FUNCTIONAL VOLLEYBALL SPIKE-JUMP LANDING BIOMECHANICS AND INJURY INCIDENCE OF ADOLESCENT FEMALE CLUB VOLLEYBALL ATHLETES

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Table of Contents

LIST OF TABLES v

LIST OF FIGURES vi

ACKNOWLEDGEMENTS vii

ABSTRACT viii

INTRODUCTION 1

Research Questions 3

METHODS 4

Research Design 4

Subjects 4

Instrumentation 5

Procedures 6

Statistical Analysis 8

RESULTS 8

DISCUSSION 11

REFERENCES 17

APPENDICES 19

Appendix A. The Problem 19

A.1. Problem statement 19

A.2. Independent variable(s) 19

A.3. Dependent variable(s) 19

A.4. Dependent measure(s) 19

A.5. Research question(s) 20

A.6. Operational definitions. 20

A.7. Experimental hypotheses. 21

A.8. Assumptions 21

A.9. Delimitations. 21

A.10. Limitations. 21

A.11. Significance of the study. 22

Appendix B. Review of Literature 23

Appendix C. Additional Methods 36

C.1. Institutional Review Board Form 36

C.2. Institutional Review Board Proposal 40

C.3. Informed consent form 42

C.4. Questionnaire(s) 46

C.5. Data collection forms 50

C.6. Specific testing protocols 51

C.7. Standard instructions 51

Appendix D. Additional Results 52

D.1. Raw data tables 52

D.2. Statistical tables 54

Appendix F. Bibliography 56

LIST OF TABLES

Table 1. Subject Demographic Means and Standard Deviations, and Club Volleyball Experience 5

Table 2. Knee Injury History Status by Leg Dominance, Hitting Arm Preference, and Landing Pattern 9

Table 3. Dependent Variable Means and Standard Deviations by Injury Status 9

Table 4. Dependent Variable Means and Standard Deviations of Dominant and Non-Dominant Legs 10

LIST OF FIGURES

Figure 1. Mean Knee Flexion Angle Difference between PIK and NIK 12

Figure 2. Mean MVGRF Difference between PIK and NIK 13

Figure 3. Mean Loading Rate Differences between PIK and NIK 13

Figure 4. Mean Knee Flexion Angle Difference between Dominant and Non-dominant Leg 15

Figure 5. Mean MVGRF Difference between Dominant and Non-dominant Leg 15

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ABSTRACT

Purpose: To functionally investigate volleyball spike-jump landing biomechanics in adolescent female club volleyball athletes to determine injury risk factors, and injury incidence. The independent variables were knee injury history (previously injured knee, PIK, and Non-injured knee, NIK) and landing leg (Dominant and Non-dominant legs). Dependent variables were lower extremity kinematics and kinetics.

Methods: We used a causal-comparative retrospective research design to identify associated knee injury risk factors. Subjects were 40 highly trained adolescent female club volleyball athletes who completed a retrospective injury questionnaire. Six high-speed three dimensional motion capture cameras and two force plates were used to collect kinematic and kinetic data. Two way analyses of variance (ANOVA) linear model ($P < 0.05$) were used to analyze two independent (injury status) and six dependent (knee flexion angle at initial ground contact (IC), knee flexion angle at maximal vertical ground reaction force (MVGRF), maximal knee flexion angle, MVGRF (N/Kg), time from IC to MVGRF (sec), and loading rate from IC to MVGRF (N/sec) variables.

Results: ANOVA findings indicated significant main effects between PIK and NIK in three of the six dependent variables. Subjects with PIKs revealed significantly larger knee flexion angles at initial contact ($p = 0.03$), exerted significantly greater maximal vertical ground reaction forces ($p = 0.029$), and significantly greater loading rates ($p = 0.0212$) compared with NIKs. Results also revealed significant main effects between dominant and non-dominant legs in three of the dependent variables. Dominant leg data results revealed larger knee flexion angles at initial contact ($p = 0.0007$), larger knee flexion angles at MVGRF ($p < 0.0001$), and larger MVGRFs ($p = 0.0035$) than in the non-dominant leg. No interaction effects were indicated in injury status (PIK vs. NIK) or in landing legs (dominant vs. non-dominant).

Key Words: LOWER EXTREMITY INJURY, KINEMATICS, KINETICS, MOTION ANALYSIS, GROUND REACTION FORCE

INTRODUCTION

Sports-related adolescent injury increases in the United States have been paralleled by increases in youth sports participation.[1] An estimated 2.6 million sports-related emergency room visits occur each year primarily to individuals between the ages of five and 14 years.[1] The majority of these sports-related injuries involve the lower extremities (LE)[1], and are commonly seen in activities such as volleyball, basketball, and soccer where cutting and repetitive jumping-landing sequences are fundamental requirements of the sport[2-4].

Consequently, in order to prevent and decrease the consistent rise in sports-related injuries, gender,[5-9] developmental stage (i.e.Tanner and musculoskeletal),[7 10] injury status,[11 12] and sport-specific skill activities[13] have been biomechanically analyzed to identify LE injury risk factors. Gender related findings indicate that females are at greater risk for injuries than their male counterparts, especially with regard to LE injuries.[5-9] These results may be attributed to factors such as larger Q-angle, genu recurvatum, and lower muscle strength values in female athletes.[5 6 9] Additionally, females demonstrate smaller hip and knee flexion angles, and larger ground reaction forces (GRF) during jumping and landing activities than males.[5 6 9]

Jumping and landing studies on pre- and post-pubescent subjects are limited and converse.[7 10] One study[7] concluded that pre-pubescent subjects were at greater risk for LE injuries than post-pubescent subjects because they demonstrated smaller knee and hip flexion angles which were associated with larger ground reaction forces (GRF) during vertical jump landings sequences.[7] Conversely, another biomechanical study which compared pre- and post-pubescent groups[10] concluded that post-pubescent subjects were at greater risk for Anterior Cruciate Ligament (ACL) injury than pre-pubescent subjects because they demonstrated smaller knee flexion angles during jump landings.[10] Additionally, rapid musculoskeletal growth confounded by sport activity stress has been shown to cause growth plate apophysis and joint surface injuries in adolescent athletes.[14] Moreover, repetitive stress and rapid increases in training at consistently high intensities have been associated with over-use and chronic injuries on the immature musculoskeletal system of adolescent athletes.[14]

Prior injury history has also been identified as a potential lower extremity risk factor in biomechanical landing studies.[11-13 15] Athletes with prior ACL injury histories revealed smaller hip and knee flexion angles upon landing than uninjured athletes.[11 12] This finding is converse to the results of one study that examined functional volleyball specific tasks and identified the relationship between patellar tendonitis and volleyball landing biomechanics.[13] Results of this study indicated that larger knee flexion angles demonstrated during landings were one of the predictors of patellar tendonitis in elite adult male volleyball players.[13]

Volleyball is the third most popular sport in the United States for adolescent female athletes.[16] Additionally, most volleyball injuries occur in the right, middle, and left front positions,[4] and the majority of these injuries occur to the LE, at the knee and ankle in both acute and overuse conditions[2-4]. Patellar tendonitis, has been identified as the most common overuse injury among volleyball athletes as a result of repetitive high-intensity jumping.[2-4] While acute knee injuries are not as common as ankle injuries, ACL sprains, have been associated with greater sports participation time losses than other injuries.[2 3]

Several studies have been conducted to examine landing biomechanics by using different jump techniques.[5-13 15] Despite having provided useful information about landing biomechanics,[5-13 15] all but the aforementioned volleyball study [13] involved non-functional, non- sport specific activities. Therefore, the purpose of this study was to functionally investigate volleyball spike-jump landing biomechanics to determine injury risk factors and injury incidence in adolescent female club volleyball athletes.

Research Questions

(1) What were the spike-jump landing kinetic differences between previous knee injury and non-injury groups?

(2) What were the spike-jump landing kinematic differences between previous knee injury and non-injury groups?

(3) What were the spike-jump landing kinetic differences between dominant and non-dominant landing legs?

(4) What were the spike-jump landing kinematic differences between dominant and non-dominant landing legs?

METHODS

Research Design

We used a causal-comparative retrospective research design. The goal of this study was to simulate a functional volleyball spike-jump landing that would occur in an actual sports setting. A retrospective injury questionnaire was administered prior to biomechanical data collection and used to identify knee injury history. (Appendix C4) The volleyball spike-jump landings of adolescent female club volleyball athletes of different knee injury histories (previously injured knee; PIK or non-injured knee; NIK), and landing legs (dominant or non-dominant) were compared to examine differences in lower extremity kinematics and kinetics. In this study, the "dominant leg" was defined as the contralateral leg of the spiking arm.

Subjects

Forty highly trained female adolescent club volleyball athletes aged 12 to 18 years volunteered to participate in this study. Subject qualifications included participation in at least three practices per week for between five and 11 consecutive months. Highly competitive club team classification was based on historic and consistent USA Volleyball Junior Olympics showings and win-loss ranking in the upper 25 percent nationally. Prior to study participation, all subjects and their parents/legal guardians read and signed written informed assent and consent forms approved by the University Committee on Human Studies (Appendix C3). General medical and injury questionnaires (Appendix C4) were reviewed by the university team physician to screen for pathologies or physical contraindications to study participation. All subjects were healthy and asymptomatic at the time of data collection and able to properly perform volleyball spike jumps. Subjects' physical characteristics are presented in Table 1.

Table 1. Subject Demographic Means and Standard Deviations, and Club Volleyball Experience

Skill Level	N	Age (years)	Club VB Experience (years)	Height (cm)	Weight (Kg)
Total	40	14.40 ± 2.21	3.84 ± 2.14	165.80 ± 8.21	60.57 ± 10.87
-High	21	16.52 ± 0.60	5.16 ± 2.22	170.23 ± 6.91	67.80 ± 9.55
-Low	19	12.32 ± 0.48	2.53 ± 0.96	160.89 ± 6.82	52.58 ± 5.43

Volleyball: VB; Injury Status: Previously Injured Knee: PIK; Non-Previously Injured Knee: PIK

Instrumentation

Injury history questionnaires were used to identify knee injury status of subjects as PIK or NIK. The definition of knee injury was any injury that resulted in volleyball practice or game participation time loss and/or medical attention. The questionnaire consisted of 14 closed and five open ended questions and anterior and posterior pictorial injury location identification. (AppendixC4)

Three-dimensional (3D) infrared motion capture system Vicon Motion Capture System (Vicon MX, Centennial, Colorado) and Peak Motus software (version 8.0, Vicon, Inc., Centennial, Colorado) were used to capture, reduce, and analyze kinematic spike-jump landing data. Six 3D cameras were placed on each side of the testing area so that at least two of the six cameras captured the position of the reflective markers (1.4 cm in diameter) during spike jump landings. Three-dimensional kinematic data were time synchronized and collected at 240 (Hz). Both kinematic and kinetic data were smoothed using the Butterworth filter optimized by Peak Motus software. Knee flexion angles were calculated with Peak Motus software using projected segmental angles.

Full body reflective marker set described previously[11] was used for placement of 24 reflective bilateral markers. Bilateral reflective marker placements included: acromioclavicular (AC) joint, anterior superior iliac spine (ASIS), posterior superior iliac spine (PSIS), greater trochanter (GT), anterior aspect of thigh (10 cm above the superior pole of patella), lateral epicondyle, tibial tubelosity, anterior aspect of distal tibia, lateral malleolus, calcaneus, and distal head of the second and fifth metatarsal bones.

Two force plates (Advanced Mechanical Technology Incorporated, Boston, Massachusetts) embedded parallel to each other and anterior to the volleyball net (representation), and flush with the floor surface were used to collect kinetic data during spike-jump landings. Ground reaction force (GRF) data were time synchronized and collected at 480 (Hz) measured in Newtons (N), and normalized to body mass.

Volleyball net fabricated by the investigator and "Spike It" (Korney Board Aid, Inc. Roxton, Texas) ball holder were used to simulate functional volleyball spiking. The simulated volleyball net was positioned anterior and parallel to the force plates and set at regulation heights. The ball holder height was adjustable to one inch increments relative to the appropriate volleyball spike-jump.

Procedures

All data were collected in the University Human Performance Laboratory by National Athletic Trainers' Association (NATA) Board of Certification (BOC) certified athletic trainers (ATC). Potential study subjects were provided with team and individual information sessions that included: introduction of study procedures via power point presentation, data collection demonstration, administration of consent and assent forms, and general medical and injury history questionnaire form completion. Following medical health clearance and injury status establishment, data collection session appointments were selected. All subjects reported for data collection rested (no organized practice or game participation) wearing sports bra, spandex volleyball tights, and volleyball shoes regularly worn during practices and games. Immediately prior to biomechanical data collection, the same female BOC ATC collected anthropometric data consisting of height, weight, body composition (3 sites), and Q-angle. All subjects were given a 10-minute warm up session on a stationary bike and self-addressed stretching session. Biomechanical test familiarization included identification of appropriate ball holder height and standard three-step approach spiking practice. Subjects were instructed to practice until they could perform three successful spike jumps. Spike jump success and consequent data collection acceptance consisted of: a proper three-step approach; appropriate ball contact (spike); and, landing with entire right and left foot placement on adjacent force plates. Upon successful and consistent spike-jump landing bout acceptance, adhesive reflective markers were attached to aforementioned marker set anatomical placement sites directly on the skin or spandex tights (ASIS, PSIS, GT) by the same female BOC ATC.

Three classifications were used to identify spike-jump landing patterns of subjects. The double leg pattern involved simultaneous ground contact with both feet and/or ground contact by individual feet in less than or equal to 33 ms. The single leg pattern involved unilateral ground contact by individual feet in greater than 33 ms.[17] Subjects were identified as exhibiting a double leg pattern or a single leg pattern when all three data collection landing trials could be classified as either double or single leg landings. When data collection landing trials involved double and single leg landings the subject was classified as exhibiting an inconsistent landing pattern.

Statistical Analysis

Two-way analyses of variance (ANOVA) linear model were used to analyze six dependent variables. Independent variables consisted of injury status (PIK or NIK) and landing leg (dominant or non-dominant). Dependent variables consisted of knee flexion angle at initial ground contact (IC), knee flexion angle at maximal vertical ground reaction force (MVGRF), maximal knee flexion angle, MVGRF (N/Kg), time from IC to MVGRF (sec), and loading rate from IC to MVGRF (N/sec). Statistical Analysis Software (SAS) version 9.1 (SAS Institute, Inc., North Carolina) was used to analyze the biomechanical data. Significance level was established at $P < 0.05$.

RESULTS

Subject descriptive data are presented in Table 1. Knee injury history status, hitting arm, and landing pattern are presented in Table 2. Dependent variable means and standard deviations of previous injury (PIK) and non-injury (NIK) history knees are presented in Table 3. Dependent variable means and standard deviations of each landing leg are presented in Table 4.

Analysis of Variance findings indicated significant main effects between PIK and NIK in three of the six dependent variables. Subjects with PIK revealed significantly larger knee flexion angles at initial contact ($p = 0.03$), exerted significantly greater MVGRF ($p = 0.029$), as well as significantly greater loading rate ($p = 0.0212$) than in the NIK.

Results also revealed significant main effects between dominant and non-dominant legs in three of the six dependent variables. Dominant leg data of subjects revealed larger knee flexion angles at initial contact ($p = 0.0007$), larger knee flexion angles at MVGRF ($p < 0.0001$), and larger MVGRF ($p = 0.0035$) than in the non-dominant leg. A tendency for larger maximal knee flexion angles ($p = 0.065$), was found in dominant legs. No interaction effects were indicated in injury status (PIK vs. NIK) or in landing legs (dominant vs. non-dominant).

Table 2. Knee Injury History Status by Leg Dominance, Hitting Arm Preference, and Landing Pattern

Skill Level	N	PIK Dominant	PIK Non-dominant	Right Arm Hitter	Left Arm Hitter	Single Leg Landing Pattern	Double Lag Landing Pattern	Inconsistent Landing Pattern
Total	40	4	5	37	3	0	35	5
-High	21	3	5	20	1	0	19	2
-Low	19	1	0	17	2	0	16	3

Table 3. Dependent Variable Means and Standard Deviations by Injury Status

Injury Hx	N	Knee Flexion Angle at IC	Knee Flexion Angle at MVGRF	Maximal Knee Flexion Angle	MVGRF (N/Kg)	Loading Rate (N/sec)	Time to MVGRF (sec)
NIC	71	12.94 ± 7.00*	57.87 ± 9.96	76.80 ± 9.67	16.71 ± 2.96**	9006.71 ± 2818.45***	0.11 ± 0.02
PIC	9	17.91 ± 5.52	60.67 ± 8.95	78.26 ± 14.10	18.93 ± 2.92	11432.91 ± 3879.95	0.12 ± 0.03

Initial Contact: IC; Maximal Vertical Ground Reaction Force; MVGRF: Previously Injured Knee: PIC; Non-Injured Knee: NIC

Table 4. Dependent Variable Means and Standard Deviations of Dominant and Non-Dominant Legs

Landing Leg	N	Knee Flexion Angle at IC	Knee Flexion Angle at MVGRF	Maximal Knee Flexion Angle	MVGRF (N/Kg)	Loading Rate (N/sec)	Time to MVGRF (sec)
Dominant	40	15.98 ± 7.96*	62.10 ± 9.12**	78.76 ± 10.46	16.34 ± 2.95***	8801.87 ± 2514.70	0.11 ± 0.02
Non-Dominant	40	11.02 ± 4.82	54.27 ± 9.03	75.17 ± 9.66	17.57 ± 2.99	9757.45 ± 3429.20	0.11 ± 0.02

Initial Contact: IC; Maximal Vertical Ground Reaction Force: MVGRF;
Significant; P<0.05.

DISCUSSION

The most important finding of our study was that the landing kinematics and kinetics of subjects who presented with a history of knee injuries (PIK) were significantly different than subjects who had not previously injured their knees (NIK) in volleyball. Subjects with previous knee injury histories initially contacted the ground with larger knee flexion angles (17.91° ± 5.52° > 12.94° ± 7.00°), greater maximal vertical ground reaction forces (18.93 ± 2.92 N/kg > 16.71 ± 2.96 N/kg) and higher loading rates (11432.91 ± 3879.95 N/s > 9006.71 ± 2818.45 N/s) during the total landing sequence, than NIK subjects. Interestingly, maximal knee flexion angles were similar between PIK (78.26° ± 14.10°) and NIK (76.80° ± 9.67°), suggesting that PIK subjects had less available knee range of motion. Since subjects with NIK initially contacted the ground with straighter knees than PIK, but both PIK and NIK end range of motion were similar, it appears that PIK had less available knee flexion range of motion to dissipate force resulting in significantly greater MVGRF than NIK. (18.93 ± 2.92 N/kg > 16.71 ± 2.96 N/kg). (Figures 1-3) This landing characteristic of PIK is similar to the previous study which compared single leg landing biomechanics of males and females.[6] Study findings demonstrated that females had smaller (less available) total knee and hip range of motion and greater peak GRFs than males.[6] The previous results further substantiated our retrospective injury data that this type of landing strategy may increase the risk of knee injury due to less of the available range of motion at the knee and hip joints to dissipate energy resulting in greater ground reaction forces[6] Since the current study is retrospective in nature, it is unclear whether our subjects' injury characteristics were related to injury development or whether the injury precipitated the development of our aforementioned injury characteristics.

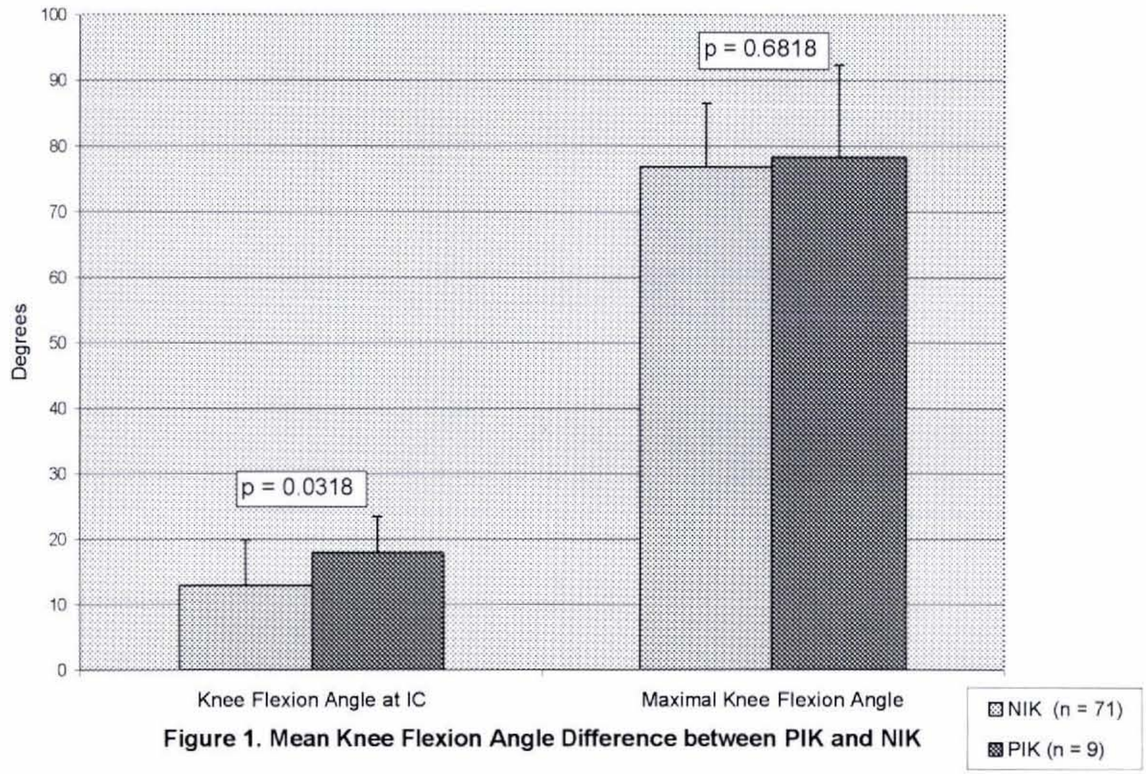

Figure 1. Mean Knee Flexion Angle Difference between PIK and NIK

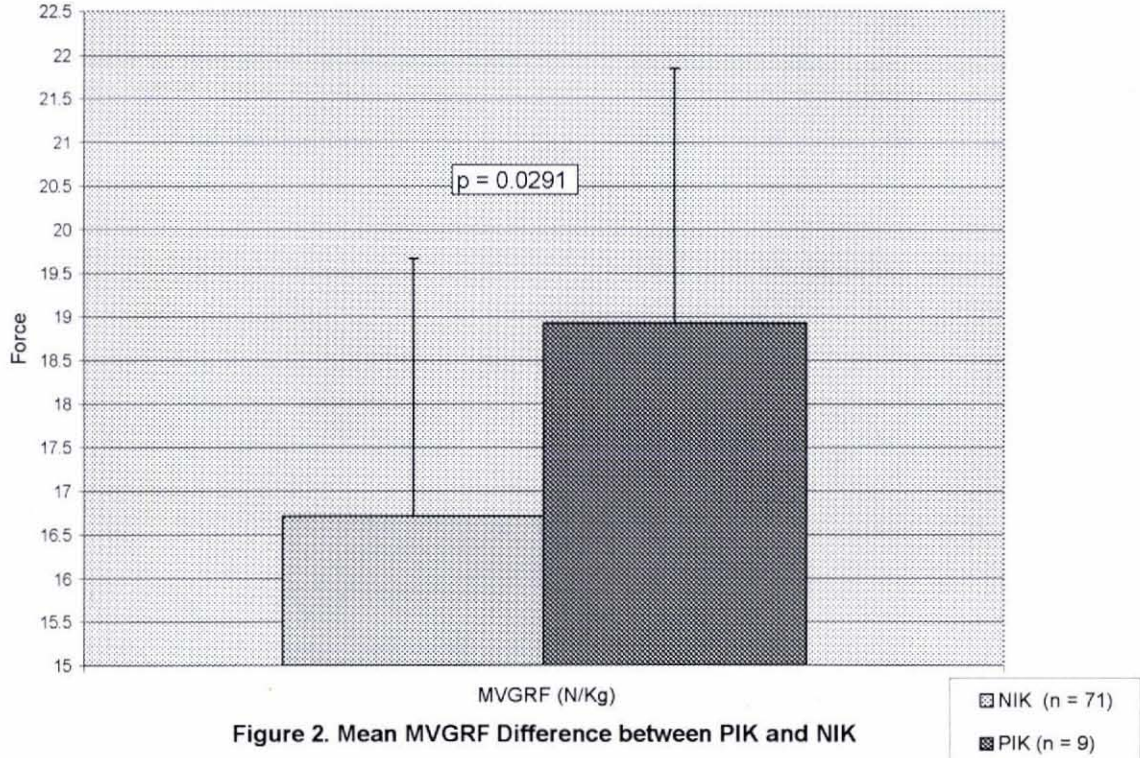

Figure 2. Mean MVGRF Difference between PIK and NIK

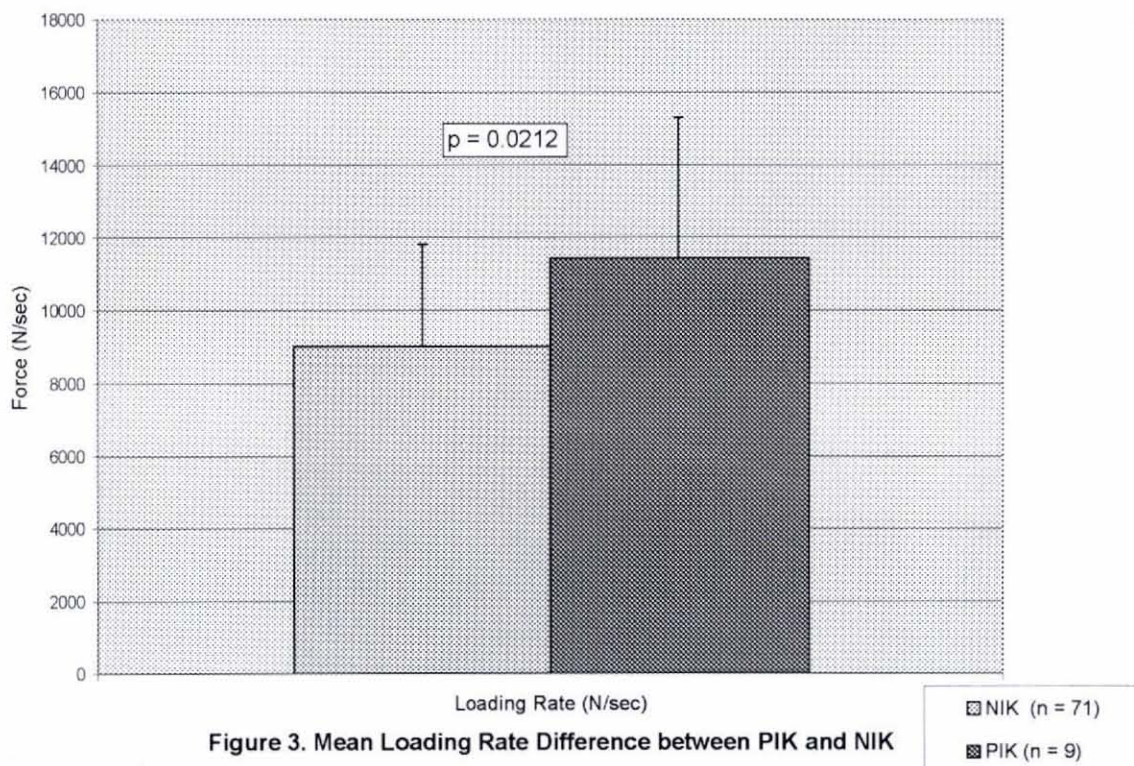

Figure 3. Mean Loading Rate Difference between PIK and NIK

Findings of our study also indicated biomechanical differences between dominant and non-dominant landing legs during functional volleyball spike jumps. Dominant leg data of our subjects revealed significantly: larger knee flexion angles at initial contact (15.98° ± 7.96° > 11.02° ± 4.82°); larger knee flexion angles at MVGRF (62.10 ° ± 9.12 ° > 54.27 ° ± 9.03°); and, smaller MVGRF (16.34 ± 2.95 N/kg < 17.57 ± 2.99 N/kg). Although not significant ($p = 0.065$), dominant leg maximal knee flexion angle data appeared larger than non-dominant leg data (Figure 5 and 6). Our findings are supported by previous biomechanical studies,[5 8 9 11] that indicated an inverse relationship between knee flexion angle and ground reaction force. Consequently, non-dominant leg data of our subjects revealed significantly smaller knee flexion angles during the landing sequence while exhibiting greater MVGRF, often referred to as "stiff landings".[5 11 18] "Stiff landing" has been identified as a risk factor for ACL injury secondary to the anterior dislocating force of quadriceps muscle[5 11 19] Conversely, large knee flexion angles during landing were identified as patellar tendonitis risk factors secondary to eccentric loading of the patellar tendon[13]. Based on the previous findings, there may be increased risk of ACL injury on the non-dominant leg and increased risk of patellar tendonitis on the dominant leg of female adolescent volleyball athletes.

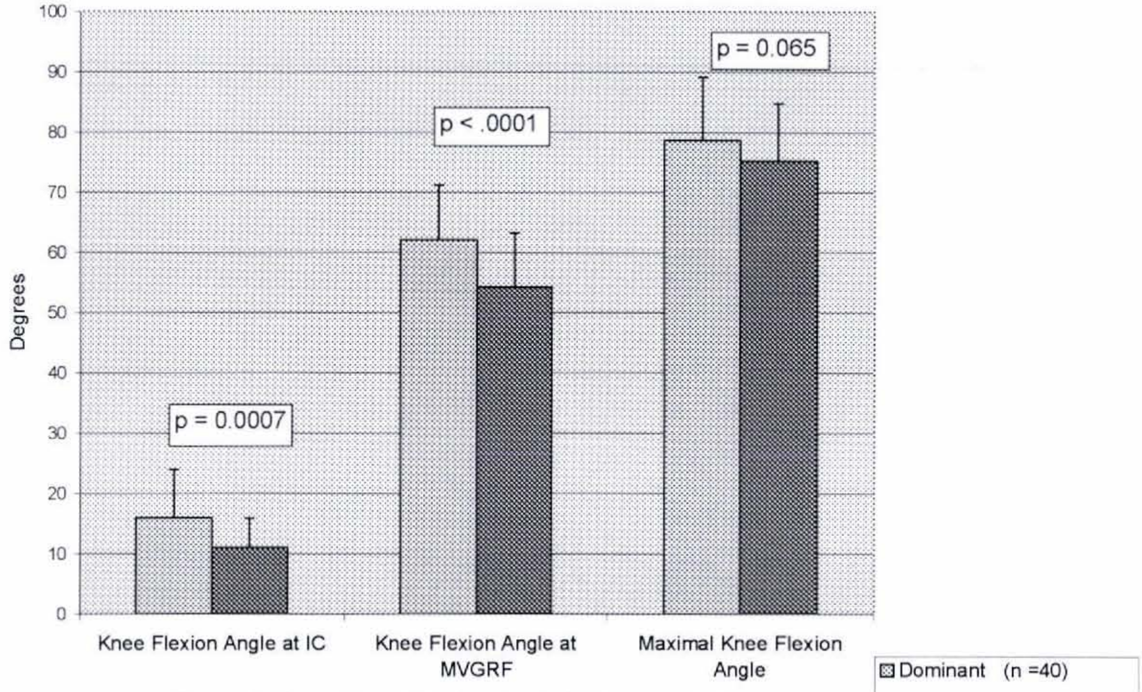

Figure 4. Mean Knee Flexion Angle Difference between Dominant and Non-dominant Leg

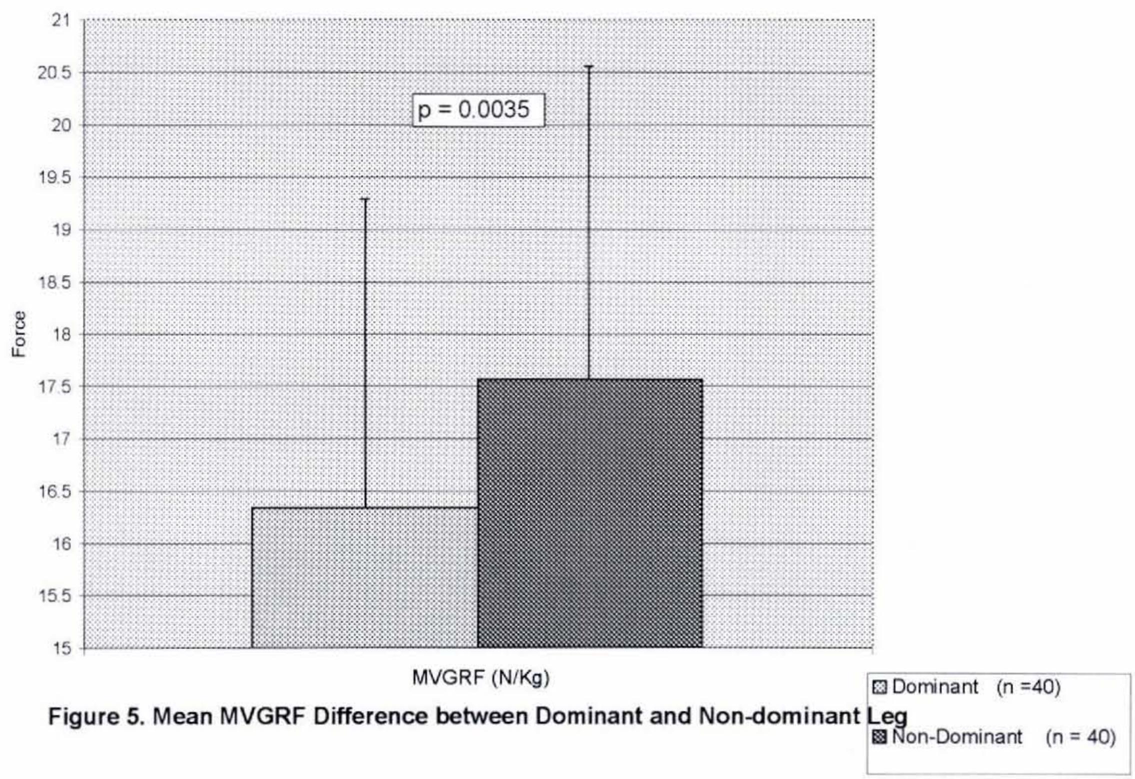

Figure 5. Mean MVGRF Difference between Dominant and Non-dominant Leg

Single leg landing has also been identified as an injury risk factor due to the fact that a single limb must dissipate and absorb the forces created by the entire body.[20] A previous study involved investigation of volleyball spike and block jump landing patterns of collegiate female athletes.[17] Results indicated that almost half of all landings from spike jumps were single leg landings, and more than two-thirds of those single leg landings were performed on the left leg.[17] The results also suggested that the occurrence of single leg landings might be related to the sequence of the spiking technique.[17] When a right-handed player spikes a ball, the trunk is laterally flexed to the left. This lateral flexion raises the right side of the body and can precipitate left foot loading (dominant leg) contact upon landing.[17]

Contrary to the previous landing pattern study,[17] the majority of our subjects demonstrated "double leg" landings with subsequent higher MVGRF on the non-dominant leg than the dominant leg. Differences in landing patterns may be attributed to the difference in subject group characteristics. The subjects of the previous study were elite college female volleyball players[17], while our subjects were adolescent female club volleyball athletes under the age of 18. Age and skill level may have influenced resulting landing patterns, as study results indicate that landing patterns vary with increased skill and experience.[7 17] In addition, it should be noted that our subjects were trained to land on both legs simultaneously to prevent injuries. These findings reflect the importance of early instruction in proper volleyball jump landing techniques by individuals associated with the development of youth volleyball players in order to prevent future knee injuries. Our study supports the importance of the sports specific functional research.

In conclusion, subject injury status and landing leg dominance influenced the kinematic and kinetic results of our study.

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APPENDICES

Appendix A. The Problem

A.1. Problem statement.

The purpose of this study was to functionally investigate volleyball spike-jump landing biomechanics to determine injury risk factors, and injury incidence in adolescent female club volleyball athletes.

A.2. Independent variable(s).

The independent variables were previous knee injury history (previous injury knee; PIK or non-injured knee; NIK), and landing leg (dominant or non-dominant leg).

A.3. Dependent variable(s).

The dependent variables were lower extremity kinematics and kinetics.

A.4. Dependent measure(s).

The dependent measures were knee flexion angle at IC, knee flexion angle at MVGRF, maximal knee flexion angle, MVGRF, Time from IC to MVGRF, and loading rate from IC to MVGRF.

A.5. Research question(s).

1. What were the spike-jump landing kinetic differences between previous knee injury and non-injury groups?
2. What were the spike-jump landing kinematic differences between previous knee injury and non-injury groups?
3. What were the spike-jump landing kinetic differences between dominant and non-dominant landing legs?
4. What were the spike-jump landing kinematic differences between dominant and non-dominant landing legs?

A.6. Operational definitions.

1. Dominant leg was defined as the contralateral leg of the spiking arm. For instance, a subject's hitting hand was right, left leg was her dominant landing leg and right leg was her non-dominant leg.
2. Successful spike jump criteria were: a proper three or four step approach; contact (spike) with the volleyball; landing on the dominant leg where the whole dominant foot must be on one of the force plates; the non-dominant leg landed on the other force plate.
3. The criteria of lower extremity injury were subject saw medical personnel (i,g, an athletic trainer, physical therapist, or doctor) for the specific condition and had to miss participation to the practice or game due to the condition.

A.7. Experimental hypotheses.

1. There will be kinematic differences between previously injured knees and non-injured knees.
2. There will be kinetic differences between previously injured knees and non-injured knees.
3. There will be kinematic differences between dominant legs and non-dominant legs.
4. There will be kinetic differences between dominant legs and non-dominant legs.

A.8. Assumptions.

The assumptions for this study were: (1) The subjects were able to understand the directions and their tasks, (2) The subjects answered the medical history and injury questionnaire honestly and correctly, and (3) The subjects were able to perform proper spike jumps.

A.9. Delimitations.

The delimitations of this study were: (1) Subjects with current injury, and (2) The subjects who played other sports except volleyball.

A.10. Limitations.

The limitations of this study were (1) Different maturation level among subjects, and (2) Small sample size.

A.11. Significance of the study.

This study focused on simulating functional movement that would occur in a natural sports setting. Only one study, conducted by Richards et al,[13] studied functional volleyball landing biomechanics in adult male athletes. This study was focused on volleyball spike-jump landings in adolescent female club volleyball athletes, the population with a greater risk of lower extremity injuries due to their physical immaturity. Investigating biomechanical characteristics associated with lower extremity injury may help to reduce lower extremity injuries and ultimately lengthen the span of the individual's athletic life.

Appendix B. Review of Literature

Lower extremity injuries are often seen in sports which require repetitive jump-land sequences such as volleyball.[4] The sports-related injuries in volleyball are commonly seen at the lower extremities[3 4], and the number of those injuries have increased over the past twenty years due to a higher number of participants in sports activities[1]. Injury history[11-13 15 19], gender difference[6 8 9 21], and different developmental stages[7 10] have drawn attention to the importance of understanding the mechanisms of injuries to prevent sports-related injuries.

Volleyball Landing and Injury Incidence

Augustsson et al.[4] conducted a survey of 225 elite Swedish volleyball players (10 men's teams and nine women's teams) to describe type, location, and severity of injury, as well as player position relative to injury incidence. The operational definition of injury was an injury that occurred as a result of participation in volleyball that caused the athlete to leave the court at the time of injury or to reduce their level of training. Injury severity was categorized by the length of time they were absent from participation. Acute and chronic injuries were not distinguished in their study. The majority of injuries were located in the athletes' lower extremities in the following percentages: ankle (23%); knee (17%); and back (16%). Most injuries were minor (absence for less than one week), or moderate (absence for two to four weeks). Major injuries (absence for more than four weeks) accounted for 19 out of 121 injuries, or 6%. Seventy-three percent of the injuries were related to the three front players (attackers and blockers) and occurred during spiking and blocking.

Agel et al.[3] reviewed 16 years of National Collegiate Athletic Association injury surveillance data specifically for women's volleyball players from the academic year of 1988-1989 to 2003-2004. They found that more than 55% of all game and practice injuries were to the lower extremities. In both game and practice situations, injuries to the ankle (44.1% from game situations and 29.4% from practice situations) and knee (14.1% from game situations and 7.8% from practice situations) were the most common locations for injuries in college female volleyball players. Menisci, collateral and cruciate ligament injuries comprised the highest proportion of the internal knee injuries. Further, more than 25% of knee injuries were caused by "no apparent contact", 21.1% involved "a player landing on another player" and 20.6% were the result of "contact with the floor". The majority of injuries (67.3%) occurred in athletes in the front three positions.

Tillman et al.[17] investigated spike and block jump take-off and landing patterns in elite female collegiate athletes. Each movement was categorized by jump type (spike or block) and phase (taking-off or landing). The jump type was further subcategorized as bilateral or unilateral (right or left) landing/take-off pattern. If one foot left the ground one frame (33ms) ahead of the other, the jump was categorized as unilateral (right or left), and a similar convention was used to categorize landing. The majority (84%) of spike jump take-off were performed using both legs and 16% of spike jumps take-off were performed using one leg (right - 2%, left - 14%). Bilateral spike jump landing percentages decreased to 55%, while unilateral leg usage increased to 45% (right - 10%, left - 35%) compared to the corresponding take-off. The authors concluded that the increased frequency of single leg landings in landing might be related to the sequence of spiking technique. When right-handed players spike balls, their trunks are laterally flexed to the left. This lateral flexion raises the right side of the body and can lead to a left foot first contact upon landing. They noted that unilateral landings could lead to a loss of balance and subsequent injury.

In summary, the majority of injuries in volleyball occur in the lower extremities, especially at the ankle and knee.[3 4] This is the result of repetitive spike and block jump-land sequences which cause tremendous forces on the lower extremities during landing.[17] Unilateral landing might increase the overall risk of lower extremity injuries.[17]

Knee Injury Risk Factors Associated with Landing

Richards et al.[13] investigated the biomechanics of volleyball spike and block jump take-offs and landings, and incidences of patellar tendonitis (or Jumper's knee) in elite male volleyball players. Three-dimensional high-speed cameras and one force plate were used to collect all biomechanical data of lower extremities. In the study, six out of ten subjects had a history of patellar tendonitis, and all subjects were right-handed. Sport specific simulation using a portable net set at regulation height (2.43 meters) where subjects hit and blocked spiked and set volleyballs, respectively during trials. Subjects repeatedly performed three different trials for each leg landing on a force plate (right and left), each task (spike and block), and each phase (take-off and landing). The logistic regression revealed that maximal left knee flexion angle during spike jump landing, peak external tibial torsional moment for the right knee during the spike jump take-off and the left knee during block jump take-off. Peak vertical ground reaction force for the right limb during both spike and block jump take-offs were revealed a predictors of patellar tendonitis.

Hewett et al.[11] investigated the relationship between lower extremity landing biomechanics and ACL injuries in female adolescent athletes. The study involved a prospective study design; prior to the season the authors collected the drop vertical jump landing data of 205 female adolescent athletes who participated in soccer, basketball, and volleyball. During the season nine ACL ruptures were reported. The landing biomechanical data of nine ACL ruptured limbs versus 390 non-injured limbs was compared to determine if any differences pre-existed. The injured limbs demonstrated significantly different knee posture and loading compared to non-injured limbs. The ACL injured group demonstrated greater knee abduction (valgus) angle (8.4 degrees greater than the non-injured) at initial contact, and at maximum knee flexion (7.6 degrees greater than the non-injured). In the ACL injured group, there was a strong correlation between knee abduction (valgus) angle and peak vertical ground reaction force, whereas no correlation was found in the non-injured group. Even though differences in knee flexion angles did not reach the level of statistical significance, the maximum knee flexion angle at landing was 10.5 degrees less in the ACL injured group than in the non-injured group. Significant knee loading was also observed in the ACL injured group but not in the non-injured group. The logistic regression analysis revealed that the knee abduction moment and angles (IC and peak values) were significant predictors of ACL injury status.

Louw et al.[12] compared landing biomechanics of subjects with previous knee injury and those without. The subjects of this study consisted of 22 adolescent male and female basketball players 14 to 16 years of age. During the landing biomechanical trials, subjects performed ten "jump-shots" landing where each foot landed five times on each force plate. They found that peak knee flexion angles were negatively correlated with peak ground reaction forces. The group with no prior knee injuries demonstrated significantly deeper knee flexion angles on landing (66.4degrees) than the group who had a history of knee injuries (57.1degrees). The high correlation between knee angle and maximum ground reaction force suggested knee flexion angle (degree) could possibly be one of the most important factors relative to impact reduction after landing from a jump which may reduce the chance of LE injuries.

Bisseling et al.[15] compared landing biomechanics in elite adult male volleyball players in relation to patellar tendonitis (jumpers' knee). The subjects were divided into three groups based on an injury questionnaire: the control group, the previous jumper's knee (PJK) group, and the recent jumpers' knee (RJK) group. Subjects with a history of recent injury or surgery at the LE or the back in the past 3 months were excluded from the study. If bilateral patellar tendinopathy was reported, the more symptomatic knee was selected for analysis. The Victorian Institute of Sport Assessment (VISA) Scale was used to record pain, function, and athletic activities. More points in the assessment indicated better knee condition. The subjects in the control group had no history of patella tendonitis, no pain during a single leg decline squat, and no palpation tenderness. They had a score of over 80 points on the VISA Scale. The subjects in the PJK group were classified as having asymptomatic patellar tendonitis, a history of pain located at the proximal patellar tendon or insertion of the quadriceps tendon, and patellar tenderness. They had no pain during single leg decline squat and were pain free in the last five months, and the VISA score was over 80 points. The subjects in the RGK group had pain during single leg decline squat, palpation tenderness, and less than 80 VISA points. The subjects performed drop jumps from 30, 50, and 70 cm high platforms. They were required to land facing forward with both feet on the ground with one foot on the force plate. They found that the knee flexion angle at time to peak vertical ground reaction force (PVGRF) was negatively correlated with PVGRF as well as with loading rate VGRF (peak VGRF value divided by time from touch down to peak value) among all three groups and heights, except for the RJK group at 70cm. The PJK group showed higher knee angular velocities and higher ankle planter flexion moment loading rates. Furthermore, the PJK group tended to have higher loading rates compared with the control group. It was concluded that the subjects in the PJK group might have a higher risk of developing patellar tendonitis due to a higher PVGRF and loading VGRF.

Aside from the kinetic and kinematic characteristics during landing task, Li et al.[19] investigated the relationship between force produced by muscles and force applied on ACL at different knee angles. They investigated the role of isolated quadriceps and combined quadriceps and hamstrings load on knee kinematics and the in-situ forces in the ACL. They used a robotic/universal force-moment sensor (UFS) to measure the in-situ forces in the ACL and knee kinematics in response to isolated quadriceps load and combined quadriceps and hamstrings loads in cadaveric knee specimens during simulated isometric extension of the knee. Ten fresh-frozen human cadaveric knees were used, and the age of the specimens ranged between 42 and 72 years old. No ligamentous injury or sign of degenerative joint disease were found in these specimens. The tibia and femur were cut to a length of 20 cm from the joint line, and the fibula was fixed to the tibia using a cortical screw. The tests were repeated at knee flexion angles of 0, 15, 30, 60, 90, and 120 degrees. The knee underwent anterior and lateral tibial translation as well as internal tibial rotation relative to a 200 N quadriceps load on the femur. Translation and rotation increased when the knee was extended to a 30 degree knee flexion angle and these motions decreased with further knee flexion. Adding 80 N of antagonistic hamstrings load, represented by applying 40 N to both medical and lateral hamstrings, decreased anterior and lateral tibial translation as well as internal tibial rotation at knee flexion angles tested, except at full knee extension. At 30 degrees of knee flexion, tibial translation was significantly reduced. The in-situ forces in the

ACL under the quadriceps load were increased with full knee extension, but the force in the ACL decreased with more knee flexion. Adding hamstrings load helped to reduce the force on the ACL which may reduce the risk of ACL injuries.

In summary, landing biomechanics might be influenced by injury history.[11 12] "Stiff leg" landing techniques, which represent less hip and/or knee flexion angle, and greater MVGRF are related to the risk of ACL injuries.[11 12] Also, greater knee flexion angles may increase the risk of patellar tendonitis.[13 15] The load on the ACL was different at different knee angles associated with force produced by quadriceps, or quadriceps and hamstrings muscles, which may be related to ACL injuries.[19]

Landing Biomechanics in Female Athletes

Schmitz et al.[6] specifically investigated single-leg landing biomechanics among recreationally active healthy young adults and compared the results between genders. They utilized single leg landings where the subjects jumped down from a 0.3 m high platform and landed on a force plate with their dominant limb. The dominant limb was defined as the preferred limb used to kick a ball. They found significant biomechanical differences between genders. The female group demonstrated 60% less hip flexion and 36% less knee flexion during landing compared with the male group. The female group also demonstrated 52% shorter hip times to peak flexion and 22% shorter knee times to peak flexion, 9% greater peak normalized vertical ground reaction force than the male group. The male group exhibited 24% significantly greater amount of energy absorption per unit of body weight at hip, knee, and ankle joints compared to the female group. They discussed that females are more prone to potential LE injuries due to the biomechanical differences.

Russell et al.[8] investigated the relationship between landing biomechanics and gluteus medius muscle strength in genders during single leg drop-jump landing. The subjects were 16 males and 16 females with ages ranging from 18 to 30 years old. The subjects' physical activity levels were unknown. In order to simulate the deceleration phase during athletic activities, the subjects performed drop landing tasks from a 60 cm high platform, and landed on their dominant limb. The dominant limb was defined as the limb on which the subjects preferred to land. The frontal-plane knee angle and the gluteus medius muscle activation were measured during the landing trials by using motion capture cameras, a force plate, and electromyography (EMG). At initial contact, females landed with valgus knee and males landed with varus knee. At maximal knee flexion, both males and females were in a position of knee varus, but the magnitude of varus was less in females than in males. The females demonstrated "relatively" greater knee valgus at the time of maximum knee flexion. There was no significant difference found in gluteus medius muscle strength between the genders. They concluded that limiting the valgus position of the knee during a single-leg landing could reduce strain on the ACL and in turn reduce the number of no-contact ACL injuries. Since single-leg landings involving forceful valgus has been identified as a common mechanism of ACL injury, and in their findings, they also suggested that the females are higher risk of ACL injury than males.

Salci et al.[5] investigated landing biomechanics and muscle strength in the lower extremities to identify gender difference. Motion capture cameras and force plates were used for landing biomechanical data collection. For the quantitative muscle strength measurement (also known as, "Biodex), angular peak torque in knee flexion and extension was determined at an angular speed of 60°/s with five repetitions in the dominant leg. The dominant leg was determined by pushing the subjects from behind and observing the foot that moved forward first. The subjects of their study were 16 elite collegiate volleyball players (eight for each gender) who had no previous history of severe lower leg injuries. In the study, researchers attempted to simulate volleyball spike and block jumps by using different jumping heights and platform distance. For spike landings, the platform was placed at a distance of 10 cm from the force plate, and for block landings the platform was placed at a distance of 15 cm from the force plate. The height of the platforms from which the subjects stepped off was 40 and 60 cm. They stepped off the platforms without jumping or lowering their body, and they landed as vertically as possible on the force plates. They found that there were biomechanical differences between genders during the landing trials. The male group demonstrated greater hip and knee flexion and less vertical ground reaction force than the female group. The male group also demonstrated significantly higher quadriceps and hamstring peak torque than the female group. Quadriceps muscle strength and knee flexion angles were positively correlated in the male group, but not in the female group.

Lephart et al.[9] investigated LE biomechanics and strength in healthy collegiate female basketball, volleyball, and soccer players compared with similar male subjects. Subjects jumped off a 20 cm platform that was placed 11 cm from the back edge of the force plate. The subjects started at a distance of 45% of their height away from the X marked on the force plate and were told to land on dominant leg. The dominant leg was defined as the leg with which subjects preferred to kick a ball. Isokinetic strength data were collected with a Biodex System to assess peak torque of the quadriceps and hamstrings. In both tasks, female subjects had significantly less knee flexion and lower leg internal rotation maximum angular displacement, and less knee flexion time to maximum angular displacement than male subjects. Female subjects demonstrated lower quadriceps and hamstring strength compared with male subjects, and this finding may play a fundamental role in the landing position observed in the female subjects during landing. The role of the quadriceps during landing seems to be critical to the distribution and absorption of the impact of forces resulting from landing. Though no significance was found in the value of the ground reaction force between genders in the study, the relative lack of knee flexion subsequent to impact in females has significant implications for the manner in which force transmission up the kinetic chain occurs.

As previous studies revealed increased knee injury risk in female, Smith et al.[21] investigated LE biomechanics between different skill levels in female athletes. The subjects of this study were NCAA Division I and Division III collegiate female soccer athletes. They examined drop vertical jumps landing biomechanics to determine the ACL injury risk factors are related to the skill levels. Sagittal- and coronal-plane movements at LE were investigated during drop vertical jump landing. Subjects showed similar physical characteristics, however, subjects mean age and previous injury histories were not reported. Leg dominance was determined as the leg preferred to use to kick a ball. They found that Division I athletes landed with a smaller knee flexion angle compared with Division III athletes. However, motion of the coronal-plane showed similar landing biomechanical characteristics in both groups. They concluded that different landing biomechanics were seen in different skill groups.

In summary, females tend to land with less knee flexion, greater reaction force, and greater knee valgus during various landing tasks compared with males.[5 6 8 9] Females also demonstrated lower muscle strength in LE.[5 8 9] These factors may increase risk of knee injury, especially in the ACL.[5 8 9 21]

Physical Development Stages and Landing Biomechanics

Hass et al.[10] conducted an LE landing biomechanical study in pre- and post-pubescent subjects using functional jumping and landing tasks. A total of 32 subjects were divided into two groups: 16 pre-pubescent girls and 16 post-pubescent women. Pre-pubescent subjects were pre-onset of menarche. Menarche is defined as an increase in height of more than 5 cm or an increase in body weight of 10% or more during the preceding 3 months. Post-pubescent subjects were defined as at least 6 years past the onset of menarche with a normal menstrual cycle. All subjects were free from any orthopedic or neurological conditions. The subjects' dominant leg was defined as the leg the subject preferred to use to perform single-leg landing. The height of the box from which the subjects performed drop jumps was decided based on each subjects maximal vertical jump. The pre-pubescent group demonstrated greater knee flexion angle and peak vertical ground reaction force, whereas the post-pubescent group demonstrated less knee flexion angle and peak vertical ground reaction force during landing. The results contradicted those of previous studies conducted by Richards et al.[13] and Swartz et al.[7] where greater knee flexion angle caused less ground reaction force during landing. They noted that a possible reason for the differences in the two groups were due to different muscle activation patterns. From the findings, they concluded that post-pubescent groups have a greater risk of knee injury.

Swartz et al.[7] examined vertical jump landings between pre- and post-pubescent groups and compared the results between genders. The definitions of pre-and post-pubescent were based on the guidelines established by Tanner, in which the onset of puberty is correlated with a growth spurt. All pre-pubescent subjects were either current or recent past participants of a youth sports program in which the athletes were required to perform jumping and landing activities (i.e. basketball, volleyball, and gymnastics). Adult subjects were recreationally active, but were excluded if they had participated in National Collegiate Athletic Association Division I jumping sports. All subjects had no severe lower back or LE injury histories. The subjects jumped from the height of 50% of their maximal vertical jump, and landed with both feet. There were differences in landing techniques between pre- and post-pubescent groups, but no difference was found between genders. The pre-pubescent group demonstrated smaller flexion angles of the knee and hip associated with greater ground reaction force during landings from vertical jumps compared with the post-pubescent group. The researchers discussed that physical maturation, skill development, and experience were factors that would influence landing biomechanical characteristics. They concluded that the pre-pubescent group had a greater knee injury risk according to their findings.

In summary, subjects in different developmental stages demonstrated different landing biomechanics, however, some of those outcomes and related injury risk factors were remain inconclusive.[7 10]

The sports-related acute and chronic injuries are often seen in the sports requires repetitive jump-land sequences, such as volleyball, and these injuries were common in lower extremities.[3 4] To understand the risk factors of lower extremity injuries, landing biomechanical studies have been conducted. The stiff leg landing techniques, which characterized by less hip and/or knee flexion angle, and greater MVGRF are closely related to ACL injuries.[5 9 11 12] Individual(s) who has a history of LE injury and female have tendency to have stiff leg landing.[11 12] Different landing strategies were used in different developmental stages, but the results related to risk of injuries have been inconclusive.[7,10] Only one study examined volleyball spike and block jump landing in male athletes, and some patellar tendonitis injury predictors were found.[13]

Appendix C. Additional Methods

C.1. Institutional Review Board Form

CHS 04/04 CHS #15023

Application for New Approval of a Study Involving Human Subjects
University of Hawai'i, Committee on Human Studies (CHS)
Spalding Hall 253, 2540 Maile Way, Honolulu, Hawai'i 96822
Telephone: (808) 956-5007

Date: March 7, 2007
PI (name & title): Iris F. Kimura, PhD, ATC, PT, Professor; Rumi Bumbera, ATC; Rie Harada, ATC; Kaori Tamura, MS, ATC; Christopher Stickley MA, ATC; Email: risogai@hawaii.edu; haradar@hawaii.edu; ikimura@hawaii.edu Phone: 956-5162/3797
Department: Kinesiology and Leisure Science
[x] Faculty or Staff [x] Student - name of supervising professor:
Iris F. Kimura, PhD, ATC, PT
Training in Human Subject Protection: When, where, & what? September 2005, October 2006, September 2006, January 2007, University of Hawaii Manoa, Human Subject Training
Project Title: Jumping Biomechanics as Predictors of Injury in Adolescent Female Volleyball Athletes
Proposed Sponsoring Agency: N/A
Start Date: April 1,2007
Complete Agency address: N/A

1. Summarize your proposed research. Outline objectives and methods.

Upper and lower extremity injuries are common among athletes who participate in jumping activities, particularly skeletally immature athletes training at high intensities for long periods of time. Currently, the research involving the relationship between injuries and jumping biomechanics are limited and primarily involves adult athletes who participate in jumping activities. The purpose of this study is to investigate spike and block "jump LANDING" kinematics and kinetics of adolescent female volleyball players to determine the relationship to upper and lower extremity injuries.

Subjects will be 100 highly trained and well-conditioned female volleyball players 10 to18 years of age recruited from local volleyball "club" teams from the greater Honolulu community. Club teams and coaches will be contacted through public club web sites and contact information. Interested club teams will be asked to volunteer to participate in the study following a power point presentation to players, parents/legal guardians, and coaches (attachment #1).

All data will be collected in one 45-minute session in the University of Hawaii, Manoa, Kinesiology and Leisure Science Human Performance Laboratory. Testing order will commence with the older competitive levels (i.e. ≤17s, ≤ 16s, ≤15s, ≤14s, ≤13s, ≤12s) and continue to the youngest competitive level. Demographic data will be collected (e.g. age, competition level, height, weight, vertical jump, Q-angle, and two skinfolds (triceps and calf) prior to biomechanical assessment. Biomechanic data collection will involve bilateral reflective markers placement on the following anatomical land marks: head, shoulders, elbows, wrists, hands, lower back, hips, thighs, knees, shins, ankles, and feet. The same *female* National Athletic Trainers' Association (NATA), Board of Certification (BOC) certified athletic trainer will collect all demographic data and apply all reflective markers. All subjects will undergo a familiarization and instructional session prior to testing. Subjects will be asked to perform three to five spike jumps and three to five block jumps (total jumps = 10). Kinematic data will be captured via Vicon Optical Capture System. Kinetic data will be collected through ground reaction forces measured via two Advanced Mechanical Technology Incorporated (AMTI) force plates.

2. Summarize all involvement of humans in this project (who, how many, age, sex, length of involvement, frequency, etc.) and the procedures they will be exposed to. Attach survey instrument, if applicable.

All data will be collected in one 45-minute session by National Athletic Trainers' Association (NATA), Board of Certification (BOC) certified athletic trainers. Subjects will be 100 highly trained and well-conditioned female volleyball players 10 to18 years of age recruited from local volleyball "club" teams from the greater Honolulu community. Club teams and coaches will be contacted through public club web sites and contact information. Interested club teams will be asked to volunteer to participate in the study following a power point presentation to players, parents/legal guardians, and coaches (attachment #1).

Volunteers will complete injury and health history questionnaires (attachment #2 & 3), which will be reviewed by a medical doctor to screen for pathologies or contraindications to subject inclusion. Only non-pregnant subjects free of injuries within the last six months will be included in the study. Signed informed both consents and the assent forms approved by the University of Hawaii Committee on Human Studies will be obtained prior to participation in the study (attachment #4, 5 & 6).

Check whether any subject of your research will be selected from the following categories:

[X] Minors [ ] Pregnant Women [ ] Mentally Disabled [ ] Fetuses
[ ] Abortuses [ ] Physically Disabled [ ] Prisoners

3. Research involving humans often exposes the subjects to risks. For the purpose of this application, "risk" is defined as exposure of any person to the possibility of injury, including physical, psychological, or social injury, as a consequence of participation as a subject in any research, development, or related activity which departs from the application of those established and accepted methods necessary to meet his needs, or which increases the ordinary risks of daily life, including the recognized risks inherent in a chosen occupation or field or service.

a. Check all the risks to human subjects that apply to your project:
[X] Physical trauma or pain [ ] Deception [ ] Experimental diagnostic procedures

[ ] Side effects of medications [X] Loss of privacy [ ] Experimental treatment procedures
[ ] Contraction of disease [ ] Worsening of illness [ ] Other – explain
[ ] Psychological pain [ ] Loss of legal rights

b. Check procedures that will be used to protect human participants from risks:
[X] M.D. or other appropriately trained individuals in attendance
[ ] Sterile equipment
[ ] Precautions in use of stressor or emotional material (explain below)
[ ] When deception used, subjects fully informed as to nature of research at feasible time (explain below)
[ ] Procedures to minimize changes in self-concept (explain below)
[X] Confideniality of subjects maintained via code numbers and protected files
[ ] Anonymity - no personally identifiable information collected
[ ] Others-- explain

c. Has provision been made to assure that Human Subjects will be indemnified for expenses incurred as a direct or indirect result of participating in this research?
[ ] Not applicable
[X] No - The following language should appear in the written consent form: ***I understand that if I am injured in the course of this research procedure, I alone may be responsible for the costs of treating my injuries.***
[ ] YES, explain:

d. Are there non-therapeutic tests that the research subjects may be required to pay for?
[ ] Not applicable
[X] No
[ ] Yes - explain below. The following language should appear in the written consent form: ***I understand that I may be responsible for the costs of procedures that are solely part of the research project.***

4. Describe mechanism for safety monitoring: How will you detect if greater harm is accruing to your subjects than you anticipated? What will you do if such increased risk is detected?

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. Subjects may also experience discomfort, muscle cramping or shortness of breath while testing. The investigators are National Athletic Trainers' Association, Board of Certification certified Athletic Trainers, First Aid/CPR certified and trained to use the portable automated external defibrillator (AED) on site. In the event of any physical injury from the research procedure, only immediate and essential medical treatment is available. First Aid/CPR and referral to a medical emergency room will be provided.

5. Briefly describe the benefits that will accrue to each human subject or to mankind in general, as a result of the individual's participation in this project, so that the committee can access the risk benefit/ratio.

Subjects may not receive direct/immediate benefits. However, subjects will receive information regarding jumping kinematics and kinetics while playing volleyball and learn about how it may affect upper and lower extremity injury incidence. Also, results of this study may assist athletic trainers, coaches and sport biomechanists in preventing volleyball related adolescent injuries.

6. **Participation must be voluntary: the participants cannot waive legal Rights, and must be able to withdraw at any time without prejudice.** Indicate how you will obtain informed consent:
   [X] Subject (or Parent/Guardian) reads complete consent form & signs ('written' form)
   [ ] Oral briefings by PI or project personnel, with simple consent form ('oral' form). Explain below the reason(s) why a written consent form is not used
   [ ] Other- explain

7. Are there any other local IRB's reviewing this proposal? [X] No [ ] Yes, Location:

I affirm:
(i) that the above and any attachments are a true and accurate statement of the proposed research and of any and all risks to human subjects.

Signed: ______________________________ Date: ______________
Principal Investigator
Signed: ______________________________ Date: ______________
Principal Investigator
Signed: ______________________________ Date: ______________
Principal Investigator
Signed: ______________________________ Date: ______________
Principal Investigato

C.2. Institutional Review Board Proposal

Jumping Biomechanics as Predictors of Injury in Adolescent Female Volleyball Athletes

Principal Investigators: Iris F. Kimura, PhD, ATC, PT; Rumi Bumbera, ATC, Rie Harada, ATC; CSCS, Kaori Tamura, ATC, MS; Christopher Stickley, MA, ATC
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Introduction

Upper and lower extremity injuries are common among athletes who participate in jumping activities, particularly those with high training volume or skeletal immaturity. Currently, the research examining the relationship between injuries and jumping kinematics and kinetics are limited and primarily involves adult athletes who participate in jumping activities. The purpose of this study is to investigate the jumping kinematics and kinetics of adolescent female volleyball players and the relationship to upper and lower extremity injuries.

Methodology

Subjects

Subjects will be 100 highly trained and well-conditioned female volleyball players 10 to18 years of age recruited from local volleyball "club" teams from the greater Honolulu community. Club teams and coaches will be contacted through public club web sites and contact information. Interested club teams will be asked to volunteer to participate in the study following a power point presentation to players, parents/legal guardians, and coaches (attachment #1).

Volunteers will complete health history and injury questionnaires (attachment #2 & 3), which will be reviewed by a medical doctor to screen for pathologies or physical contraindications to subject inclusion. Only those subjects free of injuries within the last six months will be allowed to volunteer to participate in the study. Signed informed consent and assent forms approved by the University of Hawaii Committee on Human Studies will be obtained prior to participation in the study (attachment #4 & 5).

Procedures

All data will be collected in one 30-minute session by the same *female* National Athletic Trainers' Association (NATA), Board of Certification (BOC) certified athletic trainer in the University of Hawaii, Manoa, Kinesiology and Leisure Science Human Performance Laboratory. On the assigned test/data collection day, demographic and physical characteristics will be collected prior to biomechanical assessment (e.g. age, competition level, height, weight, vertical jump, Q-angle, and two skinfold (triceps and calf)).

Reflective markers will be placed on the following anatomical land marks: head, shoulders, elbows, wrists, hands, lower back, hips, thighs, knees, shins, ankles, and feet by the aforementioned female NATABOC certified athletic trainer (attachment #6 & 7). All subjects will undergo a familiarization and instructional session prior to data collection. Subjects will be asked to perform three to five spike jumps and three to five block jumps (total jumps = 10). Kinematic data will be captured via Vicon Optical Capture System. Kinetic data will be collected through ground reaction forces measured via two Advanced Mechanical Technology Incorporated (AMTI) force plates.

Research Design:

Multiple 2 X 7 ANOVA's with repeated measures and interclass correlation analyses will be performed on the kinematic and kinetic data. Independent variables will include subject data grouped according to competition level (i.e. < 10, 11, 12, 13, 14, 15, 16, 17, 18), injury history and skill type (i.e. spike or block jump). Dependent variables will include lower extremity, upper extremity and trunk rotation, angles, velocities, and ground reaction forces. All data will be analyzed using Statistical Analysis Software (SAS) version 9.0 and statistical significance will be established at the < 0.05 probability level.

C.3. Informed consent form

INFORMED ASSENT

To Participate in a Research Study

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

I. INVESTIGATORS

Principle Investigators: Iris F. Kimura, PhD, ATC, PT; Rumi I. Bumbera, ATC; Rie Harada, ATC, CSCS; Christopher D. Stickley, MA, ATC; Kaori Tamura, MS, ATC

II. TITLE

Jumping Biomechanics as Predictors of Injury in Adolescent Female Volleyball Athletes

III. INTRODUCTION

The following information is being provided to help you decide if you would like to participate in this study. This form may have words that you do not understand. If you have questions, please do not hesitate to ask us.

The purpose of this study is to see what body movements during spike and block jump landings affect injuries. You are being asked to participate in this study because you are a highly competitive, well trained young female volleyball player.

IV. DESCRIPTION OF PROCEDURES

You and your parents/legal guardians will be asked to fill out injury and health history questionnaires before the study begins to see if it is safe for you to be in this study. You will then report to the University of Hawaii, Manoa, Kinesiology and Leisure Science Human Performance Laboratory for testing (report to KLUM Gym). Your height, weight, knee angle, 2 skinfolds (arm & leg), and vertical jump will be measured. Next, reflective markers will be applied to your head and both sides of your body on your shoulders, elbows, wrists, hands, lower back, hips, thighs, knees, shins, ankles, and feet). All measurements and reflective marker applications will be done by a female athletic trainer. You will be asked to perform 3 to 5 spike and 3 to 5 block jumps that will be recorded, however only the reflective markers will be visible on the computer. You will be given instructions and practice time until you are comfortable with the testing procedure. The entire procedure will take about 45 minutes.

V. RISKS

Due to the level of physical activity involved, there is a risk of injury. You may have muscle soreness and/or pain after testing. You may also have some discomfort, muscle cramping or shortness of breath while testing. There is also a very slim (small) chance of cardiac arrest and death. The investigators are National Athletic Trainers' Association, Board of Certification certified athletic trainers and First Aid/CPR trained. In the event of any physical injury from the research, only immediate and essential medical treatment is available. First Aid/CPR and a referral to a medical emergency room will be provided. Please note that if you are pregnant, you are not eligible to participate in this study.

VI. BENEFITS

You may not receive direct/immediate benefits. However, you will learn how your body moves during spiking and blocking landings. Results of this study may help athletic trainers, coaches and sport biomechanists prevent future injuries to young female volleyball players.

VII. CONFIDENTIALITY

Your research records will be confidential (private) to the extent permitted by law. Agencies with research oversight, such as The University of Hawaii Committee on Human Studies, have the right to review (look at) research records.

A code number (ID #) will be used instead of your name and that code # will be known only to you and the researchers. All research data and subject (identity) information will be kept under lock and key in the Department of Kinesiology and Leisure Science at the University of Hawaii at Manoa. These materials will be permanently destroyed in a period not longer than 5 years. You will not be personally identified in any publication resulting from this study. Personal information about your test results will not be given to anyone without your written permission.

VIII. CERTIFICATION

I certify that I have read and I understand the above information, that I have been given satisfactory answers to my questions concerning the study and that I am free to withdraw (quit) participation in the study at any time without prejudice or negative consequences.

I give my assent (agree) to be in this study with the understanding that my assent (agreeing) does not waive (eliminate) any of my legal rights, and it does not release the investigators or institution or any employee or agent (involved persons) thereof from liability for negligence.

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

If you have any questions related to this study, please contact any of the principle investigators: Rumi Bumbera at 956-9455, Rie Harada at 956-8793, Christopher Stickley at 956-3798, Kaori Tamura at 956-3801, or Dr. Iris F. Kimura at 956-3797 at any time.

ID # ________   ______________________________   ____/____/____

Signature of Participant   Date

If you cannot obtain satisfactory answers to your questions, nor have complaints about your treatment in this study, please contact: Committee on Human Subjects, University of Hawai'i at Manoa, 2540 Maile Way, Honolulu, Hawaii 96822, Phone (808) 956-5007.

INFORMED CONSENT

To Participate in a Research Study

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

I. INVESTIGATORS

Principle Investigators: Iris F. Kimura, PhD, ATC, PT; Rumi I. Bumbera, ATC; Rie Harada, ATC, CSCS; Christopher Stickley, MA, ATC; Kaori Tamura, MS, ATC

II. TITLE

Jumping Biomechanics as Predictors of Injury in Adolescent Female Volleyball Athletes

III. INTRODUCTION

The following information is being provided to help you decide if you would like to participate in this study. This form may have words that you do not understand. If you have questions, please ask us. The purpose of this study is to determine how body movements (joint angles) and forces sustained during spike and block jumps affect injuries. You are being asked to participate in this study because you are a highly competitive well trained female volleyball player.

IV. DESCRIPTION OF PROCEDURES

You will be asked to fill out health history and injury questionnaires prior to testing to determine if it is safe for you to participate in this study. If there are no contraindications to study participation you will be asked to report to the University of Hawaii at Manoa, Kinesiology and Leisure Science Laboratory for testing. Your height, weight, knee angle, 2 skinfolds (arm & leg), and vertical jump will be measured by a female National Athletic Trainers' Association (NATA), Board of Certification (BOC) certified athletic trainer. Next, reflective markers will be applied by a female NATA, BOC certified athletic trainer to the following landmarks on both sides of your body (ex. Head, shoulders, elbows, wrists, hands, lower back, hips, thighs, knees, shins, ankles, and feet). You will be asked to perform 3 to 5 spike and 3 to 5 block jumps, which will be recorded, however only the reflective markers will be visible (no human images). Instructions and practice time will be provided to you until you are comfortable with the procedure. The entire procedure will take about 45 minutes.

V. RISKS

Due to the level of physical activity involved, there is a risk of injury. You may have muscle soreness and/or pain after testing. You may also have some discomfort, muscle cramping or shortness of breath while testing. There is also a very remote chance of cardiac arrest and death. The investigators are NATA, BOC certified athletic trainers and First Aid/CPR trained. In the event of any physical injury from the research, only immediate and essential medical treatment is available. First Aid/CPR and a referral to a medical emergency room will be provided.

Please note that if you are pregnant, you are not eligible to participate in this study.

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

VI. BENEFITS

You may not receive direct or immediate benefits. However, you will obtain information regarding your physical characteristics and how your body moves during volleyball spike and block jump landings. Results of this study may assist athletic trainers, coaches and sport biomechanists in preventing future volleyball injuries to female athletes.

VII. CONFIDENTIALITY

Your research records will be confidential to the extent permitted by law. Agencies with research oversight, such as The University of Hawaii Committee on Human Studies, have the right to review research records.

You will be assigned a subject identification number (ID) that will be used instead of your name and will be known only to you and the study personnel. 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 Hawaii at Manoa. These materials will be permanently disposed of in a period not longer than 5 years. You will not be personally identified in any publication arising from this study. Personal information about your test results will not be given to anyone without your written permission.

VIII. CERTIFICATION

I certify that I have read and 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 to participate and to discontinue my participation in the study 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 investigators or institution or any employee or agent thereof from liability for negligence.

If you have any questions related to this study, please contact any of the principle investigators: Dr. Iris F. Kimura at 956-3797, Rumi Bumbera at 956-9455, Rie Harada at 956-8793, Christopher Stickley at 956-3798, or Kaori Tamura at 956-3801 at any time.

ID # ________ ________________________________ ____/____/____

Signature of Participant Date

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

C.4. Questionnaire(s)

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

Today's date__________ Subject ID # ________ Date of Birth ____/____/____Age______

Home Address

____

Home Phone ____________ Work Phone ________________Cell Phone_____________

Emergency Contact Person

Parent / Guardian Information   Relationship ____________________

Home Phone ____________Work Phone ______________Cell Phone____________

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

Fainting Spells	Yes No Past Present
Headaches	Yes No Past Present
Convulsions/epilepsy	Yes No Past Present
Asthma	Yes No Past Present
High Blood Pressure	Yes No Past Present
Kidney Problems	Yes No Past Present
Intestinal Disorder	Yes No Past Present
Hernia	Yes No Past Present
Diabetes	Yes No Past Present
Heart Disease/Disorder	Yes No Past Present
Dental plate	Yes No Past Present
Poor Vision	Yes No Past Present
Poor Hearing	Yes No Past Present
Skin Disorder	Yes No Past Present
Allergies	Yes No Past Present
Specific________________	Past Present

Joint Dislocation
Or separations   Yes No
Specify____________________   Past Present
___________________________   Past Present

Allergies   Yes No
Specific____________________   Past Present

Other ________________________________
___________________________   Past Present

B. Injuries

Toes	Yes No Past Present
Feet	Yes No Past Present
Ankles	Yes No Past Present
Lower Legs	Yes No Past Present
Knees	Yes No Past Present
Thighs	Yes No Past Present
Hips	Yes No Past Present
Lower Back	Yes No Past Present
Upper Back	Yes No Past Present
Ribs	Yes No Past Present
Abdomen	Yes No Past Present
Chest	Yes No Past Present
Neck	Yes No Past Present
Fingers	Yes No Past Present
Hands	Yes No Past Present
Wrists	Yes No Past Present
Forearms	Yes No Past Present
Elbows	Yes No Past Present
Upper Arms	Yes No Past Present
Shoulders	Yes No Past Present
Head	Yes No Past Present

Specify_________________________________
_____________________________   Past Present

Others ______________________________
_____________________________   Past Present

PLEASE ANSWER THE FOLLOWING QUESTIONS TO THE BEST OF YOUR ABILITY

Are you pregnant?

No_____ Yes_____
(If you are pregnant, you are not eligible to participate in this study)

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)

If there are any questions feel free to contact us at the following number and address:

Rumi Bumbera, ATC; Rie Harada, ATC, CSCS; Christopher Stickley, MA, ATC; Kaori Tamura, MS, ATC; or Iris F. Kimura, PhD, ATC, PT

University of Hawaii, College of Education
Department of Kinesiology and Leisure Science
1337 Lower Campus Road, PE/A Complex, Room 231
Honolulu, Hawaii 96822
Phone: (808) 956-5162, (808) 956-7421, or (808) 956-3797

UNIVERSITY OF HAWAII AT MANOA
DEPARTMENT OF KINESIOLOGY AND LEISURE SCIENCE
INJURY QUESTIONNAIRE

Today's Date____________ **Subject ID#** __________ **Date of Birth**___________

GENERAL QUESTIONS (circle the appropriate answer)

1. What position do you play? **OH/RH** **MB** **S** **DS**

2. Do you play any other sports? **NO** **YES** (please specify)

   ____

3. Do you play volleyball for your school? **NO** **YES**
4. Counting this year, how many years have you been on the *Jammers* or other CLUB team? Please circle one below.

   This is my (1^{st}, 2^{nd}, 3^{rd}, 4^{th}, 5^{th}, 6^{th}, 7^{th}, 8^{th}, 9^{th}) season with the *Jammers* or a CLUB team.
5. Do you wear any braces, pads, and/or special training equipments when you play volleyball?
   NO

   YES (what is it? __________, you use it for which part of your body? __________)

6. **If YES,** are you required to wear or use these devices? **NO** **YES**

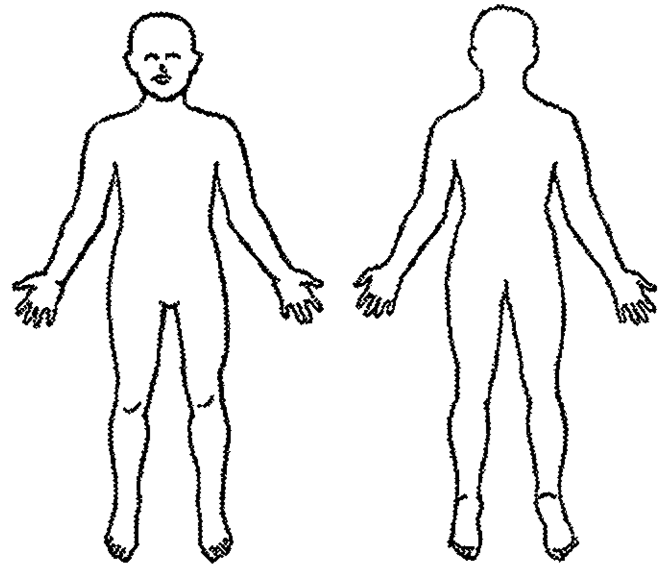
INJURY QUESTIONS (circle the appropriate answer)

Have you ever hurt yourself while playing sports?

a. **If NO,** you are finished (***PAU***)!
b. **If YES**, answer questions 1 to 10 on the next page.
c. **If YES,** more than once ASK for another Injury Questionnaire Page 2.
d. How many times? ________

INJURY QUESTIONNAIRE (page 2) **Subject ID#___________**

ON THE PICTURE BELOW, circle where (location) you have or had the injury or pain



Please answer 1 to 10 below that describes the injury location you circled

1. What sport were you injured in? ______________________________
2. How old were you when you got the injury? ________
3. Approximate date of the injury (month/year)_____________________
4. Write the name of injury (if you know what it is called) ________________________
5. Have or did you miss practices or games because of this injury? **NO** **YES**
6. Did you see a doctor for this injury/pain? **NO** **YES**
7. Did the doctor: (circle all that apply)
   a. Give you or prescribe medicine(s)
   b. Give you exercise(s)
   c. Send you to an athletic trainer
   d. Send you to a physical therapist
   e. Recommended surgery
   f. Recommended you stay out of practices/games
   g. OTHER _________________________________

8. Did you have surgery for this injury? **NO** **YES**
   a. When was the surgery? ______________________

9. Is this injury still painful? **NO** **YES**
   a. Does it hurt when you walk? **NO** **YES**
   b. Does it hurt when you run? **NO** **YES**
   c. Does it hurt when you jump? **NO** **YES**
   d. Does is hurt at rest? **NO** **YES**

10. Are you able to participate in volleyball now? **NO** **YES**

C.5. Data collection forms

Jump Study Data Collection Check List

University of Hawaii at Manoa
Kinesiology and Leisure Science

Subjects I.D. # ________________ Name________________

Age _______ Date ________

- ☐ Check in / documentation check
- ☐ Stationary bike / Stretch
- ☐ Landing trial standard instruction / practice
- ☐ Reflective marker placement / shoes coverage
- ☐ Landing trials

Block right 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Block left 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Spike 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

- ☐ Check out

C.6. Specific testing protocols

1. Anthropometric Measurements
    a. Height, Weight, Q-angle, Body composition
2. Warm-up
    a. Stationary bike riding
    b. Self stretching
3. Standard instruction
4. Practice session
5. Reflective marker placement
6. Landing trials
    a. 3 successful trials

C.7. Standard instructions

General instruction:

Hello, my name is **Name**. I am a certified Athletic Trainer and a graduate student here at the University of Hawaii Manoa. Thank you for your participation in our research. If you have any questions, please ask at any time. First aid care will be provided in case of emergency by certified athletic trainers here.

Today, we will complete a landing trial. First, we will measure your height, weight, skinfold, and knee angle. Then, you will have a warm-up session which including stationary bike riding and self-stretching. After the warm-up, we will measure your vertical jump. All measurements will be recorded. Finally, a certified athletic trainer will put markers on your body for volleyball jump trial. Before the actual volleyball jump trial, you will have another instruction session. If you have any questions, please feel free to ask us at any time.

Landing instruction:

Hello, my name is **Name**. I am a certified athletic trainer and a graduate student here at the University of Hawaii Manoa. Thank you for your participation in our research. If you have any questions, please ask at any time.

Today, we will be measuring your spike jumps. You are going to perform spike jumps until we have 3 successful trials. You can practice until you feel comfortable with your tasks.

First, you will perform spike jumps in which you will take an approach from your preferred side (right or left) to hit this suspended volleyball (placed here in this holder).

Please do the following things for this process; first, use an approach of 3 or 4 steps. Second, make sure to hit this volleyball across the net. We may ask you change the approach starting position to adjust your landing, and you will land as close as your normal spike landing. You can practice as much as you want, and we will adjust the height of the holder. Please feel free to ask questions, and tell us what the best setting is for you to do this task.

Appendix D. Additional Results

D.1. Raw data tables

Kinematic and Kinetic Data on Dominant Leg

I.D.#: Dominant Leg	Knee Flexion Angle @ IC	Knee Flexion Angle @ MVGRF	Maximum Knee Flexion Angle	MVGRF (N/Kg)	Time to MVGRF (sec)	Loading Rate (N/sec)
01U1307T1	33.54	85.85	105.23	16.78	0.12	8831.87
02U1307T1	34.08	73.63	79.94	19.21	0.12	7581.02
03U1307T1	18.49	60.60	73.93	14.24	0.12	6539.78
05U1307T1	40.00	63.97	75.22	14.39	0.11	6970.00
06U1307T1	13.42	57.27	68.27	17.32	0.10	8106.71
07U1307T1	16.96	62.31	70.27	22.93	0.10	11761.93
08U1307T1	14.22	59.47	77.10	20.62	0.11	11365.06
09U1307T1	13.86	60.79	83.94	17.72	0.11	8251.74
10U1307T1	6.35	64.96	87.64	14.46	0.14	5211.00
11U1307T1	15.19	50.70	61.16	14.32	0.10	8218.41
12U1307T1	9.44	64.52	77.57	7.44	0.14	3329.59
13U1307T1	0.20	39.08	49.02	19.26	0.10	9050.31
14U1307T1	17.27	88.22	94.00	14.78	0.16	5093.90
15U1307T1	14.52	62.74	76.86	20.34	0.09	12101.65
16U1307T1	2.58	53.83	71.48	20.02	0.11	8505.67
17U1307T1	11.84	59.34	83.63	14.76	0.12	6402.08
18U1307T1	9.75	57.66	68.16	18.23	0.12	6517.47
19U1307T1	17.11	63.24	82.57	19.48	0.11	9480.11
21U1307T1	7.50	60.78	79.94	16.54	0.12	8319.77
01U1707T1	19.02	65.42	84.20	15.55	0.11	8223.22
01U1807T1	16.32	63.59	89.94	15.77	0.11	9720.37
02U1707T1	8.65	56.52	87.62	14.84	0.11	9048.13
02U1807T1	13.61	65.76	91.31	15.46	0.11	8551.88
03U1707T1	12.38	51.30	74.72	10.91	0.11	6784.06
03U1807T1	25.30	51.73	77.77	12.57	0.10	7501.15
04U1707T1	18.77	56.84	55.58	17.03	0.12	10645.12
04U1807T1	11.76	61.67	90.26	15.82	0.10	9133.12
05U1707T1	22.88	68.14	83.92	20.66	0.10	14475.06
05U1807T1	17.96	59.73	74.04	14.21	0.21	6195.44
06U1707T1	14.67	73.27	91.69	14.80	0.12	6533.74
06U1807T1	18.54	71.08	81.54	16.23	0.12	10460.26
07U1707T1	17.13	66.92	77.43	19.23	0.09	14669.10
07U1807T1	18.15	67.05	79.42	17.64	0.11	10969.26
08U1707T1	16.73	58.59	74.43	15.62	0.11	7513.30
08U1807T1	11.61	60.81	76.97	13.66	0.11	10606.07
09U1707T1	8.55	50.67	77.83	18.96	0.10	12968.40
09U1807T1	19.42	59.65	86.66	12.86	0.12	7192.08
10U1707T1	9.66	58.97	67.36	16.63	0.10	12694.83
10U1807T1	13.45	75.60	86.80	14.68	0.12	6904.55
11U1807T1	28.14	51.80	74.92	17.59	0.12	9647.55
Mean	15.98	62.10	78.76	16.34	0.11	8801.87
SD	7.96	9.12	10.46	2.95	0.02	2514.70

Kinematic and Kinetic Data on Non-dominant Leg

I.D.#: Non-dominant Leg	Knee Flexion Angle @ IC	Knee Flexion Angle @ MVGRF	Maximum Knee Flexion Angle	MVGRF (N/Kg)	Time to MVGRF (s)	Loading Rate (N/s)
01U1307T1	11.45	50.73	82.01	13.71	0.10	8417.83
02U1307T1	14.27	41.43	65.54	14.53	0.12	5734.37
03U1307T1	16.55	64.36	77.71	18.02	0.11	8728.87
05U1307T1	21.38	53.88	74.33	14.54	0.11	6956.48
06U1307T1	11.69	53.38	63.46	18.59	0.10	8352.38
07U1307T1	10.22	58.17	67.58	15.72	0.12	6924.91
08U1307T1	13.74	78.61	81.26	9.55	0.15	3801.72
09U1307T1	8.78	53.94	77.06	17.22	0.10	9065.83
10U1307T1	10.65	64.72	85.52	13.74	0.13	5054.67
11U1307T1	16.14	66.05	83.03	19.83	0.12	9182.99
12U1307T1	7.26	46.44	77.70	22.50	0.11	12488.13
13U1307T1	5.64	40.43	52.88	20.86	0.10	9269.29
14U1307T1	17.31	59.87	82.54	17.23	0.12	8085.25
15U1307T1	4.44	37.74	63.54	14.83	0.09	8827.45
16U1307T1	4.71	49.52	73.47	16.16	0.10	7629.51
17U1307T1	9.68	54.76	80.73	16.51	0.12	6909.35
18U1307T1	12.41	63.80	78.31	20.04	0.10	8309.48
19U1307T1	14.12	61.93	79.64	14.04	0.12	6503.80
21U1307T1	6.57	60.28	75.44	17.79	0.11	9646.29
01U1707T1	8.72	56.60	95.33	17.74	0.12	8941.62
01U1807T1	21.22	66.53	88.57	18.18	0.10	12503.85
02U1707T1	5.73	53.69	63.82	14.14	0.12	7689.83
02U1807T1	10.32	58.74	86.78	15.81	0.10	9207.98
03U1707T1	8.70	47.15	76.89	19.79	0.11	13078.45
03U1807T1	6.73	32.73	72.52	18.83	0.17	6891.50
04U1707T1	15.72	47.31	49.54	21.63	0.11	14746.53
04U1807T1	10.89	62.83	91.29	16.11	0.21	4496.74
05U1707T1	8.42	48.25	83.40	14.27	0.11	9495.20
05U1807T1	12.11	54.42	68.54	21.97	0.10	19284.73
06U1707T1	8.31	49.83	80.29	17.39	0.10	8803.24
06U1807T1	5.85	45.85	65.38	17.89	0.10	13089.18
07U1707T1	4.22	46.06	65.69	18.53	0.09	13304.94
07U1807T1	13.99	58.81	72.70	15.80	0.11	9583.61
08U1707T1	16.02	64.04	76.20	18.93	0.13	8028.74
08U1807T1	8.03	55.31	73.76	20.52	0.11	15525.99
09U1707T1	1.78	44.10	78.43	17.12	0.10	12103.17
09U1807T1	9.68	55.00	77.62	20.16	0.10	14057.95
10U1707T1	11.31	48.73	61.61	24.38	0.11	17662.79
10U1807T1	15.03	57.08	78.12	22.23	0.11	11650.18
11U1807T1	21.00	57.77	78.39	16.04	0.10	10263.22
Mean	11.02	54.27	75.17	17.57	0.11	9757.45
SD	4.82	9.03	9.66	2.99	0.02	3429.20

D.2. Statistical tables

ANOVA Table for Spike-Jump Landing Kinematic and Kinetic Variables

ANOVA Table for Mean Knee Flexion Angle at IC					
Source	DF	Type I SS	Mean Square	F-Value	P-Value
Injury Status	1	197.22	197.22	4.79	0.0318
Landing Leg	1	518.16	518.16	12.57	0.0007
Injury Status*Landing Leg	1	21.60	21.60	0.52	0.4714

ANOVA Table for Mean Knee Flexion Angle at MVGRF					
Source	DF	Type I SS	Mean Square	F-Value	P-Value
Injury Status	1	62.71	62.71	0.81	0.3721
Landing Leg	1	1672.74	1672.74	21.5	<.0001
Injury Status*Landing Leg	1	3.13	3.13	0.04	0.8416

ANOVA Table for Mean Maximal Knee Flexion Angle					
Source	DF	Type I SS	Mean Square	F-Value	P-Value
Injury Status	1	17.17	17.17	0.17	0.6818
Landing Leg	1	355.1	355.1	3.5	0.0651
Injury Status*Landing Leg	1	81.81	81.81	0.81	0.3718

ANOVA Table for Mean MVGRF					
Source	DF	Type I SS	Mean Square	F-Value	P-Value
Injury Status	1	39.55	39.55	4.95	0.0291
Landing Leg	1	72.43	72.43	9.07	0.0035
Injury Status*Landing Leg	1	0.05	0.05	0.01	0.9372

ANOVA Table for Mean Time from IC to MVGRF					
Source	DF	Type I SS	Mean Square	F-Value	P-Value
Injury Status	1	0.0005	0.0005	1.36	0.2479
Landing Leg	1	0.0001	0.0001	0.22	0.6371
Injury Status*Landing Leg	1	0.0010	0.0010	2.33	0.1309

ANOVA Table for Mean Time from IC to Maximal Knee Flexion					
Source	DF	Type I SS	Mean Square	F-Value	P-Value
Injury Status	1	0.0013	0.0013	1.16	0.2859
Landing Leg	1	0.0022	0.0022	2.00	0.1614
Injury Status*Landing Leg	1	0.0003	0.0003	0.28	0.5997

ANOVA Table for Mean Loading Rate					
Source	DF	Type I SS	Mean Square	F-Value	P-Value
Injury Status	1	47017695.87	47017695.87	5.54	0.0212
Landing Leg	1	27523269.36	27523269.36	3.24	0.0757
Injury Status*Landing Leg	1	4116378.48	4116378.48	0.49	0.4882

Appendix F. Bibliography

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