix A - Power Analysis

Power Analysis

The number of subjects proposed for the study was determined by means of a power analysis. The number of subjects needed in each group (normal controls and subjects with rotator cuff disease) is dependent upon the variability of the parameter being assessed (peak torque, total work etc. for internal or external rotation) and the difference between the two groups considered to be clinically significant (Hassard, 1991). The values used for the power equation were obtained by a review of the relevant literature and were based on the isovelocity parameters of peak torque and total work (where available) for external rotation obtained in normal populations without rotator cuff disease (Ivey et al. 1985, Hageman et al. 1989, Cahalan et al. 1991, Kuhlman et al. 1992). The values for external rotation rather than internal rotation were used for these calculations as it was hypothesized that there would be no significant difference between the two groups in terms of internal rotation measures and ensuring detection of external rotation differences was thought to be critical. In calculating the power equation a difference of 20% between the two groups in terms of external rotation peak torque was considered to be clinically significant (Sapega, 1990). For this study the power index was set at 3.28 (.05 alpha for one-tailed test and .05 beta) for a power of 95%. Various calculations were made using relevant data from previous studies and the sample number obtained using these figures ranged from 13 to 37 with an average of 24 required in each group. Sample calculations based on results by Hageman et al. (1989) for male subject eccentric external rotation values, Kuhlman et al. (1992) for male subject external rotation total work follows and Cahalan et al. (1991) for concentric external rotation peak torque (Nm) in male subjects follow. The equation for determining sample size for studies involving 2 different groups (as described in Hassard, 1991) was used.

$n = 2\,(\text{PI pop.S.D}/u_1 - u_2)^2$

Based on the study by Hageman et al. (1989) for eccentric external rotation peak torque (Nm) in male subjects at 60 °/s :

$n = 2\,(3.28 \times 6.9/6.82)^2$

$= 22.02$ or 23 subjects required in each group

Based on the study by Kuhlman et al. (1992) for total work (J) for concentric external rotation in male subjects at 90 °/s:

$n = 2\,(3.28 \times 43.9/57.74)^2$

$= 12.43$ or 13 subjects required in each group

Based on the study by Cahalan et al. (1991) for concentric external rotation peak torque (Nm) in male subjects at 180 °/s:

$n = 2\,(3.28 \times 4/3.8)^2$

$= 23.84$ or 24 subjects required in each group

Based on the above calculations it was decided to attempt to recruit 20 subjects for each group for this study.

XIX. Appendix B - Nirschl Pain Scale

Nirschl Pain Scale

Tendinosis Phases of Pain

Phase I Mild pain after exercise activity, resolves within 24 hours

Phase II Pain after exercise activity, exceeds 48 hours, resolves with warm-up

Phase III Pain with exercise activity that does not alter activity

Phase IV Pain with exercise activity that alters activity

Phase V Pain caused by heavy activities of daily living

Phase VI Intermittent pain at rest that does not disturb sleep. Pain caused by light activities of daily living.

Phase VII Constant rest pain (dull aching) and pain that disturbs sleep

Reference: Nirschl, R.P. Elbow Tendinosis/Tennis Elbow, Clinic in Sports Medicine, 11(4): 851-870, 1992.

XX. Appendix C - Recruitment Letter

Letter to physio clinics and physicians

Dear Physician/Physiotherapist,

As partial fulfilment for the degree Masters of Science in Rehabilitation, I am conducting a study which will investigate the strength of shoulder internal and external rotation in subjects with shoulder impingement syndrome.

I am requesting your assistance in providing subjects with shoulder impingement syndrome who would be eligible for participation in this study. Specifically, the subjects should be otherwise healthy males between the ages of 20-45 who have been diagnosed with stage 1 or 2 rotator cuff disease. Their symptoms should be chronic in nature (< 12 weeks). Recreational athletes are eligible for inclusion in the study, however subjects involved in competitive/professional athletic activity involving a large component of overhead activity are excluded from participation.

Upon referral, all subjects will undergo a screening examination to determine their eligibility for the study. Those subjects accepted into the study will have shoulder internal and external rotation strength assessed on a Kin-Com Isovelocity Dynamometer. Strength testing will be performed during both concentric and eccentric muscle action and at four separate velocities. Subject comfort and safety was considered in choosing the specific testing protocol of this study and they will be advised that testing will be discontinued upon any report of pain. The project has been approved by the Human Ethic Committee of the Faculty of Medicine. There are no major documented risks associated with the project and confidentiality will be maintained. If you wish to have more detail regarding test protocol please do not hesitate to contact me.

XXI. Appendix D - Paraphrase & Informed Consent Form

Paraphrase and Informed Consent Form
"An Assessment of Internal & External Shoulder Rotation Strength
in Patients with Rotator Cuff Disease"
University of Manitoba 1994

PARAPHRASE

The occurrence of shoulder disorders is a significant problem in workers who predominantly use their upper limbs and in certain types of athletes. Our understanding of the mechanisms or causes of these shoulder disorders is limited. As such our ability to diagnose and prescribe treatments or rehabilitation programs for individuals suffering from shoulder disorders is also limited. This study is aimed at revealing more information about shoulder disorders by assessing the strength of some of the primary shoulder muscles. This information will assist in the development of effective and efficient rehabilitation programs for people with shoulder disorders.

Procedure

As a subject in this study, you will be asked to undergo a screening examination including some tests to measure the range of motion about your shoulder.
After the screening examination during the same day you may be asked to perform a test on special device for measurement of the strength and endurance of your muscles surrounding your right shoulder. This test will require that you provide maximal effort during the procedure. The muscle performance test will require 1 hour to complete.
After analysis of the test results, you may be asked to perform an additional muscle performance test on a separate day. This test will require 1 hour to complete.

Risks

There are no documented risks associated with the screening examination although some discomfort or pain may be temporarily experienced.

The risks associated with the muscle performance test are minimal including;

- After maximal exertion of the muscles surrounding the shoulder you may experience some discomfort which may last up to 72 hours after the test. This is a normal consequence of exercise and will resolve on its own.

- Although there have not been any published reports of muscle damage during these tests, there is a remote possibility that a tear in the muscle may occur. Similar tests have been performed on athletes and workers with and without shoulder disorders, even after surgery of the shoulder without documented damage to the muscles.

- A certain amount of discomfort may be associated with the test (as with any form of exercise) however if obvious pain arises at any instance during the test, the test will be discontinued.

You will not be identified in any published report of the results of this study. Your participation in this study is voluntary, and you are free to withdraw at any time without prejudice.

You will not receive reimbursement for participation in this study, nor will you be responsible for any costs directly related to this study.

If you have any questions or do not understand any aspect of this form, please contact;

Dr. Dean Kriellaars, School of Medical Rehabilitation
University of Manitoba

787-2289

Paraphrase and Informed Consent Form
"An Assessment of Internal & External Shoulder Rotation Strength
in Patients with Rotator Cuff Disease"
University of Manitoba 1994

CONSENT FORM

I have read the paraphrase and understand the nature of the study including the potential benefits and risks. I have satisfied any questions that I may have had with respect to this study. I agree to participate in this study and abide by the procedural requirements.

I understand that I may withdraw from the study at any time.

______________________________ ____________
Subject Date

______________________________ ____________
Witness Date

______________________________ ____________
Investigator Date

XXII. Appendix E - Screening Form

Screening Examination for Subjects with Impingement Syndrome

Name: ________________ Date:________________
Date of Birth:__________ Hand Dominance: R L
Affected Shoulder: R L Diagnosis:
Height:____Weight: __________

Length of time since onset: < 12 weeks >12 weeks

History of Shoulder Problem:
Date of onset:_______ Mechanism of onset: Acute injury___Insidious____

Treatments and investigations to date:
- Physiotherapy Yes No
- Medications
  - for shoulder Yes No
  - other Yes No
  - Corticosteroid injections Yes No
- Investigations (MRI, X-Rays, Yes No
  ultrasound, arthrogram etc.
  Impingement test)
- Other Yes No
- If "yes" to any of above questions - give specifics:

Current pain intensity: (VAS Form and Nirschl Pain Rating Scale)

Any feeling of instability in shoulder?:

Other symptoms (i.e. numbness, paraesthesia)- specify:

Relevant Past History:

Has subject ever experienced or been diagnosed with the following:

- previous right arm injuries or pathology Yes No
- frank dislocation of right arm Yes No
- other bone or joint problems i.e. arthritis Yes No
- cardiovascular problems (dizziness, Yes No
  hypertension, pain in chest)
- respiratory problems Yes No
- other (specify)

Physical Activity Level:

Has/does the subject:
    changed activity level in past 5 years Yes No
    take part in upper extremity weight training Yes No
        If "yes" - # of times/week
    been involved in competitive or professional Yes No
    upper extremity athletic activity
If "yes" to any of above questions - specify

Examination:(Modified from ASES shoulder assessment form 1993)

Scan: Cervical Spine, R) A/C, S/C joints, Elbow, Wrist and Hand
Within Normal Limits Yes No
specify (1 line)
Shoulder:

Range of Motion (see ROM form)

Signs
Tenderness:
    greater tuberosity Yes No
    lesser tuberosity Yes No
    anterior acromion Yes No
    other tenderness (list) Yes No
Swelling Yes No
    Specific tests
    Drop arm test Yes No
Impingement I (passive forward Yes No
elevation in slight internal rotation)
Impingement II (passive internal Yes No
    rotation with 90 degrees flexion)
Impingement III (90 degrees active abduction Yes No
    - classic painful arc)

Atrophy - location Yes No
Deformity : describe Yes No
Anterior apprehension
Relocation test positive Yes No
(Silliman and Hawkins 1993)

    Strength (right arm)
                Painful Grade (0-5)
    Forward elevation Yes No
    Abduction Yes No
    External Rotation Yes No

(arm at side)
Internal Rotation Yes No
(arm at side)

Other physical Findings:

Examiner's name: ____________________

XXIII. Appendix F - Range of Motion Form

Right Shoulder Range of Motion

(Measured with standard goniometer)

Name: _______________Date:____________________

Forward Flexion (supine)	Active	Passive
Abduction (supine)		
External Rotation (arm at side)		
External Rotation (arm at 90° abd>)		
Cross-body adduction		
Internal Rotation (highest post anatomy reached with thumb)		
Internal Rotation (arm at 90° abd.)		

XXIV. Appendix G - Control Screening Form

Screening Questionnaire For Control Subjects

Name: _______________ Date:____________

Date of Birth:_______________Hand Dominance: R L

Height:________Weight:________

Occupation:______________

General Medical History:

Has subject ever experienced or been diagnosed with the following:

previous right arm injuries or pathology Yes No

frank dislocation of right arm Yes No

other bone or joint problems i.e. arthritis Yes No

cardiovascular problems

(dizziness, hypertension, pain in chest) Yes No

respiratory problems Yes No

other (specify)

Physical Activity Level:

Has/does the subject:

changed activity level in past 5 years Yes No

take part in upper extremity weight training Yes No

If "yes" - # of times/week

been involved in competitive or professional Yes No

upper extremity athletic activity

If "yes" to any of above questions- specify