

**Glenohumeral Peak Torques and Strength Ratios Relationship with
Injury in Adolescent Female Volleyball Athletes**

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Bret G Freemyer

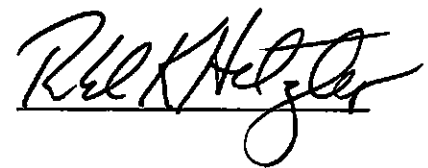
Thesis Committee:
Iris F. Kimura, Chairperson
Ronald K. Hetzler
Nathan Murata

We certify that we have read this thesis and that, in our opinion, it is satisfactory in scope and quality as a thesis for the degree of Master of Science in Kinesiology.

THESIS COMMITTEE


Chairperson





APPROVALS

We certify that we have read this thesis and that, in our opinion, it is satisfactory in scope and quality as a thesis for the degree of Master of Science in Kinesiology.

THESIS COMMITTEE


Chairperson





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ABSTRACT

Context: Research of adolescent volleyball athletes' isokinetic strength is nonexistent.

Objective: To evaluate the relationship between shoulder injuries, anthropometric characteristics, and shoulder internal and external rotation strength.

Design: Multivariate analysis of variance and covariance design with two conditions: (1) skill level and (2) previous shoulder injury.

Setting: Human Performance and Athletic Training Labs at the University of Hawai'i, Manoa.

Subjects: 38 adolescent club volleyball athletes, 10-15 years of age (mean 13.02 +/- 1.60).

Main Outcome Measures: Concentric and eccentric peak torque of the shoulder internal and external rotators on a Biodex System 3 Dynamometer at $60^{\circ}\cdot s^{-1}$.

Results: Older and more skilled athletes had significantly higher peak torque measurements in concentric and eccentric internal/external rotation compared with the athletes of the younger and lesser skill levels. No differences existed between the healthy and injured subjects in terms of peak torque produced. Strength ratios were not different across skill levels, however injured subjects produced significantly lower eccentric internal rotation/concentric external rotation ($p \leq 0.02$) than healthy subjects.

Conclusions: Differences in the internal and external shoulder rotator strength ratios appear to be related to injury prevalence more than absolute strength. Shoulder dysfunction related to strength ratio deficits may also exist in adolescent volleyball athletes.

Keywords: shoulder strength, strength ratios, isokinetic, glenohumeral internal/external rotation.

PART I

INTRODUCTION

Glenohumeral pathologies are among the most common injuries suffered by volleyball athletes and often contribute to long delays in return to training or competition¹⁻⁶. These injuries are often associated with frequent spiking and serving motions that require dynamic stabilization to maintain glenohumeral integrity^{1-4,6}. Much of this stability is provided by the rotator cuff muscles acting eccentrically during the acceleration, deceleration, and follow through phases of striking to compress the humeral head⁷.

Dynamic stabilization and compression of the humeral head in the glenoid fossa during spiking and serving is maintained by active and passive mechanisms. As the upper extremity accelerates through its range of motion, the supraspinatus, infraspinatus and teres minor eccentrically resist translation of the humeral head and assist in deceleration of the moving limb⁷⁻¹¹. Consequently, rotator cuff weakness allows increased stress on the ligamentous stabilizers of the shoulder leading to detrimental translation of the humeral head¹². Conversely, laxity in the passive stabilizers increases the workload of the rotator cuff leading to fatigue and malfunction of the dynamic stabilizers¹². Previous studies have demonstrated the relationship between rotator cuff pathologies and strength deficits in the glenohumeral and scapular muscles of injured subjects¹³⁻¹⁶. However, these studies primarily involved older, non-athletic subjects^{13, 15, 16}.

Preventing shoulder injuries through the appropriate maintenance of rotator cuff strength is of particular concern in adolescent populations due to skeletal immaturity.

The added demands of sports participation can lead to acute or overuse injuries in developing tissues^{10, 17-19} and long-term or permanent disability of the affected structures¹⁷. Unfortunately, research that involves the relationship between strength characteristics and injury in adolescent athletes is limited²⁰⁻²². Additionally, previous isokinetic studies using volleyball athletes have not examined differences in rotator cuff strength between injured and non-injured shoulders in young adolescents^{21, 23-26}. Therefore the purpose of this study was to isokinetically compare the rotator cuff strength of adolescent volleyball athletes with and without a history of shoulder injury.

METHODOLOGY:

Subjects

Subjects were 38 highly-trained, competitive female club volleyball players ranging in age from 10-15 years of age (mean 13.02 ± 1.60). Prior to study participation, subjects completed a medical and injury history questionnaire to screen for contraindications to study participation, including a history of injury to either upper extremity within the last six months. Parents and subjects completed institutional human subjects committee approved informed consent and assent forms. None of the subjects reported previous experience with isokinetic testing. Characteristics of subjects and groupings by skill level (Under [U] 12, U13, U14 or U15 year old teams) are presented in Table 1. Subject skill level was determined based on the age-level of the team to which they were assigned by the club's coaching staff. Subjects were generally assigned to teams of their respective age group, however, a few highly skilled athletes competed on teams in a higher age division.

Table 1. Subject Characteristics by Skill Level (Mean \pm SD)

	U12 n= 11	U13 n=7	U14 n=8	U15 n=12	Total n=38
Age	11.08 \pm 0.70	12.57 \pm 0.53	14.00 \pm 0.00	14.42 \pm 1.65	13.00 \pm 1.60
Weight (kg)	49.67 \pm 8.68	53.77 \pm 4.01	57.97 \pm 11.05	64.24 \pm 12.02	56.43 \pm 7.42
Height (cm)	156.5 \pm 9.20	163.7 \pm 10.67	167.50 \pm 4.82	166.7 \pm 4.41	163.3 \pm 11.14
Total limb length (cm)	52.17 \pm 4.44	55.68 \pm 3.77	56.32 \pm 2.74	57.04 \pm 3.36	55.15 \pm 4.08
% BF	25.23 \pm 5.00	26.00 \pm 2.63	24.52 \pm 6.50	27.70 \pm 5.29	25.90 \pm 5.12

Total Limb Length= measurement of distance from Acromialclavicular joint to Radial Styloid Process
% BF= body fat percentage by two site skinfold estimation.

Procedures

All data were collected by the same Board of Certification (BOC) Certified Athletic Trainer (ATC). Subjects completed injury and pain questionnaires relative to injury history, pain, and time lost due to striking arm glenohumeral pathology or pain during the previous six months. These data were used to divide subjects into healthy and injured groups. Subjects who reported shoulder pain at the time of testing were excluded from the study. All anthropometric and isokinetic peak torque data were collected during a single test session. Anthropometric measures included height, weight, body composition and striking arm length. Body composition was estimated via calf and tricep skinfolds using Lange Skinfold Calipers (Body Fat % = $0.610 \sum \text{Skin Folds} + 5.0$) (Cambridge Scientific Industries, INC) ²⁷.

Striking arm isokinetic internal and external shoulder rotation peak torque data in Newton meters (Nm) were collected using a Biodex system 3 (Biodex Medical Systems, Inc. Shirley, NY). The Biodex system 3 dynamometer (Biodex) has been found reliable and accurate in measuring glenohumeral internal and external rotation concentrically and eccentrically ^{28,29}. The Biodex was calibrated following every fifth subject. Peak torque data were collected at $60^{\circ}\cdot\text{s}^{-1}$ via two sets of five maximal repetitions of internal and external shoulder rotation, first concentrically and then eccentrically. This speed was chosen to ensure subject comfort and safety and due to reported decreases in validity and reliability in Biodex results at higher velocities ³⁰. Sets were separated by a five-minute rest period. Prior to collection of peak torque data, subjects completed warm-up and familiarization trials consisting of sub-maximal efforts and a single maximal effort in concentric and eccentric modes. Subjects were tested in a seated modified neutral

position of 90° of elbow flexion, 30° glenohumeral joint flexion and 30° abduction with stabilization straps across the hips and upper body. This position was chosen over the 90° of glenohumeral abduction position used in other studies ^{21, 23-26} because of the reduced risk of anterior instability associated with the modified neutral position ³¹. Subjects were given verbal instructions regarding testing procedures and the importance of providing maximal effort during testing. No verbal or visual feedback or encouragement was given during the isokinetic testing protocol. All subjects completed all phases of data collection with out pain or discomfort in the shoulder.

Data Analysis

Isokinetic peak and mean torque data were collected for each of the following measures: Concentric internal rotation (Con_{ir}), Concentric external rotation (Con_{er}), Eccentric internal rotation (Ecc_{ir}) and Eccentric external rotation (Ecc_{er}). Based on peak torque values for each measure, the following functional ratios were derived for each subject in accordance with previous research ^{20, 22, 26, 32-40} Con_{er} / Con_{ir}, Ecc_{er} / Ecc_{ir}, Ecc_{er} / Con_{ir} and Ecc_{ir} / Con_{er}.

All statistical analyses were performed with SAS (version 9.1.3; SAS Inc, Cary, NC). Data were analyzed via multiple multivariate analysis of covariance (MANCOVA) to control for significant interactions due to limb length differences between subjects. Following initial analysis, which revealed no significant effect of the covariate limb length on any measure, individual Analysis of Variance (ANOVA), and Tukey HSD test were used for subsequent post hoc testing for each of the strength and ratio measures. The Alpha level was set at $p \leq 0.05$.

RESULTS

Twenty-nine of thirty-eight subjects denied pain or pathology to the striking shoulder at least 6 months prior to testing. The remaining nine subjects were identified as “injured” (Two from U12, two from U14, and five from U15). Results of MANCOVA testing revealed that covariate limb length differences between subjects did not significantly affect any of the strength or ratio measures.

Strength measure and ratio differences between skill levels

Analysis revealed significant differences between skill levels for Con_{er} , Con_{ir} , Ecc_{er} , and Ecc_{ir} . Tukey HSD test identified the U15 and U14 were significantly higher in all four strength measures than U12 ($p < 0.05$). Additionally, the U15 Con_{er} was significantly higher than U13 ($p < 0.05$). No significant differences were found between skill levels for any of the four ratio measures. Table 2 shows the peak torque by skill level.

Table 2. Peak Torque (Nm) of Isokinetic Strength Measures by Skill Level (Mean \pm SD)

		U12 n=11	U13 n=7	U14 n=9	U15 n=11
Concentric	ER	11.85 \pm 3.37	13.99 \pm 3.14	16.02 \pm 2.85*	18.03 \pm 2.84*†
	IR	16.00 \pm 5.83	20.71 \pm 3.42	22.48 \pm 5.47*	24.79 \pm 4.21*
Eccentric	ER	16.21 \pm 5.17	18.49 \pm 5.21	27.00 \pm 6.91*	26.17 \pm 7.43*
	IR	22.17 \pm 4.76	28.90 \pm 4.45	35.49 \pm 6.90*	35.17 \pm 6.52*

ER = External Rotation; IR = Internal Rotation

* Significantly higher than U12 ($p < 0.05$)

† Significantly higher than U13 ($p < 0.05$)

Strength measure and ratio differences between injury history groups

No significant differences were found between healthy and injured groups for any of the four strength measures. However, differences existed between groups in the Ecc_{er}/Con_{ir} and Ecc_{ir}/Con_{er} ratios. Injured subjects produced significantly lower Ecc_{ir}/Con_{er} peak torque ratios than healthy subjects ($p < 0.05$). The Ecc_{er}/Con_{ir} peak torque ratios of injured subjects were also lower, at a level approaching significance ($p = 0.08$). The Con_{er}/Con_{ir} and Ecc_{er}/Ecc_{ir} ratios for healthy subjects were not significantly different than their healthy counterparts. Strength ratio data for healthy and injured subjects are displayed in table 3.

Table 3. Strength Ratios by Injury History (Mean \pm SD)

Ratio	Healthy	Injured
Con_{er} / Con_{ir}	0.75 \pm 0.30	0.79 \pm 0.20
Ecc_{er} / Ecc_{ir}	0.74 \pm 0.14	0.68 \pm 0.13
Ecc_{ir} / Con_{er} *	2.16 \pm 0.44	1.77 \pm 0.39
Ecc_{er} / Con_{ir}	1.14 \pm 0.34	0.92 \pm 0.29

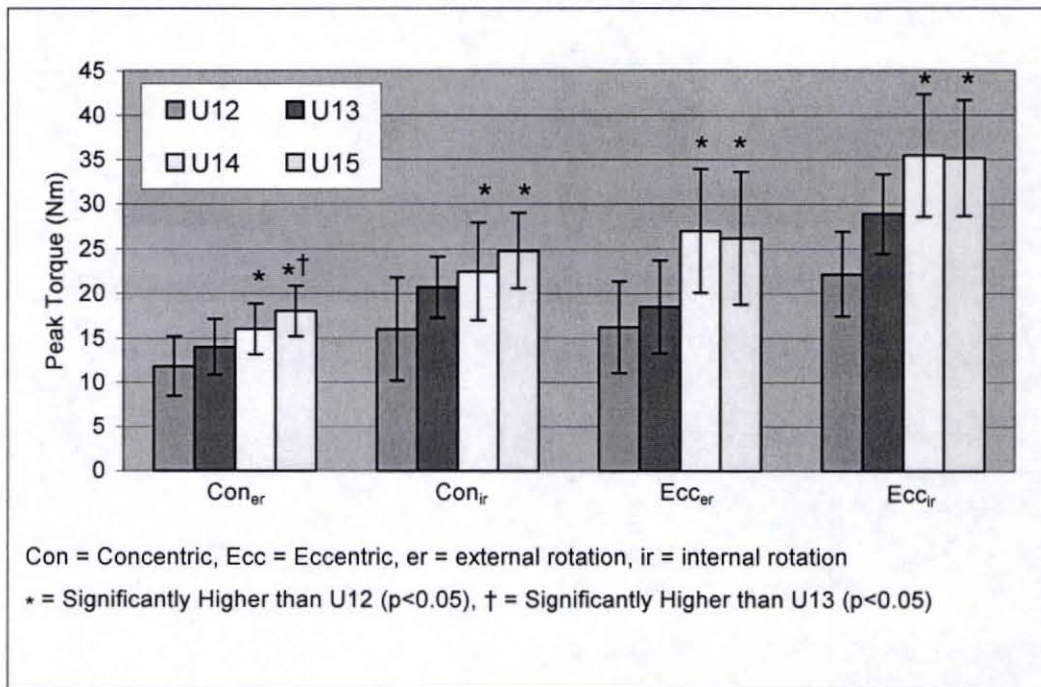
Con = Concentric; Ecc = Eccentric; er = External Rotation; ir = Internal Rotation

* Statistically significant difference between healthy and injured ($p < 0.05$)

DISCUSSION

Differences in peak torque for both concentric and eccentric glenohumeral internal and external rotation were not significant between injury status groups. This finding appears to be in opposition to conventional thinking, which advocates the development of rotator cuff strength to prevent or alleviate shoulder injuries. Although no differences in peak torque were found between healthy and injured groups, peak torque for U14 and U15 subjects were significantly higher than U12 and U13 (Figure 1). This is expected based on differences in physical development between skill levels related to height, muscle strength, and sports specific skill.

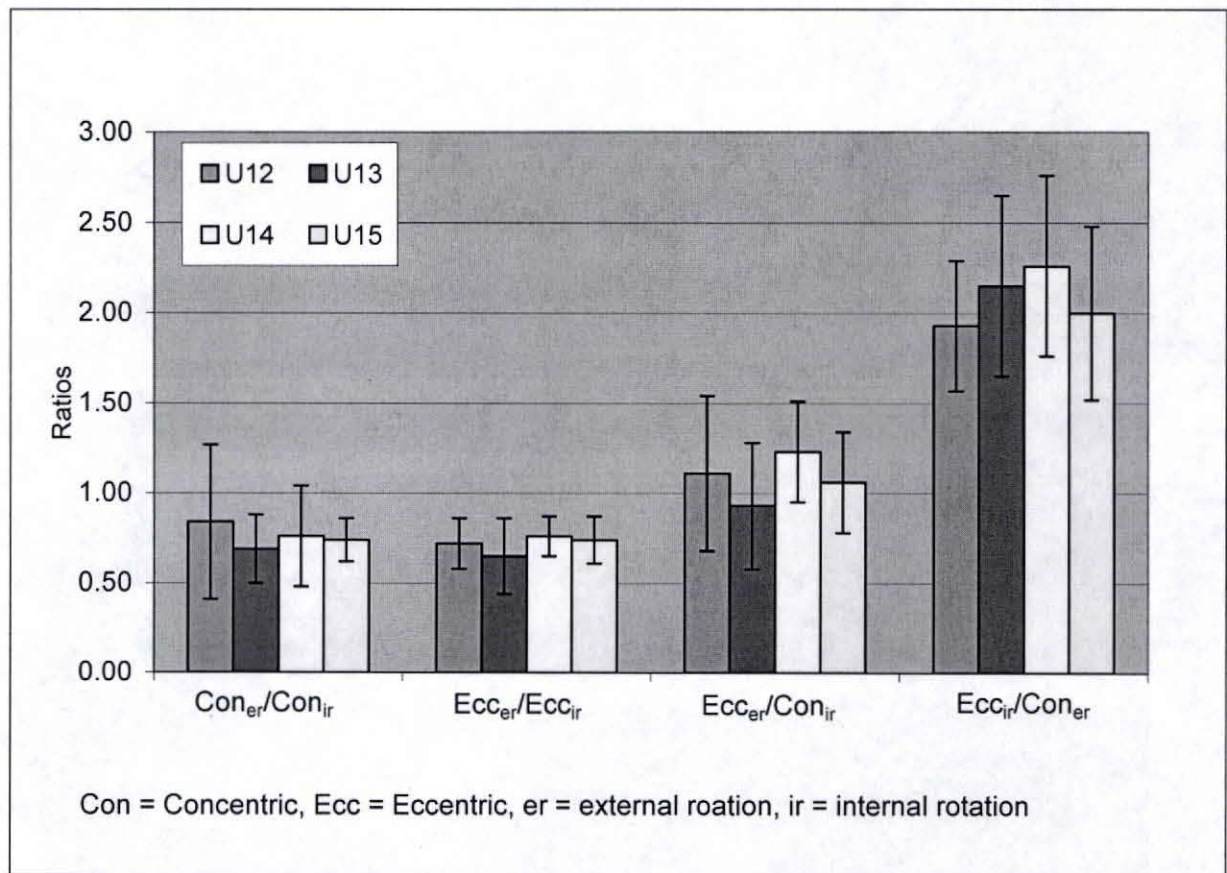
Figure 1. Mean (\pm SD) Strength Measures by Skill Level



Additionally, no differences of the strength ratios were found between skill levels (Figure 2). These findings are similar to those of Ellenbecker and Roeter²⁰ who reported no differences in strength ratios of elite junior tennis athletes based on age. These

findings have important clinical ramifications for identification of individuals at risk for developing shoulder injuries since, weakness of the rotator cuff muscles has been associated with the development of shoulder pathologies, and neither raw strength or skill level were predictive of injury history in our study.

Figure 2. Mean (\pm SD) Strength Ratios by Skill Level



In our study, no differences in Con_{er}/Con_{ir} peak torque ratios were found between injured and healthy subjects. These ratios have been previously reported to range from 0.57 to 1.19^{20-25, 32-38, 40-42} and external to internal concentric ratios of at least 2:3 to 3:4 (0.66 to 0.75) are recommended for the prevention of shoulder injuries⁴². Interestingly,

healthy subjects in our study produced ratios of at least 0.75 while injured subjects produced ratios of 0.79 exceeding the recommended range (15) (Figure 3). Therefore, despite the widespread use of Con_{er}/Con_{ir} ratios for assessing and comparing shoulder strength profiles, our findings indicate that this ratio is not a valuable criteria for identification of adolescent females at risk for shoulder pathologies (figure 3).

Results of previous studies have suggest that functional strength ratios may be the most appropriate indicator of risk for shoulder pathologies ^{11, 36, 38}. Based on the function of the rotator cuff muscles, the spiking and cocking movements in our study are represented by the Ecc_{er}/Con_{ir} and Ecc_{ir}/Con_{er} ratios, respectively. Injured subjects produced significantly lower Ecc_{ir}/Con_{er} (Cocking) ratios (1.77 ± 0.39 , $p < 0.05$) than healthy subjects (2.16 ± 0.44). Additionally, though not significantly different, group mean Ecc_{er}/Con_{ir} (Spiking) ratios were lower in injured than in healthy subjects at 0.92 ± 0.29 and 1.14 ± 0.34 , respectively (Figure 3).

The relationship between decreased cocking ratio and injury in our subjects may appear difficult to explain when evaluating the ballistic nature of spiking compared to the cocking motion, which does not appear to subject the glenohumeral joint to the same degree of high-velocity rotational stress. However, during the cocking phase of the spiking and serving motions, the combined action of eccentric internal rotation and concentric external rotation positions the arm into 90° of elbow flexion and 90° of glenohumeral abduction with maximal external rotation. Placing the shoulder in this position may lead to suprascapular nerve compression and atrophy of the infraspinatus muscle ⁴³. This has been shown to be a common, though normally painless, pathology in volleyball athletes⁴³. However, this condition has not generally been reported in younger

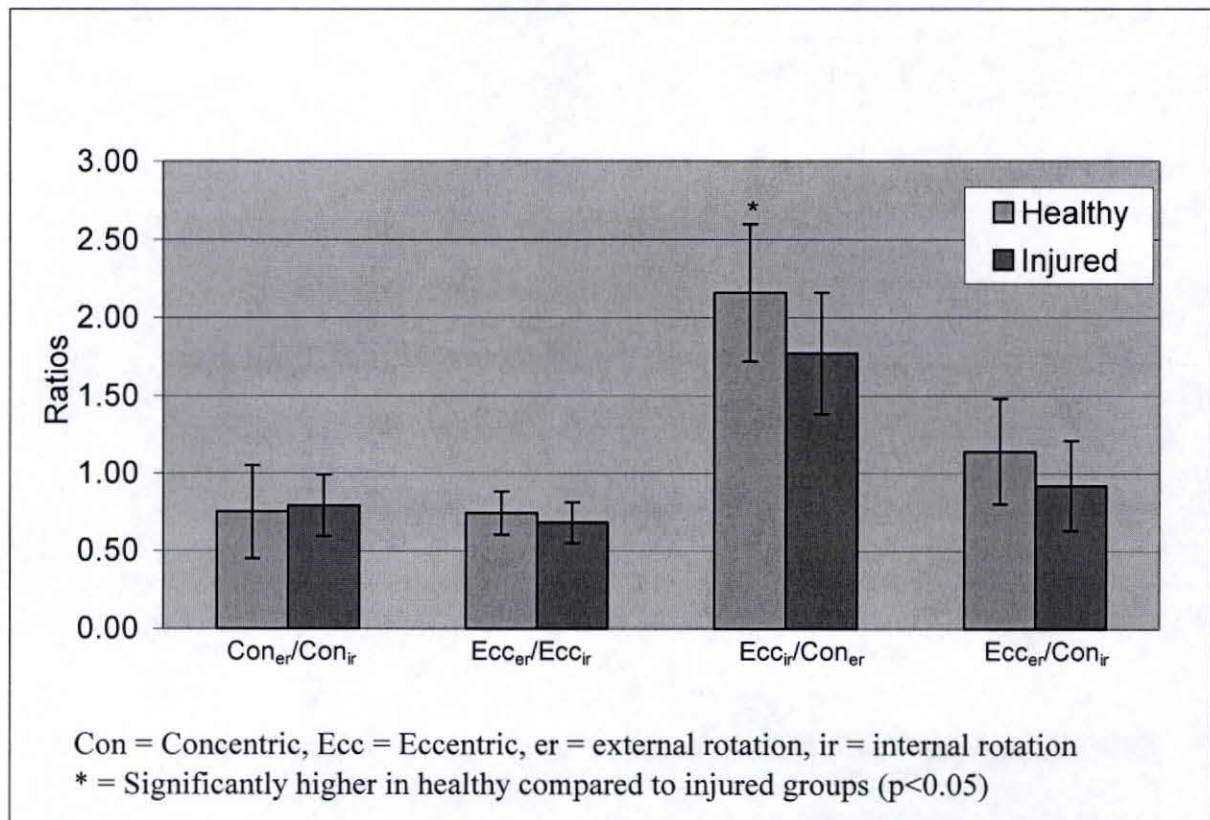
athletes and therefore, was not assessed in our subjects⁴³⁻⁴⁶. It is possible that a deficiency developed congenitally or early in sport participation may lead to increases in this condition for many volleyball athletes with a high training volume and may serve as the mechanism underlying the significantly lower cocking ratio found in our injured subjects.

The mean spiking ratio of healthy subjects in our study was 1.14, while mean spiking ratio of the injured subjects was 0.92. The lack of significance ($p = 0.08$) may be attributed to a low number of injured subjects ($n=9$) resulting in relatively low statistical power ($\beta=0.575$). This suggests that a larger sample size may have revealed a significant difference in spiking ratio between injured and healthy subjects.

The importance of an adequate spiking ratio in maintaining shoulder stability in athletes of sports involving repeated overhead motion has been reported previously^{11, 36, 38}. The below 1.0 spiking ratio found in the injured subjects in the present study support the findings of Wang et al. (2000) who reported a greater risk of injury in older individuals with spiking ratios below 1.0 combined with decreased glenohumeral flexibility. Conversely, Wang et al. (2004) reported spiking ratios below 1.0 among injured and uninjured junior volleyball athletes. They concluded that the risk factors for shoulder injury in adolescents may be less related to muscle imbalances than in adults. These authors did not report differences in spiking ratios between injured and non-injured groups thus it is difficult to determine whether lower spiking ratios were associated with injury in their adolescent subjects. Bak and Magnusson³⁸ also reported higher Ecc_{er}/Con_{ir} ratios in injured than non-injured swimmers. However, injured subjects in their study were tested while demonstrating a positive impingement sign and exhibited a

decreased concentric internal rotation peak torque with nearly equal eccentric external rotation peak torque relative to non-injured subjects. Therefore, based on the results of our study and those reported previously, a spiking ratio at, or above, 1.0 is of considerable clinical importance since athletes with spiking ratios below 1.0 appear to be at higher risk of shoulder injury.

Figure 3. Mean Strength Ratios (\pm SD) of Healthy and Injured Subjects



In our study, three of the four strength ratios were higher in the healthy group compared to the injured group. Though it is not possible to determine whether the strength ratio deficits led to the development of shoulder pain, or if the decreased strength ratios were the result of previous shoulder injury, the association between injury status and functional strength ratios appears to have important clinical consequences. Based on

our findings, relative differences in strength, between internal and external rotators of the shoulder, appear to be related to injury prevalence more so than absolute strength.

Additionally, among measures of relative strength differences in the shoulder, functional measures, such as the cocking and spiking ratio, appear to be more directly related to injury status than the traditionally used Con_{er}/Con_{ir} ratio. Further, though most rotator cuff overuse injuries present in adulthood, it appears that the strength deficits that have been associated with shoulder injury may develop earlier than previously reported. A surprisingly high number of subjects reported previous shoulder pathology (23.6%) suggesting that rotator cuff strengthening, especially to correct imbalances between the internal and external rotators, may also be indicated for injury prevention in all young adolescent females, regardless of injury history.

Part II

REVIEW OF LITERATURE

Volleyball Strength Values

Alfredson, Pietila, and Lorentzon (1998) conducted a study to assess the bilateral peak torque of shoulder internal and external rotation, concentrically and eccentrically, on the Biodex isokinetic dynamometer. Subjects were 11 non-injured Division I female volleyball athletes, age 22.0 +/- 2.6, and 11 non-active females (control) age 24.6 +/- 3.3. Concentric peak torque was measured at 60°·s⁻¹ for five repetitions and 180°·s⁻¹ for 10 repetitions, while eccentric contractions were only recorded at 60°·s⁻¹ for three repetitions. Subjects were seated and placed in 90° of both shoulder abduction and elbow flexion. Shoulder internal and external rotation peak torque was significantly higher in the dominant shoulders of the volleyball athletes compared to the control group for both concentric and eccentric contractions at 60 and 180°·s⁻¹. Con_{er}/Con_{ir} ratios in the dominant arm were reported to be 0.72 at 60°·s⁻¹ and 0.78 at 180°·s⁻¹ for the volleyball athletes and 0.69 and 0.59 for the control group, respectively.

Wang, Macfarlane, and Cochrane (2000) conducted a study to report shoulder rotator strength in elite volleyball athletes. Subjects were 10 males on the England national team. Concentric and eccentric peak torque was assessed with the subjects supine on the Kin-Com AP Muscle Testing System at speeds of 60° and 120°·s⁻¹ through 50° of internal rotation and 50° of external rotation. Con_{er}/Con_{ir} ratios were 0.67 and 0.69 for 60° and 120°·s⁻¹. Exact Ecc_{er}/Con_{ir} were not reported, however mean eccentric external rotation strength was lower than concentric internal strength during 60°/s testing.

This was attributed to strength gains in concentric internal rotation strength without eccentric external rotation strength gains. Authors state that frequent spiking may lead to degenerative changes in the rotator cuff and inability to dynamically control the shoulder during overhead activity. Wang suggested that this lower strength suggests poor shoulder control and may increase the likelihood for shoulder injuries. Six out of 10 subjects in the study reported some type of lateral shoulder pain and these low strength ratios were hypothesized as a possible predisposing factor of injury.

Wang, Juang, Lin, Wang, and Jan (2004) conducted a study on elite junior Taiwanese National Team volleyball athletes. The purpose of their study was to determine bilateral arm and gender differences in isokinetic strength. Subjects were 11 high school aged boys and 12 girls. Isokinetic testing was assessed using a Biodex isokinetic dynamometer with the arm in 90° of shoulder abduction and elbow flexion. Testing was completed through 100° of total motion, 50° each of internal and external rotation at 60° and 180°·s⁻¹. There were no significant differences in the peak torque of the dominant arms compared to the non-dominant arms for both the girls and boys. According to the authors, junior volleyball athletes don't expect to have bilateral strength differences due to the sport specific demands. Boys were reported to have Con_{er}/Con_{ir} ratios of 0.76 and 1.11 and Ecc_{er} / Con_{ir} strength ratios of 0.89 and 0.98, at 60° and 180°·s⁻¹ in the dominant arm, while females reported 0.94, 1.06, 0.82 and 0.88 for the same ratios. Four of the subjects were complaining of diffuse lateral shoulder pain on the dominant arm.

vanCingel, Kleinrensink, Stoeckart, and Aufdemkampe (2006) examined shoulder concentric internal and external rotation peak torque in elite volleyball athletes. Subjects

were 35 injury free members of the Dutch national team, with a mean age of 24. Testing was conducted using a Cybex 6000 dynamometer with subjects lying supine and placed in 90° of both shoulder abduction and elbow flexion. Tests consisted of three repetitions at 60°/s and five repetitions at 180°/s and 300°·s⁻¹ through 100° of total range of motion, 50° of both internal and external rotation. Con_{er}/Con_{ir} ratios were reported to be 0.68, 0.69, and 0.70 for three test speeds of 60, 180, and 300°·s⁻¹. Internal rotation peak torque of the dominant arms was significantly higher than both the external rotators of the same arm and the internal rotators of the non-dominant arm. External rotators were not significantly different in bilateral comparisons. This accounts for why athletes had significantly higher ratios in the non-dominant arm. Athletes underwent 3 months of preseason-strengthening program for the rotator cuff, which may lead to their results of no difference in external rotation strength bilaterally.

Summary. Con_{er}/Con_{ir} ratios have been reported to range from 0.67 to 1.11 for volleyball athletes from a variety of skills^{21,24,25} with females in these studies reported to range from 0.72 to 1.06^{21,23}. Ecc_{er}/Con_{ir} ratios were 0.89 to 0.98 in males and 0.82 to 1.27 for females. It is difficult to compare these studies due to the fact that different isokinetic dynamometers were used, testing positions changed greatly, ages and skill level were different, and testing speeds varied between 60, 120, 180, and 300°·s⁻¹.

Throwing Sports Strength Values

Wilk, Andrews, Arrigo, Keirns, and Erber conducted a study examining the shoulder peak torques of professional baseball pitchers. One hundred fifty major league baseball athletes were assessed for internal and external rotation strength of the shoulder at 180° and 300°·s⁻¹. Testing was conducted on a Biodex isokinetic dynamometer at 90°

of shoulder abduction and elbow flexion. There was a significantly lower peak torque in external rotation at $180^{\circ}\cdot\text{s}^{-1}$ in the dominant side shoulders and also in the $\text{Con}_{\text{er}}/\text{Con}_{\text{ir}}$ strength ratios at both speeds. Strength ratios of the dominant arm ranged from 61% to 65%. Authors were unsure why the external rotators of the dominant arm were weaker than the non-dominant side at the $180^{\circ}\cdot\text{s}^{-1}$ compared to $300^{\circ}\cdot\text{s}^{-1}$. They only tested in the concentric phase to prevent delayed onset muscle soreness associated with eccentric testing. The authors suggested that eccentric testing was highly valuable to overhead athletes shoulder assessment, especially for the external rotators due to their role as dynamic stabilizers.

Mikesky, Edwards, Wigglesworth, and Kunkel (1995)³³ examined the shoulder rotator peak torque of collegiate baseball pitchers. Subjects were 25 healthy males ranging from 18 to 22 years of age from Division I, II, and III schools. Testing was performed in the preseason on a Kin-Com III dynamometer at speeds of 1.6, 3.7, and 5.2 Radians per second (approximately 90° , 210° , and $300^{\circ}\cdot\text{s}^{-1}$). Testing position was 90° of both shoulder abduction and elbow flexion. No significant difference was found at any speed for eccentric and concentric internal and external rotation strength or in any of the strength ratios. $\text{Con}_{\text{er}}/\text{Con}_{\text{ir}}$ strength ratios were found to be 0.69, 0.71, and 0.72 on the dominant arm at speeds of 90, 210, and $300^{\circ}\cdot\text{s}^{-1}$. Non-dominant arm strength ratios were higher, which the authors attributed to weaker dominant arm external rotator strength, possibly due to weakness from overuse.

Ellenbecker and Mattalino (1997) conducted a study on concentric isokinetic shoulder internal and external rotation strength on professional baseball pitchers. Subjects numbered 125 and ranged from 18 to 35. Testing was conducted on a Cybex

350 isokinetic dynamometer at 210 and 300°·s⁻¹ with subjects supine and placed in 90° of shoulder abduction and 90° of elbow flexion. Total range of motion was 155°, which consisted of 65° of internal rotation and 90° of external rotation. Internal rotators of the dominant arm were significantly stronger than the non-dominant and that there were no significant bilateral differences found in the external rotators. Con_{er}/Con_{ir} ratios were 0.67 at 210°·s⁻¹ and 0.70 at 300°·s⁻¹. No eccentric testing was conducted.

Sirota, Malanga, Eischen, and Laskowski (1997) evaluated concentric and eccentric strength of external and internal rotators in 25 professional baseball players ranging from 21 to 27 years of age. Testing was conducted prior to the start of the regular season on the Kin-Com 500H Muscle Testing System with subjects seated and placed in 90° of abduction and 90° of elbow flexion. Peak torque values were obtained at 60 and 120°·s⁻¹ concentrically and eccentrically. ³⁴No significant differences were found for either dominant or nondominant arms at either speed or phase of contraction. Ratios of Con_{er}/Con_{ir} were reported to be 0.98 and 0.97 at 60° and 120°·s⁻¹ in the dominant arm.

Newsham, Keith, Saunders, and Goffinett examined the isokinetic peak torque of baseball pitchers at 180, 300, and 450°·s⁻¹. Sixteen intercollegiate pitchers volunteered for testing on the Biodex isokinetic dynamometer and were placed in 90° of shoulder abduction and elbow flexion in the frontal plane. Testing was completed through each subject's full available active range of motion. There was no significant difference between dominant and nondominant arms at any of the test speeds for internal or external rotation. Strength ratios were reported to be 0.64 to 0.68 for the Con_{er}/Con_{ir} strength ratio and Ecc_{er}/Con_{ir} could not be calculated due to the fact that eccentric testing was not performed due to risk of delayed muscle onset soreness.

Noffal (2003) conducted a study on 16 non-pitching college baseball players and compared them with 43 college students not involved in overhead sports. The baseball players ranged in age from 18 to 23 and the non-throwers were 18 to 32. Subjects were supine, placed in 90° of shoulder abduction and 90° of elbow flexion on the Biodex dynamometer, and tested at 300°·s⁻¹. Peak torque was assessed through 150° range of motion between 60° of internal and 90° of external rotation. Non-throwers had significantly higher ratios of Ecc_{er}/Con_{ir}. T-tests revealed that this was due to significantly stronger internal rotation strength in the throwing group, without significant differences in external rotation strength. Con_{er}/Con_{ir} ratios were 0.65 and 0.73 for the dominant and non-dominant arms of throwers and 0.75 and 0.80 for non-throwers. Ecc_{er}/Con_{ir} strength ratios were 1.17 and 1.48 in dominant arms and non-dominant arms of the throwers and 1.37 and 1.60 for the non-throwers.

Mulligan, Biddington, Barnhart, and Ellenbecker conducted a study to examine concentric and eccentric torque of the shoulder internal and external rotators of high school aged baseball pitchers. Subjects ranged from 13-19 years of age and reported 2 to 12 years of pitching experience. Thirty-nine pitchers were tested on the Kin-com isokinetic dynamometer at speeds of 90 and 180°·s⁻¹, with the shoulder placed in 30° of abduction and through 45° of both internal and external rotation. Significantly lower peak torque was seen in both concentric internal rotation and the Con_{er}/Con_{ir} strength ratio at 90°/s in the dominant arm. Con_{er}/Con_{ir} strength ratios were found to be 0.58 and 0.71 at 90 and 180°/s.

Summary. Isokinetic dynamometry has been used by a plethora of authors to examine internal and external rotation torque of high school, college, and professional

baseball athletes^{22, 32-36, 41}. Con_{er}/Con_{ir} strength ratios have been reported to range from 0.58 to 0.94 and Ecc_{er}/Con_{ir} ratios from 0.62 to 1.17 in the dominant arms of these baseball athletes. Wilk et al.⁴¹ found a significant decrease in external rotation peak torque in the dominant arm compared to the non-dominant arm. However, more recent studies have not had similar results (T. S. Ellenbecker & Mattalino, 1997; Mikesky et al., 1995; Mulligan et al., 2004; Newsham et al., 1998; Noffal, 2003; Sirota et al., 1997). Ellenbecker & Mattalino (1997) and Mulligan et al. (2004) reported significantly stronger dominant side internal rotators, a finding not similar to the other studies, which reported no bilateral differences in IR or ER with varying test speeds. Due to differences in dynamometers and testing position, speed, and contraction phases caution must be taken when directly comparing these studies.

Isokinetic Torque in Overhead Sports

Chandler, Kibler, Stracener, Ziegler, and Pace examined the shoulder internal and external rotation of 24 college tennis athletes. Eleven males and 13 females were isokinetically tested at 60 and 300°·s⁻¹ on a Cybex dynamometer with the subjects supine and the arm abducted to 90°. Dominant side internal rotation peak torque was significantly stronger than the non-dominant in all measurements except the endurance ratio. In the Con_{er}/Con_{ir} ratio, peak torque and average power were significantly higher in the non-dominant arm, 0.70 compared to 0.61. Conversely, external rotation had only one significantly stronger measurement on the dominant side, peak torque at 300°·s⁻¹. Authors stated that even though different in nature, tennis still maintains a high degree of similarity to other overhead sports in terms of adaptations expected at the glenohumeral

joint. The decrease in the Con_{er}/Con_{ir} ratio was attributed to internal rotation strength increases, without concomitant increases in external rotation strength.

Bak and Magnusson conducted a study on swimmers from the Danish National Team. Fifteen swimmers were separated into injured and healthy groups. Seven swimmers were assigned as injured by basis of having non-traumatic injury, while still continuing to swim. All had positive Hawkins' Test for shoulder impingement, six of which had glenohumeral laxity (Drawer test, Apprehension sign, and Sulcus sign) indicating secondary impingements. The remaining eight were considered healthy and pain free. Isokinetic testing was conducted on a Kin-com dynamometer with the arm in 80° of abduction, 20° of forward flexion, and the elbow flexed to 90° . Testing was conducted at $30^\circ \cdot s^{-1}$, concentrically and eccentrically, until the patient could not improve on peak torque produced. Comparing bilaterally revealed no significant difference in external rotation strength and a trend toward lower concentric and eccentric internal rotation strength in the injured swimmers' shoulders. Con_{er}/Con_{ir} and Ecc_{er}/Ecc_{ir} ratios were not significantly different, however they did surprisingly find that the Ecc_{er}/Con_{ir} ratio to be significantly greater in the injured shoulder. Injured swimmers displayed significantly stronger Con_{er}/Con_{ir} , and Ecc_{er}/Con_{ir} ratios compared to the healthy group's dominant shoulders. Ratios for the injured side, healthy side, and control group were 0.83, 0.78, and 0.66 in the Con_{er}/Con_{ir} and Ecc_{er}/Con_{ir} ratios were reported to be 1.08, 0.89, and 0.86.

Ellenbecker and Roetert examined internal and external rotation peak torque of elite male and female junior tennis athletes. Subjects ranged in age from 12-21 and all were healthy and pain free during testing. The Cybex isokinetic dynamometer was used

to assess shoulder rotation peak torques at 210 and 300°·s⁻¹. Subjects were placed supine with the shoulder in 90° of abduction with available range of motion from 90° of external rotation to 65° of internal rotation. Analysis of variance showed no significant difference in the strength ratios of younger (12-17) and older subjects (18-21). Boys and girls both displayed significantly stronger dominant side internal rotators and no difference in external rotation strength. Male Con_{er}/Con_{ir} ratios were reported to be 0.64-0.72 and females 0.61-0.76 in the dominant arms.

Summary. Although different than volleyball in nature, tennis and swimming still relies heavily on the shoulder internal and external rotators for optimal performance. Isokinetic testing of these athletes has yielded similar results in Con_{er}/Con_{ir} ratios, which were reported to range from 0.61 to 0.83. Internal rotation strength has been shown to be generally higher on the dominant arm with no change in the bilateral external rotation strength. Ecc_{er}/Con_{ir} ratio was found to be higher in injured swimmers compared to their non-injured teammates. However, this may be due to the fact that injured swimmers were found to have lower concentric internal rotation strength in their dominant arm, which would result in a higher Ecc_{er} / Con_{ir} ratio, since the eccentric external rotators were almost exactly the same and reported to be 0.50 and 0.49 in the injured and control groups (Newton-Meters per kilogram).

Shoulder Strength with Rotator Cuff Pathology

MacDermid, Ramos, Drosdowech, Faber, and Patterson conducted a study examining the effect of chronic rotator cuff tendinitis or subacromial impingement had on isokinetic strength. Twenty-four men and 12 women were compared with a control group of 48 healthy men and women. All subjects had undergone either a home or active

rehabilitation, complained of persistent pain for at least three months, and not been prescribed surgery. Strength testing was completed on the Lido isokinetic dynamometer with subjects seated and the shoulder in 45° of abduction and 30° of forward flexion. Testing was through 90° of total range of motion at 75°/second in both the concentric and eccentric phases. Those with rotator cuff pathologies were significantly weaker than those without symptoms and in external and internal rotation peak torque during concentric, eccentric and isometric testing. The injured subject's reported external rotation mean torque values of 12, 19, and 17 for concentric, eccentric, and isometric contractions compared to 21, 28 and 27 in the healthy group and internal rotation mean peak torques of 15, 21, and 24 compared to 22, 28, and 33. The authors state that the evidence in this study further illustrates the impact that rotator cuff tendinopathies can have on quality of life and importance of rotator cuff strength as a component of that disability. They also found that isometric testing was equally affected as isokinetic testing for patients with rotator cuff tendinopathies.

McCabe, Nicholas, Montgomery, Finneran, and McHugh conducted a study to examine the effect of rotator cuff tear size on shoulder strength. Forty-six males and 15 females with rotator cuff tears and/or subacromial impingements who were scheduled for arthroscopic surgery were included in the study. Mean duration of symptoms was 22 months (+/- 42) and all but 19 sustained the injury to their dominant arm. Isometric strength testing was completed with handheld dynamometers (Lafayette Instruments) for resisted elevation with the arm placed in the scapular plane at 90° of abduction with full external rotation (full can), resisted external rotation in 90° of abduction, and resisted abduction at 10 and 90°. Injured arms displayed significantly lower isometric strength

compared to the uninjured in positions of abduction at 90°, full can test, abduction at 10°, and external rotation at 90° abduction. Abduction at 10° was the only one significantly affected by rotator cuff tear size and thickness. Subjects were also shown to be weaker with full thickness tears, retracted tears, and having multiple tendons involved. Twenty of 28 patients with more than a 50% deficit (than contralateral side) were shown to have large or massive tears.

Tyler, Nahow, Nicholas, and McHugh examined if glenohumeral rotation weakness could be detected in subjects with shoulder impingements. Of the 39 subjects, 17 had shoulder impingements by having positive Neer's Test, Hawkins-Kennedy Test, or both. Peak torque of glenohumeral internal and external rotation was conducted using handheld dynamometry (HDD) and isokinetically using a Biodex System 3 dynamometer at 60 and 180°·s⁻¹. Subjects were tested in the scapular plane, which consisted of placing the shoulder in 45° of abduction and 30° of forward flexion with 90° of elbow flexion and forearm in neutral. The 90-90 position consisted of 90° of abduction, elbow flexion, and shoulder external rotation. No significant weakness was present during different positions or speeds during isokinetic testing, however HDD did reveal significant weakness in external rotation during both testing positions. Authors explain that this may occur due to the fact that during isokinetic testing peak torque occurs during the mid range of motion compared to isolated manual muscle testing used in HDD. The deficit may still exist in isokinetic testing, but be isolated to the terminal ranges of motion.

Summary. Isokinetic and HDD has been used to attempt to determine weakness in subjects with shoulder dysfunctions. HDD has been found to be accurate in determining bilateral isometric strength differences in patients with shoulder dysfunction

^{13, 16} however, isokinetic dynamometry has had varying results ^{13, 15}. A possible explanation as to why isokinetic dynamometry doesn't show actual deficits is that during isokinetic testing peak torques are usually obtained during mid range of motion when actual deficits may only occur during terminal ranges of motion¹⁶.

Epidemiology of Volleyball Injury

Aagaard and Jorgensen completed a retrospective study of injuries in Elite Danish volleyball athletes after the 1993-1994 season. Surveys were introduced to the players before the season to serve as a familiarization, and then data was collected following the competitive season. Seventy females and 67 males participated in data collection procedures. Male's injury risk (injuries/player/year) was higher, however when training times were figured in, males and female incident rates (injuries/player/1000 hours) were similar. Most injuries during training were reported as overuse in nature (55%), while match play injuries were mainly acute (74%) with the ankle, knee, shoulder and fingers being the four typical body sites reported for injury. Ninety percent of shoulder and 87% of knee injuries were overuse in nature compared to 97% of finger and 86% of ankle injuries being acute. The rate of shoulder and knee overuse injuries was higher, longer in duration, and more debilitating in females compared to males. Most injuries occurred along the net (57% of female and 62% of male), with blocking and spiking was identified as the most hazardous event.

Aagaard, Scavenius, and Jorgensen conducted an analysis of injury patterns of indoor and beach volleyball athletes. Subjects were 295 elite and recreational subjects recruited from elite and recreational indoor volleyball leagues in Denmark. Two hundred

ninety-five subjects returned at least one of the preseason or postseason questionnaires and 119 returned both. The reply rate of 80% was based on 295 replies divided by an estimation of 10 to 11 players per team. Danish volleyball athletes played a significant amount more of indoor compared to beach volleyball. Elite athletes played twice as many hours per year compared with the recreational athletes, and men played a significant amount more than women. The most typical injuries of volleyball athletes were the ankle, shoulder, finger, and knee. Shoulder injuries were the second most common area reported, mainly being overuse in nature. Subjects reported that they were unable to play an average of 12.2 (+/- 3.9) days due to shoulder injury, retained symptoms for 82.7 (+/- 10.4) days, and 30% had to see a physician for their injury. In comparing the indoor game versus the beach version, there were no detectable differences in acute and overuse injury patterns. However, there was a significant amount more of beach shoulder injuries, possibly due to the fact that there are only two players, which means more serving and spiking per game.

Wang and Cochrane conducted a study to measure the prevalence and incidence of new injuries, re-injuries, and chronic injuries of male's shoulders in elite volleyball athletes. Men's first division volleyball had nine and 10 teams registered over the two years of data collection (1997/1998 and 1998/1999 seasons). A total 59 athletes completed data collection procedures out of the 75 possible. Thirty-seven injuries were reported from the 59 athletes during the first season, however two reported two different shoulder injuries, resulting in 29 total injuries. All but one occurred on the dominant arm, and 18 of 29 were insidious in nature. Twenty-five of the 29 injuries were reported to around the area of the anterior tip of the shoulder or lateral to the greater tuberosity

with spiking reported as the action (23 of 29) that caused the injury. Eleven of the 27 subjects needed to completely stop training to heal and all most all had pain during spiking or activities of daily living (24/27). The second year follow up found that only five did not have the same shoulder pain and most injuries were still related to spiking (45 of 52). The main finding of their study was that a high prevalence of shoulder overuse injuries involving the rotator cuff was found in top-level volleyball athletes, mainly due to the spiking action and high training regime.

Bahr and Reeser examined injuries of world class beach volleyball athletes via retrospective surveys. During the Federation Internationale de Volleyball Beach (FIVB) World Championships in Austria 2001, 188 athletes competed and 178 of those participated in the study. The survey covered 7.5 weeks, which included training, six women's and 8 men's tournaments, and other possible national or regional tournaments. Acute injuries numbered 54, with 43% causing the athlete to miss at least a day of training or competition. These acute injuries were mainly the knee (30%), ankle (17%), and finger (17%). A total of 79 overuse injuries were reported by 67 players, with 17 being in the shoulder, making it third most common overuse injury behind low back pain and knee injuries. The shoulder was the second most common place of overuse injury that athletes sought out medical care for over the 7.5 weeks. These numbers were attributed to stresses that result from frequent spiking and jump serving seen in the beach volleyball game.

Verhagen, Van der Beek, Bouter, Bahr, and Van Mechelen conducted a one season prospective study of volleyball injuries on 50 teams from Dutch Division II and III male and female teams. A total of 486 subjects completed questionnaires in

September (preseason), 419 completed the data collection process (158 men and 261 women) in May (postseason). Acute injuries totaled 78, with 65 being of the lower extremity and 41 of those being ankle sprains. The average time missed for acute injury was 4.0 weeks. Twenty-five overuse injuries occurred, averaging a 4.0 weeks missed. The shoulder was the most frequently occurring area affected by overuse injury (32%), followed by the back (32%) and knee (20%), and resulted in the most time missed for any injury at 6.2 weeks.

Summary. Epidemiological studies have examined athletes mainly of professional competition in both the indoor and beach games. Whether prospective or retrospective, acute injuries tend to be located in the ankles and fingers, while overuse injuries were primarily found in the shoulder, back, and knee. The high prevalence of shoulder overuse injuries can be one of the most debilitating and result in the most time missed ¹, especially in females ⁶. Spiking and serving are the actions most typically associated with causing and leading to the pain and overuse injuries.

APPENDIX A

INFORMED ASSENT To Participate in a Research Study

I. INVESTIGATORS

Principle Investigators:
Vanessa Martin, ATC
Bret Freemyer, ATC
Christopher D. Stickley, MA, ATC

Supervising Professor:
Iris F. Kimura, PhD, ATC, PT

Department of Kinesiology and Leisure Science
University of Hawai'i at Manoa
1337 Lower Campus Road, PE/A Complex Rm. 231, Honolulu, HI 96822
Phone: 808-956-7606
Fax: 808-956-7976

II. TITLE

Relationship of shoulder injuries to strength and somatic characteristics of female athletes in striking and throwing sports

III. INTRODUCTION

The reason for this study is to see if your shoulder strength and physical stature can be used to see if you're likely to get shoulder injuries. Currently, no information comparing shoulder strength and body types as possible signs of future injury exists. Generally, females have less upper body muscle strength compared to men, which may make them more likely to get injured. You are being asked to be a part of this study because you are a female volleyball player. This research study will allow two graduate students at the University of Hawai'i earn their master's degree. You will first be asked to fill out a page of questions about your shoulders. Then you will have both shoulders tested for strength. After your volleyball season is finished, you will be asked to fill out a similar page of questions about your shoulders.

The following information is being provided to help you decide if you would like to participate in this study. All forms will be reviewed with you and your parents/legal guardians by the investigators. This form may have words that you don't understand. If you have questions, please ask them. You may choose not to be a part of this study, and can quit at any time. All information about you will be kept private. Only the researchers and you will see your information.

IV. DESCRIPTION OF PROCEDURES

You and your parent/guardian will fill out a medical history form before the study begins. You will then come to the University of Hawai'i at Manoa

Athletic Training/Aquatic Laboratory to measure your height, weight, arm length and skin folds, and fill out a questionnaire about your shoulders. Next, strength tests will be performed on your shoulders using an electric weight machine. You will go through two tests on the machine where you will move your shoulder back and forth. There will be at least a five minutes of rest between two, five repetition tests. The questionnaire and tests should only take about 15 minutes. After your competitive volleyball season is over you will fill out another page of questions about your shoulders.

V. RISKS

Since you are being asked to work hard during this study there is a chance of injury. You may have muscle soreness and/or pain in your shoulder after testing. There is also a very remote chance of cardiac arrest and death. You may also have some discomfort, muscle cramping or shortness of breath while testing. If you do get an injury from the tests, only immediate and essential medical treatment is available. First Aid/CPR and a referral to a medical emergency room will be provided. The investigators are Board of Certification Certified Athletic Trainers, First Aid/CPR trained.

You should understand that if you are injured in the course of this research process that you and your parent/guardian may be responsible for the costs of treating your injuries.

VI. BENEFITS

You may not directly gain anything from this study, but will have the experience of being part of a scientific experiment. You will get information about your body and how the strength of your shoulder may affect you when you play volleyball. The results of this study may help prevent shoulder injuries in the future.

VII. CONFIDENTIALITY

Your research records will be private as much as allowed by law. You will not be personally identified in this study. A number will be used instead of your name and will be known only to you and the researchers. Information about your test results will not be given to anyone without your written permission. All of your information will be kept under lock and key in the Department of Kinesiology and Leisure Science at the University of Hawai'i at Manoa. This information will be permanently destroyed of within 5 years. Agencies with research supervision, such as The University of Hawaii Committee on Human Studies, have the right to look at your research records.

VIII. CERTIFICATION

I confirm that I have read and that I understand the above written material, that my questions have been answered and that I have been told that I am free to take away my assent and to quit the project/study at any time without retaliation or repercussion.

I give my assent to be in this project with the understanding that such assent does not give up any of my legal rights, nor does it allow the principle investigator or institution or any employee or agent thereof from liability or negligence.

I understand that a parent or legal guardian must sign a consent form as well for me to participate in this study.

If you have any questions related to this study, please contact principle investigators Vanessa Martin at (918)808-8648, Bret Freemyer at 956-5162, Christopher Stickley at 956-7421 or you may contact Dr. Iris F. Kimura at 956-3797 at any time.

Signature of individual participant

Date

If you cannot obtain satisfactory answers to you questions, or have complaints about your treatment in this study, please contact: Committee on Human Subjects, University of Hawaii at Manoa, 2540 Maile Way, Honolulu, Hawaii 96822, Phone (808) 956-5007.

APPENDIX B

INFORMED CONSENT

To Participate in a Research Study

IX. INVESTIGATORS

Principle Investigators:
Vanessa Martin, ATC
Bret Freemyer, ATC
Christopher D. Stickley, MA, ATC

Supervising Professor:
Iris F. Kimura, PhD, ATC, PT

Department of Kinesiology and Leisure Science
University of Hawai'i at Manoa
1337 Lower Campus Road, PE/A Complex Rm. 231, Honolulu, HI 96822
Phone: 808-956-7606
Fax: 808-956-7976

X. TITLE

Relationship of shoulder injuries to strength and somatic characteristics of female athletes in striking and throwing sports

XI. INTRODUCTION

The purpose of this study is to examine possible shoulder strength and physical characteristic related predictors of shoulder injury. You are being asked to be a part of this study because you are a competitive female softball player. Currently, no information comparing shoulder strength and body types as possible signs of future injury exists. Generally, females have less upper body muscle mass compared to men, which may make them more likely to get injured. To our knowledge this study will be the first of it's kind, which is why you were selected as a possible subject. This research study is being conducted as two separate master's degree theses by University of Hawai'i graduate students. You will be asked to complete an injury and pain questionnaire prior to performing a strength test in both shoulders. At the end of the competitive season you will complete a follow-up injury and pain evaluation questionnaire.

The following information is being provided to help you decide if you would like to participate in this study. All consent and assent forms will be reviewed with all participants and parents/legal guardians by the investigators. This consent form may have words that are unfamiliar to you. If you have questions regarding this form, please discuss them with the research staff

members. Your participation in this research study is voluntary and you will not be paid. You may voluntarily cease participation in this study at any time. All information collected about you will be kept confidential.

XII. DESCRIPTION OF PROCEDURES

Before your participation in the study can begin, you will be asked to fill out a medical history information questionnaire, which will be screened by a medical doctor. On the day of testing you will report to the University of Hawai'i at Manoa Athletic Training/Aquatic Laboratory. You will be asked to complete an injury and pain questionnaire, followed by measurements of your anthropometric characteristics, such as height, weight, limb length, and skin folds. Next, strength tests will be performed on your shoulders using an electric weight machine. You will go through two tests on the machine where you will move your shoulder back and forth. There will be at least a five minutes of rest between two, five repetition tests. The Biodex testing and questionnaire will last approximately 15 minutes. Once you have completed your competitive season you will complete a follow-up injury and pain evaluation questionnaire.

XIII. RISKS

Due to the level of physical activity involved, there is risk of muscle strains, soreness, and pain. A very remote possibility of cardiac arrest and death also exists. You may also experience discomfort, muscle cramping or shortness of breath while testing. In the event of any physical injury from the research procedure, only immediate and essential medical treatment is available. First Aid/CPR and a referral to a medical emergency room will be provided. The investigators are Board of Certification Certified Athletic Trainers, First Aid/CPR certified, and trained to use the portable automated external defibrillator (AED) on site.

You should understand that if you are injured in the course of this research procedure that you alone may be responsible for the costs of treating your injuries.

XIV. BENEFITS

You may not directly benefit from this study although you will gain the experience of being part of a scientific experiment. You will obtain information regarding your physical characteristics and the strength of your shoulder and how it affects you throughout the season. Results of this study may assist strength trainers, coaches, and sport biomechanists in preventing future shoulder injuries in athletes.

XV. CONFIDENTIALITY

Your research records will be confidential to the extent permitted by law. You will not be personally identified in any publication about this study. A code, which will be known only to study personnel and yourself, will be used instead of your name on records of this study. Personal information about your test results will not be given to anyone without your written permission. In addition, all data and subject identity information will be kept under lock and key in the Department of Kinesiology and Leisure Science at the University of Hawai'i at Manoa. These materials will be permanently disposed of in a period not longer than 5 years. Agencies with research oversight, such as The University of Hawaii Committee on Human Studies, have the right to review research records.

XVI. CERTIFICATION

I certify that I have read and that I understand the foregoing, that I have been given satisfactory answers to my inquiries concerning the project procedures and other matters and that I have been advised that I am free to withdraw my consent and to discontinue participation in the project or activity at any time without prejudice.

I herewith give my consent to participate in this project with the understanding that such consent does not waive any of my legal rights, nor does it release the principle investigator or institution or any employee or agent thereof from liability or negligence.

If you have any questions related to this research study, please contact principle investigators Vanessa Martin at (918) 808-8648, Bret Freemyer at 956-5162, Christopher Stickley at 956-7421 or you may contact Dr. Iris F. Kimura at 956-3797 at any time.

Signature of individual participant

Date

If you cannot obtain satisfactory answers to you questions, or have complaints about your treatment in this study, please contact: Committee on Human Subjects, University of Hawaii at Manoa, 2540 Maile Way, Honolulu, Hawaii 96822, Phone (808) 956-5007.

APPENDIX C

INFORMED CONSENT FOR LEGAL GUARDIAN To Participate in a Research Study

XVII. INVESTIGATORS

Principle Investigators:
Vanessa Martin, ATC
Bret Freemyer, ATC
Christopher D. Stickley, MA, ATC

Supervising Professor:
Iris F. Kimura, PhD, ATC, PT

Department of Kinesiology and Leisure Science
University of Hawai'i at Manoa
1337 Lower Campus Road, PE/A Complex Rm. 231, Honolulu, HI 96822
Phone: 808-956-7606
Fax: 808-956-7976

XVIII. TITLE

Relationship of shoulder injuries to strength and somatic characteristics of female athletes in striking and throwing sports

XIX. INTRODUCTION

The purpose of this study is to examine possible shoulder strength and physical characteristic related predictors of shoulder injury. Your child is being asked to participate in this study because she is a competitive volleyball player. Currently, no information comparing shoulder strength and body types as possible signs of future injury exists. Generally, females have less upper body muscle mass compared to men, which may make them more likely to get injured. To our knowledge this study will be the first of it's kind, which is why they were selected as possible subjects. This research study is being conducted as two separate master's degree theses by University of Hawai'i graduate students. You will be asked to complete an injury and pain questionnaire prior to performing a strength test in both shoulders. At the end of the competitive season your child will complete a follow-up injury and pain evaluation questionnaire.

The following information is being provided to help you decide if you would like for your child to participate in this study. All consent and assent forms will be reviewed with all participants and parent/legal guardians by the investigators. This consent form may have words that are unfamiliar to you. If you have questions regarding this form, please discuss them with the research staff members. Your child's participation in this research study is voluntary and she will not be paid. You or your child may voluntarily cease participation in this

study at any time. All information collected about your child will be kept confidential.

XX. DESCRIPTION OF PROCEDURES

Before your child's participation in the study can begin, you will be asked to fill out a medical history information questionnaire, which will be screened by a medical doctor. On the day of testing your child will be asked to report to the University of Hawai'i at Manoa Athletic Training/Aquatic Laboratory. You will be asked to complete an injury and pain questionnaire, followed by measurements of your child's anthropometric characteristics, such as height, weight, limb length, and skin folds. Next, strength tests will be performed on your child's shoulders using an electric weight machine. They will go through two tests on the machine where they will move their shoulder back and forth. There will be at least a five minutes of rest between two, five repetition tests. The Biodex testing and questionnaire will last approximately 15 minutes. Once your child has completed their competitive season your child will complete a follow-up injury and pain evaluation questionnaire.

XXI. RISKS

Due to the level of physical activity involved, there is risk of muscle strains, soreness, and pain. A very remote possibility of cardiac arrest and death also exists. Your child may also experience discomfort, muscle cramping or shortness of breath while testing. In the event of any physical injury from the research procedure, only immediate and essential medical treatment is available. First Aid/CPR and a referral to a medical emergency room will be provided. The investigators are Board of Certification Certified Athletic Trainers, First Aid/CPR certified and trained to use the portable automated external defibrillator (AED) on site.

You should understand that if your child is injured in the course of this research procedure that you alone may be responsible for the costs of treating their injuries.

XXII. BENEFITS

Your child may not directly benefit from this study although they will gain the experience of being part of a scientific experiment. Your child will obtain information regarding their physical characteristics and the strength of their shoulder and how it affects them throughout the season. Results of this study may assist strength trainers, coaches, and sport biomechanists in preventing future shoulder injuries in athletes.

XXIII. CONFIDENTIALITY

Your child's research records will be confidential to the extent permitted by law. You child will not be personally identified in any publication about this study. A code, which will be known only to study personnel and your child, will be used instead of their name on records of this study. Personal information about your child's test results will not be given to anyone without your written permission. In addition, all data and subject (identity) information will be kept under lock and key in the Department of Kinesiology and Leisure Science at the University of Hawai'i at Manoa. These materials will be permanently disposed of in a period not longer than 5 years. Agencies with research oversight, such as The University of Hawaii Committee on Human Studies, have the right to review research records.

XXIV. CERTIFICATION

I certify that I have read and that I understand the foregoing, that I have been given satisfactory answers to my inquiries concerning the project procedures and other matters and that I have been advised that I am free to withdraw my consent and to discontinue my child's participation in the project or activity at any time without prejudice.

I herewith give my consent for my child to participate in this project with the understanding that such consent does not waive any of our legal rights, nor does it release the principle investigator or institution or any employee or agent thereof from liability or negligence.

If you have any questions related to this research study, please contact principle investigators Vanessa Martin at (918)808-8648, Bret Freemyer at 956-5162, Christopher Stickley at 956-7421 or you may contact Dr. Iris F. Kimura at 956-3797 at any time.

Name of your child

Signature of participant's parent or legal guardian

Date

If you cannot obtain satisfactory answers to you questions, or have complaints about your treatment in this study, please contact: Committee on Human Subjects, University of Hawaii at Manoa, 2540 Maile Way, Honolulu, Hawaii 96822, Phone (808) 956-5007.

APPENDIX D

UNIVERSITY OF HAWAII AT MANOA DEPARTMENT OF KINESIOLOGY AND LEISURE SCIENCE MEDICAL HISTORY FORM

Name _____ Date of Birth _____

Name _____
Address _____

Home Phone _____ Work Phone _____ Other Phone _____

Emergency Contact Person

Name _____ Relationship _____

Home Phone _____
WorkPhone _____

Hospital Preference _____

Doctor Preference _____ Phone _____

Please identify any condition that you have or had that might restrict your participation in physical activity. If you answer yes to any of the following, please describe the proper aid requirements on the next page.

- | | | |
|--|------------------------------------|--|
| A. General Conditions | B. Injuries | |
| 1. Fainting Spells Yes No Past Present | 1. Toes Yes No Past Present | |
| 2. Headaches Yes No Past Present | 2. Feet Yes No Past Present | |
| 3. Convulsions/epilepsy Yes No Past Present | 3. Ankles Yes No Past Present | |
| 4. Asthma Yes No Past Present | 4. Lower Legs Yes No Past Present | |
| 5. High Blood Pressure Yes No Past Present | 5. Knees Yes No Past Present | |
| 6. Kidney Problems Yes No Past Present | 6. Thighs Yes No Past Present | |
| 7. Intestinal Disorder Yes No Past Present | 7. Hips Yes No Past Present | |
| 8. Hernia Yes No Past Present | 8. Lower Back Yes No Past Present | |
| 9. Diabetes Yes No Past Present | 9. Upper Back Yes No Past Present | |
| 10. Heart Disease/Disorder Yes No Past Present | 10. Ribs Yes No Past Present | |
| 11. Dental plate Yes No Past Present | 11. Abdomen Yes No Past Present | |
| 12. Poor Vision Yes No Past Present | 12. Chest Yes No Past Present | |
| 13. Poor Hearing Yes No Past Present | 13. Neck Yes No Past Present | |
| 14. Skin Disorder Yes No Past Present | 14. Fingers Yes No Past Present | |
| 15. Allergies Yes No Past Present | 15. Hands Yes No Past Present | |
| Specific _____ Past Present | 16. Wrists Yes No Past Present | |
| | 17. Forearms Yes No Past Present | |
| | 18. Elbows Yes No Past Present | |
| 16. Joint Dislocation Or separations Yes No | 19. Upper Arms Yes No Past Present | |

Specify _____ Past Present
17. Other _____
_____ Past Present

20. Shoulders Yes No Past Present
21. Head Yes No Past Present
Specify _____ Past Present
22. Others _____
_____ Past Present

PLEASE ANSWER THE FOLLOWING QUESTIONS TO THE BEST OF YOUR ABILITY

Have you injured either shoulder in the last 6 months?

No _____ Yes _____ (if so, explain)

Have you injured either elbow in the last 6 months?

No _____ Yes _____ (if so, explain)

Have you injured either wrist in the last 6 months?

No _____ Yes _____ (if so, explain)

Have you injured either hand in the last 6 months?

No _____ Yes _____ (if so, explain)

Do you have any predisposing cardiorespiratory or cardiovascular conditions that the researcher should be aware of?

No _____ Yes _____ (if so, explain)

Do you have any other medical problems that the researcher should be aware of?

No _____ Yes _____ (if so, explain)

Have you ever undergone any type of surgery?

No _____ Yes _____ (if so, explain)

Signature of participant Date _____

Under 18 Parent/Guardian Signature Date _____

APPENDIX E

Volleyball Injury and Pain Questionnaire

Name _____

Please fill out this pre-season questionnaire. These questions are about the volleyball season you are now playing in. If you have any questions please ask. Take your time and answer each question as best as you can.

- | | | |
|--|------------|----------|
| 1. Does your spiking shoulder hurt? | Yes | No |
| 2. Does your spiking shoulder ever hurt during practice? | Yes | No |
| 3. Does your spiking shoulder hurt during every practice? | Yes | No |
| 4. Does your spiking shoulder ever hurt during games? | Yes | No |
| 5. Does your spiking shoulder hurt during every game? | Yes | No |
| 6. Do you play in games when your spiking shoulder hurts? | Yes | No |
| 7. Do you play in practice when your spiking shoulder hurts? | Yes | No |
| 8. Do you stop practicing when your spiking shoulder hurts? | Yes | No |
| 9. Do you stop playing in games when your spiking shoulder hurts? | Yes | No |
| 10. Have you seen a doctor in the last 6 months because your spiking shoulder hurts? | Yes | No |
| 11. Did the doctor tell you that you have an injury to your spiking shoulder? | Yes | No |
| 12. What was the name of the injury to your spiking shoulder? | _____ | |
| 13. Did the doctor tell you that you could not play because you have an injury to your spiking shoulder? | Yes | No |
| 14. Do you have to go back to the doctor before you can play again? | Yes | No |
| 15. Did the doctor tell you that you can play with your injury?
If yes, can you play all the time? | Yes
Yes | No
No |

16. Were you able to tell the doctor how you hurt your spiking shoulder? Yes No
17. Have you had this injury before? Yes No
18. Do you get regular medical care for your spiking shoulder? Yes No
19. Do you plan to follow the doctor's directions? Yes No
20. Have you seen the doctor more than one time for your spiking shoulder injury? Yes No
 If yes, was it for the same injury? Yes No
21. Did you see the doctor for more than one injury to your spiking shoulder? Yes No
22. Does your spiking shoulder hurt for more than 1 day? Yes No
 If yes, rate your pain –

Very Little Pain				Medium Pain					Worst Pain Ever
1	2	3	4	5	6	7	8	9	10

APPENDIX F

Biodex Instructions

Warm ups

Con/Con:

You will begin the warm up on the machine the down by your leg. You will pull the handle to the up toward the ceiling and then pull the handle back toward your leg. You will move 5 times up and 5 times down. The first 4 times you move the handle only give half of your full strength. On the last give use your full strength. Notice that the faster you move the handle the harder it feels.

Ecc/Ecc:

The next warm up is 5 more up and down movements but a little different. You start with the handle down next to your leg again. This time to start, pull the handle pull down instead of pushing the handle up. Notice that even though you pull down, the handle moves up. When you reach the end of the motion, now push back against the handle to make the handle return to the down position. Notice that even though you push the handle backs it will move down toward your leg. The first 4 should be half of your strength while the last should use all your strength.

Test:

Con/Con:

For the test you must give your full effort. Try to move the handle as fast as you can and as hard as you can. You will pull the handle to the up toward the ceiling and then pull the handle back toward your leg. You will move 5 times up and 5 times down.

Ecc/Ecc:

For the last test I want you to start the handle by pulling down toward your leg. The handle will move up toward the ceiling, but I need you pull down as hard as you can. Try to stop the handle from moving up. When the handle does not move any farther up, push back as hard as you can and the handle will start moving down toward your leg. Push back as hard as you can and try to stop the handle from moving again. You will be finished after the handle moves up and down 5 times.

APPENDIX G

RAW DATA

Subject	Team	Age	Shoulder pain	Height cm	Weight (kg)	Limb Length (cm)		
						AC-LE	LE-SP	Total
1	12	12	i	149.86	55.40	28.00	27.50	55.50
2	12	11	i	157.48	54.00	31.00	26.00	57.00
3	12	10	h	152.40	44.10	24.00	24.50	48.50
4	12	11	h	151.77	64.54	31.00	30.00	61.00
5	12	10	h	149.86	37.70	26.00	22.00	48.00
6	15	14	h	166.37	95.45	34.00	26.50	60.50
7	14	14	i	158.12	80.45	34.50	26.50	61.00
8	14	14	h	172.09	51.36	31.00	27.00	58.00
9	14	14	h	161.29	60.45	33.00	26.50	59.50
10	14	14	i	168.28	47.27	31.50	23.50	55.00
11	14	14	h	166.37	50.09	31.50	25.00	56.50
12	14	14	h	163.20	61.20	31.00	24.40	55.40
13	14	14	h	172.72	60.00	31.00	22.00	53.00
14	14	14	h	167.64	45.00	29.00	24.00	53.00
15	14	14	h	168.28	65.90	31.50	24.00	55.50
16	13	12	h	163.83	46.36	26.00	24.00	50.00
17	13	13	h	147.96	55.00	32.00	28.00	60.00
18	13	12	h	150.50	52.30	28.25	23.50	51.75
19	13	13	h	167.64	58.18	31.00	25.00	56.00
20	13	12	h	163.83	52.27	34.00	26.00	60.00
21	13	13	h	172.72	54.54	30.00	26.00	56.00
22	12	12	h	161.93	53.60	28.00	23.50	51.50
23	13	13	h	176.53	57.72	32.00	24.00	56.00
24	15	15	h	168.28	48.63	31.50	27.00	58.50
25	15	14	h	157.48	61.40	28.00	25.00	53.00
26	15	15	h	165.74	60.09	29.50	25.00	54.50
27	15	15	h	161.93	68.63	29.50	25.50	55.00
28	15	15	i	155.58	55.00	27.50	25.00	52.50
29	15	15	i	165.10	60.68	32.50	26.50	59.00
30	15	15	h	160.02	75.45	34.00	28.00	62.00
31	15	14	h	163.83	68.63	30.00	24.00	54.00
32	15	15	i	156.21	60.09	32.00	28.00	60.00
33	15	15	i	163.83	58.64	33.00	27.50	60.50
34	15	11	i	167.64	58.18	28.50	26.50	55.00
35	12	11	h	162.56	52.73	31.00	26.00	57.00
36	12	11	h	170.18	37.73	26.50	23.00	49.50
37	12	11	h	171.45	57.23	27.50	24.00	51.50
38	12	11	h	175.90	48.18	26.50	24.00	50.50
39	12	11	h	170.18	53.18	26.00	20.50	46.50
40	12	12	h	164.47	37.73	27.00	22.50	49.50

subject	Skinfolds(mm)				Concentric		Eccentric	
	Triceps	Calf	Sum	%BF	ER	IR	ER	IR
1	17	18	35	26.35	10.40	15.50	9.30	19.50
2	23	24	47	33.67	18.80	26.00	16.20	23.80
3	14	15	29	22.69	10.10	19.90	19.70	24.90
4	12	16	28	22.08	13.50	22.90	23.30	30.80
5	9	11	20	17.20	6.20	14.60	14.50	15.40
6	20	25	45	32.45			28.60	43.60
7	22	26	48	34.28	13.40	22.10	23.90	31.10
8	13	15	28	22.08	11.50	24.80	23.70	36.40
9	11	14	25	20.25	19.70	26.50	31.70	47.40
10	9	10	19	16.59	15.80	13.00	20.20	29.10
11	14	15	29	22.69	15.30	25.50	29.40	32.10
12	20	30	50	35.50	17.70	14.00	20.60	30.00
13	15	17	32	24.52	14.80	23.90	41.00	42.90
14	9	14	23	19.03	15.60	23.40	21.30	28.80
15	16	18	34	25.74	20.40	29.10	31.20	41.60
16	19	22	41	30.01	14.90	21.60	12.60	25.10
17	14	19	33	25.13	18.00	18.20	19.20	29.80
18	16	20	36	26.96	14.20	18.80	24.60	24.90
19	15	19	34	25.74	15.00	17.80	25.50	30.00
20	16	17	33	25.13	9.90	21.40	12.20	27.70
21	12	15	27	21.47	16.30	27.70	17.80	37.90
22	16	18	34	25.74	13.80	14.40	20.60	25.60
23	17	20	37	27.57	9.60	19.50	17.50	26.90
24	11	14	25	20.25	20.00	28.40	25.50	33.00
25	20	24	44	31.84	15.00	19.40	33.30	38.30
26	16	24	40	29.40	11.90	22.20	22.10	34.00
27	21	28	49	34.89	18.50	25.40	29.10	39.70
28	14	19	33	25.13	15.50	24.60	20.60	29.70
29	15	17	32	24.52	18.60	23.20	19.80	30.20
30	23.5	23	46.5	33.37	18.90	24.50	28.50	41.60
31	22	20	42	30.62	20.80	29.10	38.60	41.10
32	17	20	37	27.57	20.60	21.60	19.50	22.30
33	10	12	22	18.42	20.80	33.70	35.40	44.40
34	13	18	31	23.91	17.70	20.60	15.50	32.60
35	14	18	32	24.52	15.50	19.50	23.40	27.40
36	11	14	25	20.25	10.90	10.10	16.90	20.80
37	20	25	45	32.45	10.40	5.20	10.10	17.60
38	14	20	34	25.74	15.10	26.20		
39	18	24	42	30.62	9.70	14.40	9.70	17.10
40	11	16	27	21.47	11.10	13.50	14.60	21.00

Subject	Con _{er} /Con _{lr}	Ecc _{er} /Ecc _{lr}	Ecc _{lr} /Con _{er}	Ecc _{er} /Con _{lr}
1	0.67	0.48	1.88	0.60
2	0.72	0.68	1.27	0.62
3	0.51	0.79	2.47	0.99
4	0.59	0.76	2.28	1.02
5	0.42	0.94	2.48	0.99
6		0.66		
7	0.61	0.77	2.32	1.08
8	0.46	0.65	3.17	0.96
9	0.74	0.67	2.41	1.20
10	1.22	0.69	1.84	1.55
11	0.60	0.92	2.10	1.15
12	1.26	0.69	1.69	1.47
13	0.62	0.96	2.90	1.72
14	0.67	0.74	1.85	0.91
15	0.70	0.75	2.04	1.07
16	0.69	0.50	1.68	0.58
17	0.99	0.64	1.66	1.05
18	0.76	0.99	1.75	1.31
19	0.84	0.85	2.00	1.43
20	0.46	0.44	2.80	0.57
21	0.59	0.47	2.33	0.64
22	0.96	0.80	1.86	1.43
23	0.49	0.65	2.80	0.90
24	0.70	0.77	1.65	0.90
25	0.77	0.87	2.55	1.72
26	0.54	0.65	2.86	1.00
27	0.73	0.73	2.15	1.15
28	0.63	0.69	1.92	0.84
29	0.80	0.66	1.62	0.85
30	0.77	0.69	2.20	1.16
31	0.71	0.94	1.98	1.33
32	0.95	0.87	1.08	0.90
33	0.62	0.80	2.13	1.05
34	0.86	0.48	1.84	0.75
35	0.79	0.85	1.77	1.20
36	1.08	0.81	1.91	1.67
37	2.00	0.57	1.69	1.94
38	0.58			
39	0.67	0.57	1.76	0.67
40	0.82	0.70	1.89	1.08

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